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Food waste amount, type, and climate impact in urban and suburban regions in Finnish households

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ABSTRACT

Households produce about half the food waste in Europe, significantly affecting the environment and society. To measure and understand all the impact, there is a need for both primary and direct data, as well as an evaluation of methods. To respond to this need, new knowledge about households' FW and the applicability of waste composition analysis method in urban housing and areas is provided. This knowledge is applicable for planning FW studies, considering various measurement methods, the extrapolation of country-level FW values, and the introduction of decreasing interventions for households. The novelty of this study lies in its comprehensiveness: outcomes from three different city regions are analysed, and the method's robustness is evaluated. The goal of this research was to study the amount and quality of food waste in mixed waste and separately collected biowaste in Finnish households. Other goals were to estimate the unnecessary climate impact of lost food and to assess the validity of the chosen methodology. The study responds to the lack of comprehensive and recent first-hand data and reports results from three different city areas, using a relatively large number of samples that encompass 98,000 inhabitants, or about 50,000 households. The data were collected on four separate occasions: in the Helsinki area during September 2015 and October 2018, in the Turku area during June 2019, and in the Tampere area during September 2016. The results suggested that the average amount of food waste varied between 53.0 kg/cap/y and 62.1 kg/cap/y, and the amount of originally edible food waste varied between 23.0 kg/cap/y and 28.4 kg/cap/y. When extrapolating the food waste results to all study areas, the Helsinki produced about 57,000–62,000 t/y, Tampere about 16,000 t/y, and Turku about 25,000 t/y, for a total of about 100,000 t/y. The *Meat and fish* type group contributed most to the climate impact of originally edible FW (37–47%), while its share of food waste was much smaller, at 10–12%. The total climate impact was assessed as 0.10 Mt CO_2eq/y when the climate impacts per capita annually ranged from 52.9 kg $CO_2eq/cap/y$ to 61.4 kg $CO_2eq/cap/y$ in the different regions. Due to the results' consistency, the waste composition analysis methodology can be recommended for measuring FW from both mixed and biowaste flows in urban and suburban areas. The study was conducted in cooperation with local waste management companies to increase resource efficiency and the opportunities to share facilities and to decrease study costs.

1. Introduction

A recent UN report (UNEP, 2021) estimated that global food waste (FW) from households, retail, and food services was about 17% of all global food production, around 931 Mt of food, and about 79–118 kg per capita annually. The previous FAO report in 2011 estimated that about a third of food produced in the entire food supply chain globally was lost or wasted, amounting to 1.3 Gt each year (Gustavsson et al., 2011). In Europe, FW amounted to a total of about 88 Mt and about 173 kg per capita annually, which was about 20% of the total food produced in the same area (Stenmarck et al., 2016). This enormous amount of lost food causes significant environmental and economic impacts (FAO, 2013) affects food security (Foley et al., 2011), and is a resource efficiency issue for a healthy diet and sustainable food production (Willett et al., 2019). These figures clearly show the need to monitor and decrease the amount of food waste and related climate and environmental impacts through unnecessary food production. All actions and political or commercial innovations to decrease FW require support from data, knowledge, and understanding of the generation of FW, and there is especially a need for direct measurements and standardised methods (Xue et al.,

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2017).

About half the total FW in Europe is caused by households (Stenmarck et al., 2016) and the European Union and its member states have adopted the UN Sustainable Development Goals (UN, 2015) to halve food waste at the retail and consumer levels by 2030. To make the measurements uniform and follow the targets, the European Commission has established a common measuring and reporting methodology for FW levels (EU, 2019). The waste composition analysis (WCA) is one of the methods suggested for households. There is therefore a need for publications about results and outcomes with the method. It is important to estimate whether the method is reliable, and how applicable it is for different areas, waste flows, housing types, and FW types.

This study's goal is to produce detailed information about the current FW amount and quality in Finnish households, estimate its climate impact, and test the WCA method. Suitable and appropriate measurement methods for monitoring FW are necessary for tracking FW amounts, following the trends and direction of waste flows, and achieving reductions. The most suitable method varies, depending on data requirements, resources, and the part of the food supply sector (Møller et al., 2014). It has been reported that diary studies tend to underestimate the amount of FW (Giordano et al., 2018). Quested et al. (2020) reported that all diary estimates studied were lower than corresponding WCA estimates, and van der Werf et al. (2020) noted that self-reporting had difficulties with recording all portions and estimating FW volumes. WCA is a method in which waste material and FW are physically separated and sorted, while the overall process is conducted by researchers (FWS 2016). The results could provide detailed information about FW amounts, both edible (EFW) and inedible (IFW), food type categories, and the packaging stage (Lebersorger and Schneider, 2011).

WCA has some disadvantages from the FW perspective: a lack of data on liquid FW, composting at home, and a lack of information about the causes of FW (if not specifically collected from other waste flows or questionnaires). When combined, WCA and a diary study provide accurate data concerning the amounts of FW and information on the reasons for FW (Quested et al., 2020).

Although the WCA method is appropriate for FW amount studies, and it provides more reliable results than the diary method, there are reports from only a few studies, and publications in scientific journals are scarce. In Europe, the WCA method has been used in households in the Netherlands (van Dooren et al., 2019), Norway (Hanssen et al., 2016), the UK (WRAP, 2020), Austria (Lebersorger and Schneider, 2011), and Denmark (Edjabou et al., 2016). Three review studies discussing households' FW methodology were found: Caldeira et al. reported eight WCA studies in households since 2015 (Caldeira et al., 2019); Amicarelli and Box (2020) reported four studies in Europe; and Withanage et al. reported (2021) eight studies. Most of these peer-reviewed European WCA studies used restricted sampling with selected households, ranging from 7 (Sosna et al., 2019) to 1474 (Edjabou et al., 2016). Lebersorger and Schneider (2011) had a larger sample size of ten municipalities in their study of municipal waste in Austria, which included 125,000 inhabitants from both rural and urban areas. Our study responds to the lack of comprehensive studies, because results from three different city areas are reported, using a relatively large number of samples (a total of 140), which encompass 98,000 inhabitants and about 50,000 households.

The present study includes several novel approaches and uses robust methods which produce more accurate data than previous studies: unlike diary studies, WCA does not underestimate FW amounts; and unlike many previous WCA studies, the present study has a comprehensive data set from three city regions. It is the first WCA study to focus on Finnish households and includes an analysis of both edible and inedible FW; the previous Finnish diary study included only edible FW (Silvennoinen et al., 2014). A climate impact assessment of FW of Finnish households has been included in the present study.

2. Material and methods

2.1. Food waste definition and terms

In this study, *food waste* (FW) was defined as all wasted food or food material, including originally *inedible food waste* (IFW), including coffee grounds and vegetable peelings, and originally *edible food waste* (EFW), all the food that could have been eaten by humans before discarding (Table 1). This definition is derived from the FUSIONS definitional framework (Östergren et al., 2014).

2.2. Samples and sorting

Four WCA studies were conducted. They included both mixed and bio waste in three waste management areas: 1. the Helsinki area (2015 and 2018); 2. the Tampere area (2016); and 3. the Turku area (2019). These areas included the capital, Helsinki, with a population of 1,200,000 inhabitants, the City of Tampere, with 226,000 inhabitants, and the City of Turku, including its surrounding areas, with 447,000 inhabitants. All the areas are in Southern Finland, and they include urban city districts and suburban districts with detached and other small houses. Both were studied to obtain complete results. All WCAs were undertaken outside the holiday seasons (Christmas, Easter), and the fact that household FW probably varied little according to the time of year was considered (Edjabou, 2015), except for apples from gardens in the autumn (Silvennoinen et al., 2013). Rather than conducting a follow-up study between years, WCA was conducted in different years and areas to investigate if the WCA method would produce consistent results in different areas with different housing structures. Resources were saved by conducting studies in the years when waste management companies had their WCA on mixed waste.

The sampling strategy was stratified sampling. Different types of housing FW were studied separately, depending on whether the house had only mixed waste collection, or if it also had biowaste collection. *Type 1* housing had only mixed waste collection and lacked separate biowaste collection, comprising detached houses, terraced houses, or other small buildings with typically fewer than 10 apartments. *Type 2* housing had both mixed waste and biowaste collection, typically including buildings with more than 10 apartments. Combining data from these two flows meant it was possible to estimate the total solid FW in the areas with mixed waste and separately collected biowaste.

All the studies were undertaken in cooperation with local waste management companies. The companies sorted mixed waste fractions to analyse the composition of mixed waste (Kivo, 2017), and the fractions, including food waste, were further sorted. Separately collected biowaste samples were taken directly from the loads and sorted.

There were 79 waste loads, from which 140 samples were taken for sampling. Each sample's mass was circa 100 kg of waste. The loads were related to specific routes of waste collection with housing of either Type 1 or Type 2, and a known number of inhabitants, a total of about 98,000 inhabitants (Table 2, Supplementary Materials Table 1). The average number of persons living in a Finnish household (a household-dwelling

Table 1
Description of different types of waste in this study.

Type of waste	Description
Mixed waste	All mixed waste e.g. paper, glass, plastics
Biowaste	All biowaste, e.g. food, garden waste, soft tissue paper
Separately collected biowaste	Biowaste collected from separate containers sorted by households
Food waste (FW)	All food waste from households
Originally edible food waste (EFW)	All food that could have been eaten by humans before discarding
Originally inedible food waste (IFW)	Food material that could not have been eaten by humans, e.g. coffee grounds, peelings, shells, bones, and skins.

Table 2
Study area, year, study periods, number of samples, loads and inhabitants along study routes.

Study area	Year	Study period	No. of samples	No. of loads	No. of inhabitants along study route
Helsinki area	2015	31.8–18.9.	42	23	26,607
Tampere area	2016	29.8–16.9.	25	17	10,731
Helsinki area	2018	1.10–17.10.	43	28	33,781
Turku area	2019	3.6–14.6.	30	11	26,950
Total			140	79	98,069

unit) in 2019 was 1.97 (OFS, 2020), which means there were about 50, 000 households along the study routes (98,069/1.97 = 49,781). Multiple samples were taken from some loads, because this was a common practice among waste management companies. This reduced the study's scope, but it also increased the results' accuracy. The average mass of waste from the 79 loads included was 2673 kg. The samples covered once or twice weekly waste collection from the sample areas. The study's route planning, waste collection, and mixed waste sampling were performed by municipal waste management companies in the Helsinki (HSY, 2016; HSY, 2018), Tampere (Pirkanmaan Jätehuolto Oy, 2017), and Turku (Hansen, 2020) areas.

The sorting method was manual by researchers (Supplementary Materials Fig. S1), and sampling was done according to the instructions of Finland's Organisation of Municipal Solid Waste and its standard for mixed waste composition analysis (Kivo, 2017). These instructions were supplemented with FW sorting practices applied by research discussing WCA (Lebersorger and Schneider, 2011). FW was not taken out of packages before being weighed, and it was sorted by the package state in which it had been abandoned. The states here were *loose* food waste, food waste in *opened packages*, and food waste in *unopened packages*. The number of food packages was also separated after weighing and monitored in two studies (Helsinki 2018 and Turku 2019). Liquid FW like beverages and milk were found in unopened packages. Most wasted liquids are normally emptied into the sewer, and only a small portion of liquid FW can therefore be monitored in WCA.

The work of separating and sorting waste was conducted in study shelters organised near the waste management stations (Supplementary Materials Fig. S1). All FW was manually sorted, and edible FW was weighed by type: *Vegetables*; *Potatoes*; *Fruit and berries*; *Bread*; *Meat and fish*; etc. (Table 3). Inedible parts like bones, peelings, and skins were collected and weighed together. Fine particles, including coffee grounds that had fallen through the sorting table's sieve, were also sorted and weighed.

Table 3
The groups in which food waste was sorted, and the food fractions they included.

Food waste type groups	Includes the following food fractions	Category
Vegetables	All vegetables (other than potatoes, fruit and berries, and apples from garden)	Fruit and vegetables
Potatoes	Potatoes, potato products	
Fruit and berries	Fruit, dried fruit, berries, jams	
Apples	Apples from gardens	
Pasta and rice	Boiled and raw pasta and rice	Cereals
Bread	All breads	
Meat and fish	Pig, bovine, poultry and fish meat, meat products and cold cuts, crustaceans, eggs	Animal-based products
Cheese and other dairy products	All cheese and other dairy products	
Other products	Homecooked food, ready-made and takeaway food, cereal products other than bread, gravies and spices, desserts, pastries, snack and confectionary products, beverages	Products and meals with a combination of raw materials

2.3. Data and statistical analysis

The measured waste amounts for each sample were measured, providing results for both the total amount of FW and all its subcategories, which are described in Tables 3 and 4. Because these totals included packages containing food to facilitate measurement, the significance of the weight of these packages compared to the total weight of FW in the samples was calculated to discern the significance of the error. As some samples were obtained from a single load of waste, the weighted average for the results of these samples was calculated, because each load represented a certain waste collection route in the area. Using multiple samples from the same route increased the estimate's accuracy. For each load, the percentage of originally edible food waste was calculated.

These results were further processed by checking the type of housing (Type 1 or 2) where each load had been collected and calculating the total mass of all food waste categories for both types by multiplying the mass of each load by the corresponding FW percentage and adding the masses together. These masses could then be related to the total mass of all waste to obtain FW percentages for each housing type and FW group.

Next, the total FW masses were divided by the number of inhabitants along the waste collection routes to obtain the amount of FW produced per inhabitant and year for each housing and FW type. These data were extrapolated to the whole city area by multiplying the amount of FW per person by the total number of inhabitants in both housing types and dividing the resulting total mass by the total number of inhabitants in the area. This equates to the weighted average amount of waste generated per inhabitant and year in the city area. To prepare to calculate the climate impact of food waste, it was important to divide this result into parts to discover how much FW belonging to each product group was generated per inhabitant.

It was assumed that FW produced per person and year was normally distributed. Descriptive statistics for the collected data were calculated. They included the weighted mean and weighted standard deviation of the FW percentage of the collected loads. As the number of collected loads was lower than 30 in each city, Student's T distribution was used to calculate the results' margin of error.

Propagation of error was used when the values from the base samples were converted, which used the FW percentage as a unit, to kg/cap/y instead. Propagation of error was also used when values from multiple loads were combined to calculate our results. The statistical analysis was used to determine the validity of the waste collection and separation methods. Large fluctuations in data can reveal errors in the experimental setup but can also indicate the true dispersion in the measured quantity.

2.4. Assessment of the climate impact

The climate impact assessment of sorted food groups and fractions was assessed based on a Life Cycle Assessment (LCA), consisting of a global warming potential impact category. Here, the climate impact is equal to the carbon footprint (CF). No other environmental impact categories are included in this study. This CF information about foods is from the literature, presented in Table 2 of the Supplementary Material. The carbon footprint assessment is a standardised procedure as defined in ISO 14067, in which all the greenhouse gases of the life cycle of a product are assessed, based on the principle of LCA. The data presented in Table 2 of the Supplementary Material are based on the typical average best available carbon footprint results and estimates for the Finnish market situation and production of these foodstuffs. The system boundaries for the CFs of food were from the production of farm inputs through delivery to the retailers. The main life cycle phases included in the system boundaries of the CFs were the production of inputs (e.g. fertilisers, lime, seeds) to agriculture, agricultural primary production,

Table 4
Amount of food waste in different types of housing and total kg/cap/y. IFW = originally inedible food waste, EFW = originally edible food waste.

Type of house/kg/cap/y	IFW in mixed waste	IFW in separately collected biowaste	IFW Total	EFW in mixed waste	EFW in separately collected biowaste	EFW Total	Total FW
Type 1 Houses without separately collected biowaste							
Helsinki 2015	27.2	-	27.2	24.2	-	24.2	51.4
Helsinki 2018	21.9	-	21.9	25.4	-	25.4	47.3
Tampere 2016	39.5	-	39.5	26.8	-	26.8	66.4
Turku 2019	35.7	-	35.7	25.2	-	25.2	60.9
Type 2 Houses with separately collected biowaste							
Helsinki 2015	19.2	13.0	32.2	18.0	4.7	22.7	54.9
Helsinki 2018	16.9	13.1	30	19.7	4.9	24.6	54.6
Tampere 2016	14.7	17.1	31.8	16.7	12.3	29.0	60.7
Turku 2019	11.5	17.3	28.8	13.0	6.8	19.8	48.7
Total on average							
Helsinki 2015	21.1	10.0	31.1	19.4	3.6	23.0	54.1
Helsinki 2018	18.0	10.2	28.2	21.0	3.8	24.8	53.0
Tampere 2016	20.9	12.8	33.7	19.2	9.2	28.4	62.1
Turku 2019	26.4	6.7	33.1	20.5	2.6	23.1	56.2

food-processing stages, and transport. Shopping trips, retail, storage, packaging production, refrigerant leakages, the cooking of food, and the waste management of EFW were not included. The impacts of land use on the soil organic carbon (SOC) stocks were not included because of a lack of data and suitable assessment methods and principles. The key literature data sources behind the average CFs of different product groups are presented in Table 2 of the Supplementary Material. The origin of food products affects carbon footprints, and weighted averages were used for different origins when possible. Finally, in the climate impact assessment, EFW was multiplied by the respective CFs.

Vegetables (EFW) consists mainly of tomatoes, cucumber, peppers, and lettuce. Most tomato and cucumber production takes place in Finland. The CFs of major vegetables produced in Finland typically have higher values than e.g. imports from Spain, which explains why the average CFs of vegetables are a little higher than is typical in the global LCA-based literature sources. *Potatoes* are mainly produced in Finland, and partly in Sweden. There were no major differences between potato CF results between Sweden and Finland. Consumption of *Fruit and berries* products in Finland is dominated by imported fruit, especially bananas, citrus fruit, apples, and melons. Concerning the *Pasta and rice* group, pasta products dominate Finnish consumption. Most of the EFW of *Meat and fish* products is meat. The meat consumed is produced mainly in Finland, and it consists largely of pork, chicken, and beef. The most recent Finnish CF data were used for *Meat and fish* products. Most of the beef consumed comes from dairy breed beef production. The CF data of beef production were derived from Hietala et al. (2021a), taking the shares of beef and dairy breed beef into account. The best up-to-date estimates of average Finnish chicken consumption are in Usva et al. (2021), and the CF of average pork consumption was based on Hietala et al. (2021b). In Finland, fish is mainly imported. The most consumed milk and dairy products are produced in Finland, but *Cheese and other milk products* are also imported.

The *Other products* group consisted of many subproject groups and food items such as homecooked meals (which could not be divided into actual food types), cereal products other than bread, ready-made and takeaway food, gravies and spices, desserts, pastries, confectionary, snacks, and drinks, all food that could not be sorted in the other categories. In the climate impact assessment, food product group specific literature sources were used when possible. Regarding some specific sub-groups such as ready-made meals, which consist of multiple types of product groups, the weighted average CF of all product groups was used to make an estimate in the case of Helsinki 2018. These two approaches produced somewhat similar results, and this CF of the weighted average of all products was ultimately used.

Finally, the average climate impact of food waste per person per year for all three regions was combined. The climate impact for Finland as a whole was explored by multiplying the climate impact per person per year by the total number of inhabitants of Finland.

3. Results

3.1. Amount of food waste

The average total FW in all households (Types 1 and 2) varied between 53.0 and 62.1 kg/cap/y, depending on the study area and year (Table 4). The originally edible FW (EFW) amounted to 23.0–28.4 kg/cap/y, and originally inedible food waste (IFW) to 28.2–33.7 kg/cap/y (Table 4, Fig. 1). The share of FW found in separately collected biowaste varied, being smallest in the Turku area at 17%, the Helsinki area in 2015 (19%), and the Helsinki area in 2018 (26%), and largest in the Tampere area, with 35% of total FW.

Amounts of FW in different housing types varied in Type 1 between 47.3 and 66.4 kg/cap/y (only mixed waste, without separately collected biowaste) and in Type 2 (mixed waste with separately collected biowaste) between 54.6 and 60.7 kg/cap/y (Table 4). When extrapolating the FW results to cover all study areas, the Helsinki region produced FW of about 57,000–62,000 t/y, Tampere about 16,000 t/y, and Turku about 25,000 t/y, for a total of about 100,000 t/y.

The originally edible FW (EFW) was separated by the package state in which it had been abandoned. Loose EFW *without a package* was the largest proportion, accounting for about half the total food waste, at 40–60%, the share of EFW in *opened packages* was 30–40%, and EFW in *unopened packages* was the smallest, at 9–18%. The weight of the packages was 3–4% of total FW in mixed waste. Separately collected biowaste generally did not contain any food packages, or the amount was minimal.

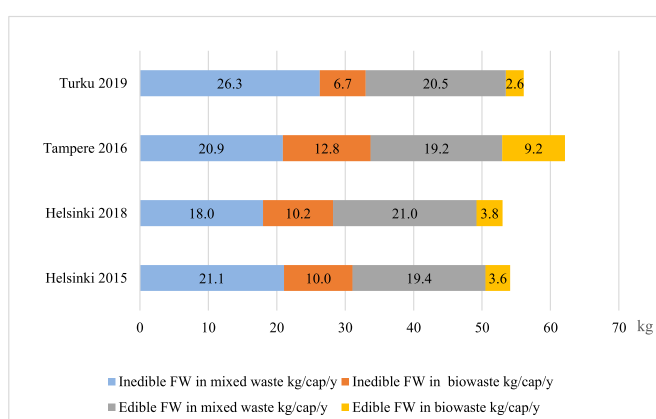

Fig. 1. Food waste amounts in all household types and the contribution of originally edible food waste in mixed waste and separately collected biowaste.

3.2. Types of food waste

Originally inedible FW (IFW) consisted of all kinds of food-based material that were unsuitable or possibly unsuitable for humans (Table 1). IFW included coffee grounds, coffee filter papers, teabags, vegetable and fruit peelings, inedible parts of vegetables, fruit, meat, and fish, e.g. seeds, cores, bones, and skins. The amount of IFW was 53–59%, and of originally edible FW (EFW) 41–47%, of total FW.

Originally edible food waste (EFW) was sorted further for different food types (Fig. 2, Supplementary Materials Fig. S2). The largest type group varied, but the main types were *Fruit and vegetables* (including *Potatoes*), 21–34%, *Other products* 22–30%, *Bread* 12–20%, and *Meat and fish* 10–12% (Fig. 2, Supplementary Materials Fig. S2). The *Other products* group consisted of homecooked meals, cereal products other than bread, ready-made and takeaway food, gravies and spices, desserts, pastries, confectionary, snacks, and beverages – all food that could not be sorted in other food types. The type groups that generated the least FW were *Pasta and rice*, at only 2–3%. The animal-based products *Meat and fish* and *Cheese and other milk products* groups together had a relatively high percentage of 16–17% of EFW.

3.3. Statistical analysis of samples

The study included 79 loads of mixed and biowaste, from which 140 samples were taken. The results of the statistical analysis are presented in Supplementary Materials Table 3. In general, the margin of error, corresponding to a 95% confidence level, for the FW percentage of loads was low, given the relatively small number of loads, which indicates that the waste composition was similar across the samples when differences in city area, housing type, and the type of collected waste were considered. The low margins of error indicate that the sorting methods can be used for assessing FW amounts, even when the sample is small.

The higher error margins can be explained by the small number of loads collected. In particular, there were few loads for separately collected biowaste, which led to a higher margin of error compared to mixed waste loads. Type 1 housing in Tampere had a very high margin of error, as this study area included a large variety of different housing types (detached houses, small terraced houses) in addition to the low number of loads. Error margins for Type 1 housing in Helsinki 2015 and Turku 2019 also show this effect, but not nearly to the same extent. In Turku, Type 2 housing had an even higher margin of error than Type 1 housing relative to the result of FW in kg/cap/y value.

Supplementary Materials Table 4 shows the propagation of errors, because the unit is changed to kg/cap/y, and multiple study areas are combined to condense the results. The same effects are observable in this format: the values for separately collected biowaste and mixed waste in Type 1 housing in Tampere have high uncertainty.

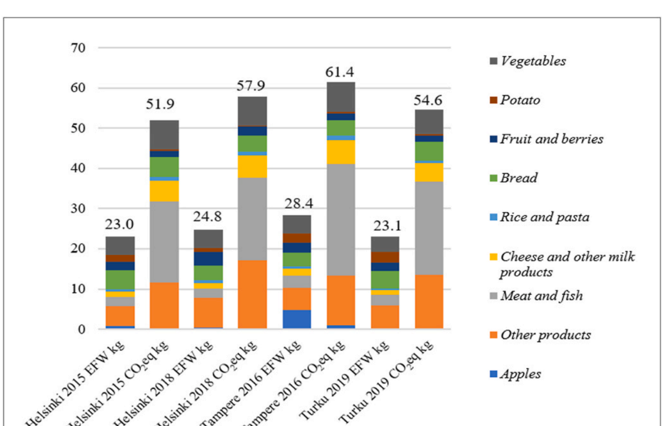

Fig. 2. Amount of edible food waste (kg) and respective climate impact (kg CO_2eq) per capita and per year in all studied regions divided by food groups.

3.4. The climate impact of food waste

Per capita climate impacts in the studied regions differed. They were largest in Tampere (61.4 kg CO_2eq/cap/y), while climate impacts in Helsinki ranged from 51.9 to 57.9 kg CO_2eq/cap/y, and in Turku 54.6 kg CO_2eq/cap/y, as presented in Supplementary Materials Table 4.

Meat and fish made the most remarkable contribution to the climate impact in all studied regions, ranging from 36 to 45% of the total climate impact. Fig. 2 clearly shows that the relatively small EFW of *Meat and fish* still makes the largest contribution to the total climate impact of EFW in all regions, and this is basically arising through wasted meat and meat products. The *Other products* group, comprising all homecooked food, including meat, makes the second largest contribution to the climate impact, at 20–29%, depending on the region. The contribution of other food waste groups was smaller. Even mostly discarded *Vegetables*, *Potatoes*, *Fruit and berries*, and local *Apples* together caused only 15–18% of the climate impacts of total EFW, while they represented 38–50% of the total mass of EFW. The climate impacts of EFW in relative shares of product groups between the regions were mainly similar, with a small exception in Tampere, where the contribution of *Meat and fish* was relatively larger than in other regions, and at the same time, *Other products* caused the smallest relative climate impact. Tampere caused the largest total climate impact (61.4 kg CO_2eq/cap/y), the largest total EFW, and EFW of *Meat and fish* was also the largest. Helsinki 2015 had the smallest EFW and smallest EFW of *Meat and fish*, and the smallest total climate impact (51.9 kg CO_2eq/cap/y). The climate impacts in Tampere seemed to be 15% larger than in Helsinki 2015; the other regions were closer to each other.

4. Discussion

The amount of FW in the study areas varied between 53.0 and 62.1 kg/cap/y, being largest in Tampere and smallest in Helsinki. Together, all three city regions produced about 0.1 Mt of FW annually. The total FW in the Finnish food chain is about 0.64 Mt/y (Riipi et al., 2021), so the households of these three regions produced about 15% of all FW in Finland.

There are some differences between the study regions. The amount of FW was larger in Tampere and Turku than in Helsinki. Originally edible FW was largest in Tampere (28.4 kg/cap/y) and smallest in Helsinki (23.0 and 24.8 kg/cap/y) and Turku (23.1 kg/cap/y). Inedible FW was also largest in Tampere (33.7 g/cap/y) and smallest in Helsinki (28.2 kg/cap/y). The larger amounts in Tampere and Turku can be explained by the regional structure. Although they have large apartment buildings, their suburbs include more detached and small houses than Helsinki. Detached housing with one or a few apartments has been found to produce more waste in general (HSY, 2018). Apple trees are also common in the gardens of detached houses, and the large amount of EFW in the Tampere can also be partly explained by the large amount of *Apples* (garden) (4.8 kg/cap/y). The study period was in September, when apples ripen. When *Apples* were excluded, the amounts of EFW were quite similar in all regions. The regions may also differ in food habits (cooking food from raw materials causing more inedible parts or eating more often away from home due to population demography and employment status).

The share of edible food waste varied between 41% and 47% of total FW, and similar results have been reported from Belgium, 45% (Roels and Von Gijseghem, 2017) and Sweden, 47% (Naturvårdsverket, 2020). Larger amounts have been reported from the Netherlands, 53% (van Dooren et al., 2019), Denmark, 56% (Edjabou et al., 2016), Norway, 58% (Hanssen et al., 2016), and the UK, 60% (WRAP, 2015). The differences may imply challenges in defining what is edible and inedible, but they may also be a result of variation in diet and the use of fruit and vegetables, coffee, or other food types, with a large share of inedible parts.

The amount of FW found in separately collected biowaste ranged from 17% to 35%, highlighting a great need of improvement in households' biowaste separation skills. The differences between regions probably stemmed from the differing waste management: the number of housing types involved in biowaste collection and the timeframe in which areas started collection. For example, in Turku, there was a large amount of unsorted biowaste in mixed waste, but the area had just started biowaste collection in 2016. The FW data for mixed waste in Turku were also more dispersed, which can be explained by differences in households' sorting routines as they adapted to the new system. The other regions started biowaste collection earlier – Helsinki in 1992 and Tampere in 2004; and they had less unsorted biowaste, probably because their inhabitants had grown accustomed to sorting.

It is important to decrease biowaste in mixed waste because it disrupts the incineration process and leads to a loss of material and nutrients instead of circulation to other products. In the coming years, the amount of FW in mixed waste will probably decrease, as new laws making it mandatory to collect biowaste separately if buildings have five or more apartments will come into force in 2022 (Finlex, 2021). In Finland, the amount of municipal waste has grown from 500 kg/cap/y in 2015 to 565 kg/cap/y in 2019 (OSF, 2019), and it has been found to be correlated with economic growth (OSF, 2021). This is also a factor that affects the amount of FW in households. The timeline from 2015 to 2019 is too short for a study of whether guidance and raising awareness of FW issues have affected household routines and habits. In this study, WCAs in different regions and years were conducted to determine if the method would produce consistent results.

The most discarded type of FW consisted of fresh and perishable food (*Fruit and berries, Vegetables, Bread*) and a combination of raw materials like homecooked food (*Other products*). *Meat and fish* accounted for 10–12%, and *Cheese and other milk products* for 5–6%, of total EFW. In other countries, similar results were found in Sweden (Naturvårdverket, 2020) and the UK (WRAP, 2014), where the same three groups were among the most discarded products in households. In Norway, bakery products were discarded most, but fruit and vegetables, and home cooked food followed (Hanssen et al., 2016), and in Denmark, fresh vegetables and salads dominated, followed by fruit and bakery products (Edjabou et al., 2016). The type of FW products seems quite similar overall, at least in Europe.

Compared with European household FW studies, our results for FW 53.0–62.1 kg/cap/y, were somewhat lower than in Britain, at 69 kg/cap/y (WRAP, 2020), Sweden, at 95 kg/cap/y – or 69 kg/cap/y without liquids (Naturvårdsverket, 2020), Norway, at 81 kg/cap/y (Hanssen et al., 2016), or the European average at 92 kg/cap/y – or 71 kg/cap/y without liquids (Stenmarck et al., 2016). Similar FW amounts have resulted from Germany, at about 60 kg/cap/y (Leverenz et al., 2021) and the Netherlands, at 41–48 kg/cap/y (van Dooren et al., 2019). An examination of the results from other WCA studies shows great variation, with amounts from 43 kg/cap/y to 129 kg/cap/y, and with FW definitions and monitoring methods (Caldeira et al., 2019), which is why the studies are probably mostly incomparable. In any case, this study and the previous diary study (Silvennoinen et al., 2014) showed quite similar EFW amounts in Finnish households.

The biggest contribution to climate impacts from EFW was derived from the *Meat and fish* group, and actually mainly from meat, even if EFW was dominated by *Fruit and berries, Vegetables, Potatoes,* and *Apples* by mass. The result is in line with previous studies. Massow et al. (2019) found that around a third of the climate impacts came from meat and fish food waste, while the respective EFW contributed only 6%. Similar results are also found in the retail sector, where Scholz et al. (2015) found that the meat department contributed 3.5% of the wasted mass, while it accounted for 29% of the total climate impacts of EFW. The contribution of *Meat and fish* from all the products varied between 36 and 45% of the total climate impact, and meat and meat products were clearly dominant from the climate impact perspective. If the impacts of land use on the soil organic carbon (SOC) stock could be included in the carbon footprint assessment of different food products, the results might change slightly within different food products categories, but it is difficult to assess the total cumulative impact for the results, because the SOC assessment methods are still evolving (Joensuu et al., 2021).

Although the amount of total EFW was quite similar in the studied regions, from the climate impact assessment perspective, *Meat and fish* were highlighted in Tampere. This followed from the 20–38% larger EFW amount of *Meat and fish* compared to other regions, and the large climate impact of *Meat and fish* products compared to other product groups.

Based on our study, when attempting to decrease the climate impact of unnecessary EFW, the most essential issue is to limit the amount of meat and meat products EFW. When extrapolating the climate impacts of EFW (0.10 Mt CO2eq/y in the three main Finnish regions) to the national level and all households, the climate impact was 0.31 Mt CO_2eq/y on average. This national annual total climate impact of food waste is approximately the same as the climate impacts of driving an average of 139,000 passenger cars a year in Finland. In the previous similar national assessment by Silvennoinen et al., in 2015, the estimate was 0.35 Mt CO_2eq/y from household food waste, resulting now in a 13% smaller impact than the previous estimate. This difference between studies cannot be justified because the actual climate impact decreased more between years as an outcome of improved food waste data and the climate impact assessment in this later study. By halving current household food waste, as targeted by the European Commission and Government of Finland and assuming a reduction will take place evenly in all product categories, the climate impact saving is 0.15 Mt CO_2eq. If the relative decrease of EFW of meat products were greater, the climate impact savings would be even greater. According to the analysis, this targeted 50% reduction of EFW would account for a decrease of only around 1–3% in the climate impact of food consumption by all Finns compared to the total climate impacts of food presented by Saarinen et al. (2019).

The similarity of FW amounts between study areas in general indicates that the results provide a reliable overview of household FW in urban and surrounding regions in Finland. The reliability is further reinforced by the low overall margin of error of FW percentages in collected loads, although this could be further improved by increasing the number of sampled loads, especially the number of separately collected biowaste loads.

WCA is one of the methods suggested in the European Commission's common measurement methodology (EU, 2019). When considering the method for urban household measurements, the results justify WCA as appropriate and robust, at least for conditions in Finland: it provides data on FW amount and type, and researchers can conduct it without the underestimation typical of the diary method. The study's results show consistency and similarity in the amount and type of FW in different regions, although the housing types and waste management history were different. It also provides detailed information concerning the amount of inedible (IFW) and edible (EFW) FW, the packaging status of FW, and the type of food material.

Despite these benefits, the WCA method has some disadvantages: it provides no data on liquid FW, home composting, or the causes of FW. Additionally, the actual sorting of food and food types from total waste mass is somewhat challenging when the waste mass has blended and food types that are difficult to separate. For a comprehensive understanding and the various purposes of FW monitoring, the WCA method should therefore still be supported by conducting occasional EFW diary studies.

Obtaining data about edible FW and its share of the total is critical when considering how to decrease and halve FW: for households, edible FW can be minimized, but inedible FW is not if food is still cooked at home.

IFW data are difficult to obtain through any other method, because coffee grounds are challenging to measure and self-report daily by households, for example. At least in Finland, it is resource efficient and beneficial to conduct these studies in cooperation with waste management companies when they are undertaking mixed waste composition analysis, because costs and facilities can be shared.

5. Conclusions

This study of food waste in households is the first waste composition analysis considering amounts, types, and housing with different waste collection methods in Finland. It responds to the need for reliable data on household FW flows with robust measurement methods and comprehensive sampling and background data. The study's results showed that approximately 0.1 Mt/y of food were wasted in the Helsinki, Tampere, and Turku regions together, and the annual amount per capita was 53.0–62.1 kg of FW. Originally, edible food waste amounted to 23.0–28.4 kg/cap/y, and inedible food waste amounted to 28.2–33.7 kg/cap/y. The total climate impact was assessed as 0.10 Mt CO_2eq/y when the climate impacts per capita annually ranged from 52.9 kg CO_2eq/cap/y to 61.4 kg CO_2eq/cap/y in the different regions.

The most wasted food groups were fruit and vegetables (including *Vegetables, Fruit and berries,* and *Potatoes*), the *Other products* (including homemade food), *Bread*, and *Meat and fish*. *Meat and fish* products made the most significant contribution to the total climate impact of EFW. From climate impact reduction of EFW point of view, the minimisation of EFW of meat should be clearly prioritised.

All four different studies in three regions resulted in somewhat similar FW amounts per capita and similar FW types, even though they differed in some of their waste management history and practices. The results' consistency supports waste composition analysis as a suitable method for measuring FW from both mixed and biowaste flows in urban and suburban regions in Finland. Cooperation with waste management companies increased resource efficiency and opportunities to share facilities during the study.

CRediT authorship contribution statement

Kirsi Silvennoinen: Conceptualization, Methodology, Investigation, Resources, Writing – original draft, Project administration, Writing – review & editing. **Sampsa Nisonen:** Investigation, Writing – original draft, Data curation, Formal analysis, Software, Writing – review & editing. **Juha-Matti Katajajuuri:** Conceptualization, Methodology, Investigation, Writing – original draft, Data curation, Formal analysis, Writing – review & editing.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.134430.

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