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Estimating food waste generated and packaging placed on the market at national level

Food waste model updates version 3.0

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Contents

Abstract

The aim of this report is twofold. Firstly, it illustrates the latest refinements applied to a food waste model based on material flow analysis, which performs yearly estimations of food waste generated by food category and stage of the food supply chain. Since 2019, the European Commission Joint Research Centre (JRC) has developed this harmonized model to estimate food waste generation as a tool to assess data reported by MSs on food waste generation. Earlier versions of the model are presented in De Laurentiis et al. (2021) and De Laurentiis et al. (2023). The refinement presented in this report involved updating underlying data sources used to estimate food losses at primary production and food waste across the supply chain, refining the modelling of certain food groups at manufacturing, distribution and consumption stages, and adding a new product (i.e. sugarcane) to the model. The resulting model estimated for year 2021 a generation of 73 million tonnes of solid food waste (fresh mass) across the food supply chain at EU level.

Secondly, the report aims to present a methodology to estimate the generation of packaging waste linked to food and beverages consumption. The methodology is based on the use of Euromonitor International's Packaging industry research, which provides annually updated information on consumer product sales by their packaging (differentiated by typology, size, and material) including food and beverage products. The total packaging materials associated to the retail sales of 27 food and beverage product categories, in 19 Member States (MSs) between 2008 and 2022 are estimated. The developed methodology will be used to support MSs in the mandatory reporting of packaging waste quantities, and will be used to benchmark the quantities reported, in the context of the monitoring of the attainment of the recycling targets set out in the Packaging Directive (EU 2018/825).

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1 Introduction

This section contextualises the two activities presented in this report: the refinement of the food waste model and the model to estimate packaging waste.

1.1 Food waste

Food waste has been gaining particular attention in the last years and policies are being put in place to contribute to its reduction. In 2015 the United Nations General Assembly made one of the most important steps towards fighting food waste with the definition of Sustainable Development Goal (SDG) target 12.3: 'by 2030 halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains including post-harvest losses'. This target was set under the SDG 12 – Responsible Consumption and Production. In the same year the European Commission (EC) included food waste as one of the priority areas of the first European Circular Economy Action Plan[1], as well as incorporating into article 9.1.g of the Waste Framework Directive the requirement for Member States to prevent food waste generation as a contribution to UN SDG12.3. The commitment of the EC in targeting food waste was reiterated in the New Circular Economy Plan[2] and in the Farm to Fork strategy[3]. Finally, the EC has proposed, as part of the revision of the Waste Framework Directive, to set legally binding food waste reduction targets to be achieved by Member States by 2030. According to the legislative proposal[4], Member States would be required to take the necessary measures to reduce food waste by the end of 2030: by 10%, in processing and manufacturing, and by 30% (per capita), jointly at retail and consumption (restaurants, food services and households).

Measuring food waste at each stage of the food supply chain (FSC) and by type of food category is fundamental in order to set proper targets for food waste reduction. Directive (EU) 2018/851[5] obliges European Union (EU) Member States (MSs) to reduce the generation of food waste along the food supply chain (FSC) and therefore to monitor and assess the implementation of the waste prevention measures taken. To contribute to the harmonization of food waste quantification in the EU, the Commission Delegated Decision (EU) 2019/1597[6] established a common methodology and minimum quality requirements for the uniform measurement of food waste generated in MSs. Data should be reported according to what is established in Commission Implementing Decision (EU) 2019/2000[7] laying down a format for reporting of data on food waste and for submission of the quality check report as aid down in Directive 2008/98/EC[8]. By year 2023 MSs reported data on food waste generation for reference years 2020 and 2021. Currently, there is a legislative process reaching the final stages for the use of reference year 2020 as baseline to assess progresses towards the objective of food waste reduction according to the Waste Framework Directive.

[1] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Closing the loop - An EU action plan for the Circular Economy COM/2015/0614 final

[2] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A new Circular Economy Action Plan For a cleaner and more competitive Europe COM/2020/98 final

[3] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system COM/2020/381 final

[4] Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 2008/98/EC on waste. https://eur-lex.europa.eu/resource.html?uri=cellar:c2b5929d-999e-11e5-b3b7-01aa75ed71a1.0018.02/DOC_1&format=PDF

[5] DIRECTIVE (EU) 2018/851 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 amending Directive 2008/98/EC on waste

[6] COMMISSION DELEGATED DECISION (EU) 2019/1597 of 3 May 2019 supplementing Directive 2008/98/EC of the European Parliament and of the Council as regards a common methodology and minimum quality requirements for the uniform measurement of levels of food waste

[7] COMMISSION IMPLEMENTING DECISION (EU) 2019/2000 of 28 November 2019 laying down a format for reporting of data on food waste and for submission of the quality check report in accordance with Directive 2008/98/EC of the European Parliament and of the Council

[8] DIRECTIVE 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 November 2008 on waste and repealing certain Directives

In this context, the JRC has developed a model for the estimation of food waste and its components in the EU at MS level, based on data currently available, adopting a consistent approach across countries, and enabling the assessment of temporal trends, presented in De Laurentiis et al. (2021). The results of the model were provided to MSs who were allowed, since the first reporting year, to use them for data gap-filling purposes, in case they could not collect data for all the stages of the food supply chain. In addition, when not used by the MSs, the model results were used by Eurostat to cross check whether the quantities reported were in the correct range, allowing them to identify potential errors, for instance in the unit of measure used or due to a double accountancy of products or the inclusion of wastewaters. In the coming years, the model will continue to be used to benchmark the quantities reported by the MSs, in order to identify potential outliers, and to assess the quality of data in the years in which in depth-methods are not used (i.e. when the reported food waste quantities are estimated using Annex IV instead of Annex III of Delegated Decision (EU) 2019/1597).

The model estimates food waste at each stage of the food supply chain and at food group level, by developing a material flows analysis (MFA) of the food system in each MS; it is hereafter referred to as the MFA model. The material flow analysis considers only the mass of food products, therefore excluding the mass of any related packaging materials. This report presents the proposed methodological updates of the MFA model leading to version 3.0 (Section 2). These include:

- an update in the country-specific food waste coefficients (Section 2.1);
- an update of coefficients to estimate food losses at primary production (Section 2.2);
- the inclusion of additional products (Section 2.3);
- modelling improvements based on market sales data (Section 2.4)
- additional modelling improvements (Section 2.5).

Results obtained from the updated MFA model (version 3.0) are illustrated for the year 2021 and are presented in Section 2.6. Lastly, this report includes the updated version of Annexes 1, 2, 3, and 4 as in De Laurentiis et al. (2021) and in De Laurentiis et al. (2023). Annex 1 contains the full list of coefficients (technical coefficients and food waste coefficients) used by the MFA model with their respective data source. Throughout this report, schemes are provided whenever necessary to illustrate the modelling of the different food groups and stages of the food supply chain. In these schemes, the coefficients used by the model are identified with coefficient codes that are then repeated in the tables of Annex 1. Annex 2 contains the full list of data sources used to extract data on production, trade and other uses (e.g. feed). For each data source (e.g. FAO Commodity Balance Sheets), information is provided on the list of food products extracted, detailing the name of the food product (e.g. barley), its product code in the original data source (e.g. FAO2513) and the product flows indicators (e.g. production, imports, exports). In addition, when alternative data sources are used by the model (i.e. in the process of integrating missing data by using a second data source having a different classification system), the correspondence between the product codes from the two data sources is provided. Annex 3 reports the total results of the MFA model, both at EU27 level and for each MS, for all years considered (2003-2021), while Annex 4 reports the most relevant results for each MS and for EU27 for the year 2021.

1.1.1 Food waste and losses definitions

The lack of common agreed definitions at international level on food waste and food losses represents a major issue when trying to compare different studies and projects. Another obstacle when comparing different studies is that some of these only report on the edible component of food waste, and therefore these studies are not fully comparable with the total amounts of food waste that have to be reported mandatorily to the Commission. In this regard, even if some definitions of what is “edible” or “inedible” are available, in reality this difference can be highly subjective and can vary due to cultural reasons. Animal parts or fruit and vegetable peels may not be considered edible in some cultures, while in other countries these are commonly eaten. Even within a particular culture, the “edibility” may depend on the degree of processing (UNEP, 2024).

Table 1 illustrates the different definitions of « food », « food loss », « food surplus », « food waste » and « inedible or non-edible parts » adopted by the European Commission and by the United Nations. The two sets of definitions present a good alignment, with food waste encompassing in both cases edible and inedible components of food removed from the food supply chain from production until consumption. The main difference is that for the purpose of the Food Waste Index, monitored by UNEP, only food waste generated at retail and consumer levels is included, while earlier stages of the supply chain are accounted for by the Food Loss Index.

Table 1. Comparison between UN and EC definitions of "food", "food loss", "food surplus", "food waste", "inedible or non-edible parts", and "municipal solid waste".

	Definition adopted by UN	Definitions adopted by the European Union legislation
Food	*Any substance – whether processed, semi-processed or raw – that is intended for human consumption. "Food" includes drink, and any substance that has been used in the manufacture, preparation or treatment of food. "Food" also includes material that has spoiled and is therefore no longer fit for human consumption. It does not include cosmetics, tobacco or substances used only as drugs. It does not include processing agents used along the food supply chain, for example water to clean or cook raw materials in factories or at home* (UNEP, 2021).	*'Food' (or 'foodstuff') means any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be ingested by humans. 'Food' includes drink, chewing gum and any substance, including water, intentionally incorporated into the food during its manufacture, preparation or treatment. It includes water after the point of compliance as defined in Article 6 of Directive 98/83/EC and without prejudice to the requirements of Directives 80/778/EEC and 98/83/EC.* (Article 2 of REGULATION (EC) No 178/2002 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL).
Food losses	*Food loss is defined as all the crop and livestock human-edible commodity quantities that, directly or indirectly, completely exit the post-harvest/slaughter production/supply chain by being discarded, incinerated or otherwise, and do not re-enter in any other utilization (such as animal feed, industrial use, etc.), up to, and excluding, the retail level. Losses that occur during storage, transport and processing, also of imported quantities, are therefore all included. Losses include the commodity as a whole with its non-edible parts decrease in edible mass at the production, post-harvest and processing stages of the food chain* (UNEP, 2024).	No official definition. Nevertheless, the following definition can be deduced from the EU legislative documents. Food losses can be defined as losses of crops prior to harvesting (including crops ploughed in or left on the field) and mortality of animals ready for slaughter, as these streams are excluded from the definition of food waste at primary production, according to Article 2 of REGULATION (EC) No 178/2002 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL).
Food surplus	*Food surplus refers to food that is redistributed for consumption by people, used for animal feed or used for bio-based materials / biochemical processing* (UNEP, 2021).	*Surplus food, consisting of finished food products (including fresh meat, fruit and vegetables), partly formulated products or food ingredients, may arise at any stage of the food production and distribution chain for a variety of reasons. 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* (Chapter 2.2 of COMMISSION NOTICE EU guidelines on food donation (2017/C 361/01)).

Food waste	In UNEP (2024) food waste is defined as: *food and the associated inedible parts removed from the human food supply chain*. Nevertheless, the same report states that: *the Food Waste Index tracks the global and national generation of food and inedible parts wasted at the retail and consumer (household and food service) levels*.	Food waste is defined as: *all food as defined in Article 2 of Regulation (EC) No 178/2002 of the European Parliament and of the Council that has become waste* (Article 1 of DIRECTIVE (EU) 2018/851 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 Amending Directive 2008/98/EC on Waste). 'Waste' means any substance or object which the holder discards or intends or is required to discard (Article 3 of DIRECTIVE 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 November 2008 on waste and repealing certain Directives). *The definition of 'food' laid down in Regulation (EC) No 178/2002 of the European Parliament and of the Council encompasses food as a whole, along the entire food supply chain from production until consumption. Food also includes inedible parts, where those were not separated from the edible parts when the food was produced, such as bones attached to meat destined for human consumption. Hence, food waste can comprise items which include parts of food intended to be ingested and parts of food not intended to be ingested* (COMMISSION DELEGATED DECISION (EU) 2019/1597 of 3 May 2019 supplementing Directive 2008/98/EC of the European Parliament and of the Council as regards a common methodology and minimum quality requirements for the uniform measurement of levels of food waste).
Edible parts of food	Edible parts of food waste are described as: *the parts of food that were intended for human consumption* (UNEP, 2024).	*Edible food parts are the components associated with a food, in its fresh mass status, that are usually consumed by humans in the MS, either as is (raw consumption) or after processing or cooking. The definition of edible food parts might differ from country to country, or from region to region, according to local culture and habits* (Guidance on food waste – Eurostat 2022).
Inedible/non edible parts of food	*Components associated with a food that are not intended to be consumed by humans. Examples of inedible parts associated with food could include bones, rinds and pits/stones* (UNEP, 2024).	No official definition. However the following statement (not legally binding) is provided in (Guidance on food waste - Eurostat): *Eurostat strongly recommends the reporting country to define a list of inedible parts of the food considered whenever they voluntarily provide information on the measurement of edible food waste; this list will permit the comparability of information.*

Source: Authors' own elaboration

1.2 Packaging

Directive 94/62/EC[9] contains measures designed to prevent the production of packaging waste and to promote its reuse, recycling and recovery. To this end, it sets recycling targets for EU countries, which depend on the type of material (e.g. 50% of plastic, 75% of paper and cardboard, 70% of glass by 2025). In this context, EU countries need to report wasted quantities and recycled quantities, following the methodology set out in decision EU/2019/665[10], providing the rules to calculate the attainment of the recycling targets. Moreover, Regulation 2021/770[11] lays down rules on calculating the own resource based on plastic packaging waste that is not recycled, as referred to in point (c) of Article 2(1) of Decision (EU, Euratom) 2020/2053[12] (the 'own resource based on non-recycled plastic packaging waste'). The Regulation also establishes annual reporting obligations in its Article 5(5). To support Member States in this process, and benchmark the quantities of packaging waste reported, the JRC developed a method to estimate the generation of packaging waste linked to food consumption.

Section 3 details the methodology developed to estimate the amount of packaging materials linked to food and beverages consumption in a country over one year. The methodology is developed at Member State level and allows to estimate the quantities of the main packaging materials (e.g. PET plastic, HDPE plastic, glass) used over one year for the main food and beverage products consumed. It relies on the use of Euromonitor International, a business intelligence provider researching consumers, services, and B2B industries including Packaging. On the packaging industry Euromonitor International publishes annually updated data on the sales of units of packaging (differentiated by typology, size and material) associated to food and beverage products. These data include both retail and food service volume sales.

By using this approach, the total packaging materials related to the sales of food and beverage products are estimated for 19 countries, for all years between 2008 and 2022, considering 27 food and beverage products. In addition, the results of the packaging data analysis (e.g. total quantity of PET plastic used for drinking milk containers in Italy in 2020) combined with data on Euromonitor International food and beverage product level sales data (e.g. total volume of milk sold in Italy in 2020), were used to calculate country-specific coefficients that can be used in combination with food consumption or sales data (depending on the availability) to estimate the use of packaging materials in the absence of a database providing detailed information on packaging sales. Furthermore, performing this analysis for several years will allow to evaluate trends in usage of different packaging materials in order to identify potential substitution effects between packaging materials; material substitution often occurs as a consequence of new legislation, changes in consumer expectations, availability and cost of resources.

[9] EUROPEAN PARLIAMENT AND COUNCIL DIRECTIVE 94/62/EC of 20 December 1994 on packaging and packaging waste

[10] COMMISSION IMPLEMENTING DECISION (EU) 2019/665 of 17 April 2019 amending Decision 2005/270/EC establishing the formats relating to the database system pursuant to European Parliament and Council Directive 94/62/EC on packaging and packaging waste

[11] COUNCIL REGULATION (EU, Euratom) 2021/770 of 30 April 2021 on the calculation of the own resource based on plastic packaging waste that is not recycled, on the methods and procedure for making available that own resource, on the measures to meet cash requirements, and on certain aspects of the own resource based on gross national income

[12] COUNCIL DECISION (EU, Euratom) 2020/2053 of 14 December 2020 on the system of own resources of the European Union and repealing Decision 2014/335/EU, Euratom

2 Modelling food waste: methodology and results

This study builds on the material flow analysis (MFA) model presented in De Laurentiis et al. (2021) (version 1.0) and further developed in De Laurentiis et al. (2023) (version 2.0).

In all the reports, food, food waste and food losses follow the definitions adopted by the European Union (see **Table 1**). An illustration of the definition of food waste used in this report is provided in **Figure 1**.

The MFA model quantifies food waste at each stage of the food supply chain – primary production (PP), processing and manufacturing (P&M), retail and distribution (R&D), food services, and household consumption. The model consists of several material flow analyses of the food system in each MS and for each year between 2003 and 2021. In each MFA, the entire food system is mapped, from the harvesting of crops to the consumption of food, and the flows leaving the system are quantified and differentiated between losses at primary production, food waste at each stage of the supply chain, and by-products generated at primary production and at processing and manufacturing. 11 food groups are considered in the model: sugar, cereals, fruit and nuts, vegetables, potatoes, oilseeds, meat, fish, eggs, dairy, and cocoa and coffee. Food waste quantities are provided at product group level, for all 27 MSs and all years considered in the analysis.

The model uses as input annual data retrieved from official statistics on:

— production, trade and non-food uses of crops (taken from FAOSTAT commodity balance sheets unless specified differently)

— production, trade and non-food uses of livestock products (taken from FAOSTAT commodity balance sheets unless specified differently)

— production and trade of manufactured food products (taken from Prodcom unless specified differently).

These are combined with:

(i) coefficients extracted from sales data to complement missing information in official statistics (e.g. to differentiate between amounts of a certain product purchased by households and amounts purchased by food services),

(ii) coefficients taken from the scientific literature to estimate food waste generated at primary production, distribution, and consumption, and

(iii) coefficients taken from technical literature (reporting production efficiencies) or derived from data collected directly from trade associations to estimate the food waste and by-products generated at processing and manufacturing.

Whenever country-specific food waste and food losses coefficients are not available, coefficients taken from other countries are used as proxies. Furthermore, as the food waste coefficients used by the model are fixed in time (due to a general lack of data providing temporal variations in patterns of food waste generation), the temporal variations in the food waste estimates yielded by the model result only from variations in volumes of produced and traded quantities of food, and do not capture actual changes in food waste generation patterns due to changes of consumers' behaviour and of food business operators' practices.

The accuracy of the model is affected by a number of factors, including but not limited to:

— possible data gaps and inaccuracies in the official statistics used,

— the lack of publicly available information to accurately model the processing stage of many products (e.g. in particular on the distinction between waste and by-products generated),

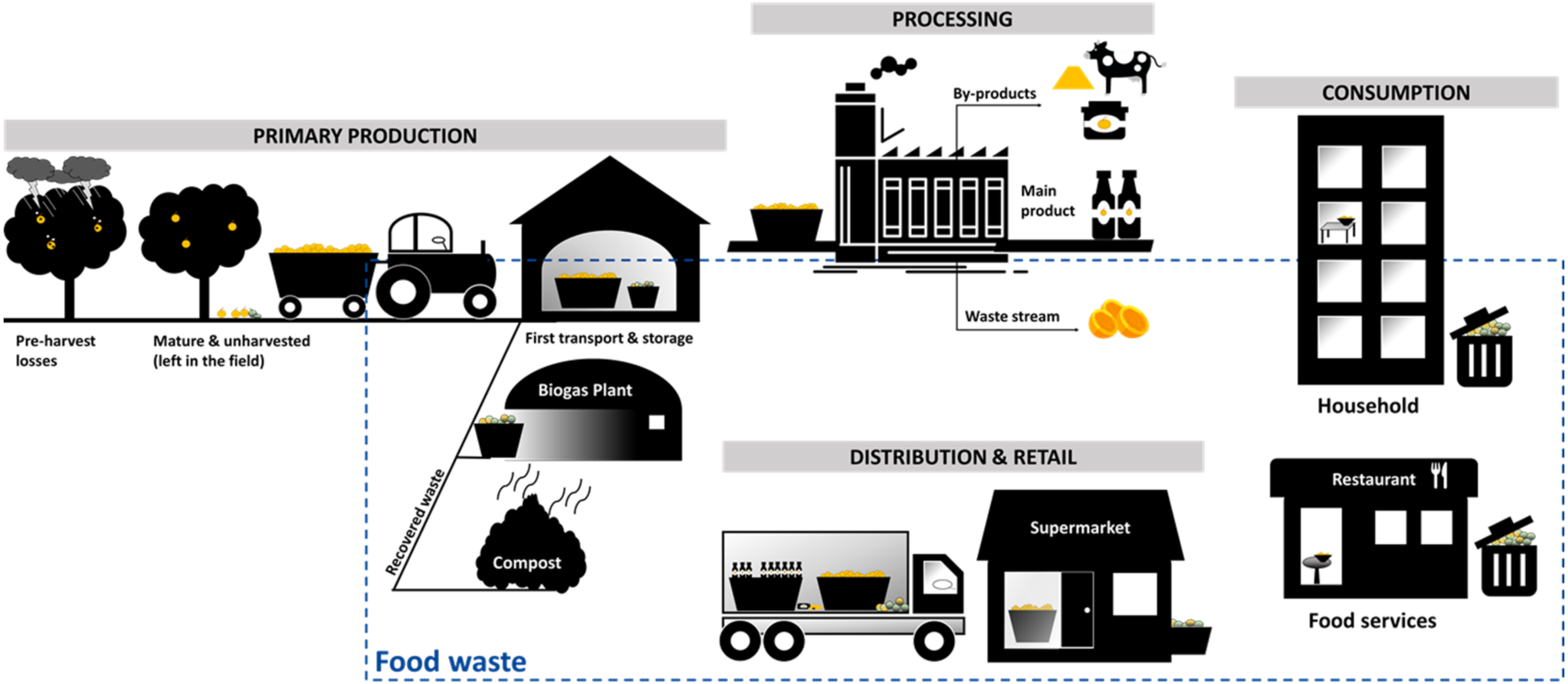
— the lack of studies providing coefficients to estimate food waste taking into account differences in food waste generation patterns across countries and years.

The main uses of the model for policy support are to compare the estimated amounts with the food waste quantities reported by MSs for measurements applied according to Annex III of Delegated Decision (EU) 2019/1597 (i.e. direct measurements, waste composition analysis, diaries and the like), and to allow data quality checks for estimations performed according to Annex IV of Delegated Decision (EU) 2019/1597, for instance when measured data (according to Annex III) from former years are scaled with socio-economic indicators. Furthermore, the information provided by the model was used complementarily to data on food waste generation reported by MSs in the context of the impact assessment of a legislative proposal setting legally binding food waste reduction targets for MSs[13]. In this context, since the annual reported food waste quantities are not disaggregated at the level of product groups, these quantities were combined with information extracted from the MFA model on the contribution of the different product groups to the food waste generated in each country and stage of the supply chain. This allowed to perform a more accurate analysis of the environmental impacts embodied in food waste and consequently of the potential environmental savings that would be obtained by meeting the targets (Sala et al., 2023, De Jong et al., 2023).

This report presents a number of improvements of the MFA model identified as potentially relevant in the last model update as agreed between JRC and DG ESTAT (De Laurentiis et al. 2023). All updates are presented in Sections 2.1 – 2.5, while the resulting estimates are presented in Section 2.6.

[13] Commission staff working document. Impact Assessment Report. Accompanying the document: Directive of the European Parliament and of the Council amending Directive 2008/98/EC on waste.

Figure 1. Boundaries of food waste as defined in EU legislation (Directive (EU) 2018/851)



Source: adapted from Sanchez Lopez et al., 2020

2.1 Update of country-specific food waste coefficients

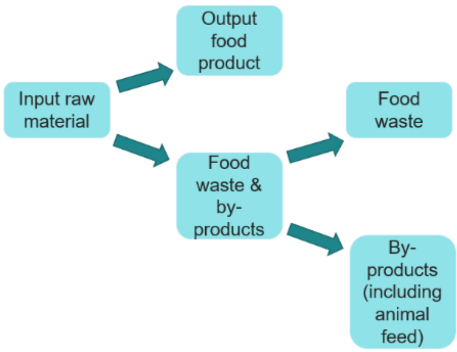
Existing literature was explored to retrieve country-specific coefficients for the estimation of food waste along the food supply chain, defined at food group level. In detail, these coefficients were searched via Scopus database, using the following keywords in the search instruction: "food" AND "waste" AND "country name". The search was limited to journal articles, books and book chapters written in English language. Since the last update on food waste coefficients had been done in 2022 (as presented in De Laurentiis et al., 2023), the timeframe considered was January 2022 – September 2023. The search produced 743 total records, which were further screened by analysing title and abstract to exclude those that were out of scope. A second screening was done in order to exclude those works that:

- used food waste coefficients deriving from previous work rather than suggesting new coefficients (in which case the articles cited were analysed instead);
- carried out a qualitative analysis or used a different food waste definition from the one adopted in the model;
- had already been used to extract food waste coefficients in the previous version of the model (version 2.0).

After this last screening stage, 8 papers were considered suitable and thus selected.

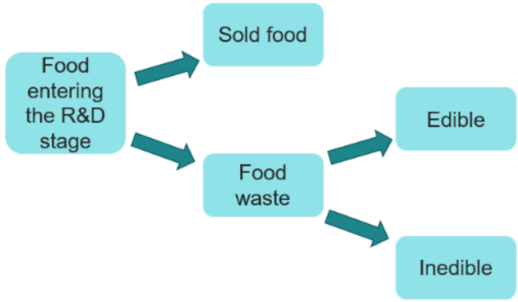
Furthermore, in addition to the selected works, a report by the Swedish Board of Agriculture Jordbruksverket, (2023) was consulted: this work was not found through the initial literature search as it belongs to the grey literature (information produced outside of traditional publishing and distribution channels), but it was identified at a later stage as a potential data source for food waste coefficients. **Table 2** provides an overview of the food waste coefficients extracted from this review. To explain the terminology used in this table, three schemes are provided below (**Figure 2, Figure 3**, **Figure 4**) that present the modelling of each stage of the supply chain. In addition to the coefficients presented in **Table 2**, a coefficient was taken from (Ioannou et al., 2022), expressing the yield of olive oil produced (20%) from the olives destined to oil production, and used to improve the modelling of olive oil production for Cyprus.

Figure 2. Diagram illustrating the modelling of the processing and manufacturing (P&M) stage.



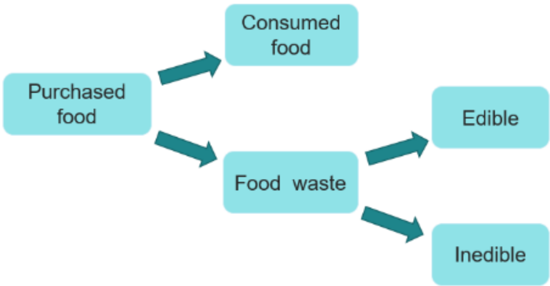
Source: Authors' own elaboration

Figure 3. Diagram illustrating the modelling of the retail and distribution (R&D) stage.



Source: Authors' own elaboration

Figure 4. Diagram illustrating the modelling of the household (HH) stage.



Source: Authors' own elaboration

Table 2. Country-specific coefficients. FSC: food supply chain, PP: primary production, P&M: processing and manufacturing, R&D: retail and distribution, HH: households.

Reference	Country	Food category	Food product	FSC stage	Data source	Food waste and by-products	By-products	Food waste	Edible food waste
Hildersten, (2023)	Sweden	Cereals	Rye	P&M	Industrial data	6%			
Martindale & Schiebe, (2017)	Austria	Fruit	Frozen fruit	HH	Survey			0.6%	0.6%
		Vegetables	Frozen vegetables	HH	Survey			0.9%	0.9%
		Potatoes	Frozen Potatoes	HH	Survey			0.5%	0.5%
		Cereals	Frozen Pasta	HH	Survey			0.5%	0.5%
		Fish	Frozen Fish	HH	Survey			0.5%	0.5%
Ioannou et al. (2022)	Cyprus	Fruits & Nuts	Citrus, Other	P&M	Survey	15%			
		Fruits & Nuts	Oranges	P&M	Survey	15%			
		Fruits & Nuts	Grapes	P&M	Survey	30%			
Fine et al. (2015)	France	Oilcrops	Rape and Mustard Oil	P&M	Industrial data	65.8%			
		Oilcrops	Soyabean Oil	P&M	Industrial data	78%			
		Oilcrops	Sunflowersee d Oil	P&M	Industrial data	63.6%			

Reference	Country	Food category	Food product	FSC stage	Data source	Food waste and by-products	By-products	Food waste	Edible food waste
Amicarelli et al. (2022)	Italy	Potatoes	Processed potatoes	P&M	National reports	12.5%			
Iriondo-Dehond et al. (2020)	Spain	Cocoa & Coffee	Coffee	P&M	Industrial data	2%			
Pedretti et al. (2023)	Italy	Vegetables	Vegetables, Other (spinach)	P&M	Industrial data	29%			
Pietrangeli et al. (2023)	Italy	Cereals	Bread	R&D	Diary			5.1%	5.1%
Jordbruksverket, (2023)	Sweden	Dairy	Dairy*	P&M	Industrial data			5%	
		Dairy	Dairy*	P&M	Industrial data		18%		
		Vegetables	Vegetables, other	P&M	Industrial data	44%			

*food waste from whey

Source: Authors' own elaboration

2.2 Update of country-specific food loss coefficients

Country-specific coefficients for the estimation of food losses were searched via Scopus database, using the following keywords: "food waste/food loss primary production" and "food waste/food loss agricultural stage". The search was limited to journal articles, books and book chapters written in English language. Since the last update on food losses had been done in 2022 (De Laurentiis et al., 2023), the timeframe considered was January 2022 –September 2023. The search produced 751 total records, which were further screened by analysing title and abstract to exclude those that were out of scope. After this first initial screening, 15 studies were analysed in more detail. Nevertheless, they were all excluded (**Table 3**) due to one or more of the following reasons:

A. Use of food losses coefficients deriving from previous works rather than suggesting new food loss coefficients (1 study);

B. Adoption of a different definition of food losses from the one used in the MFA model (e.g. by considering post-harvest losses as food losses, or by not making a distinction between food waste and food losses) (8 studies);

C. Use of a different approach to quantify food losses (e.g. qualitative analysis) (5 studies);

D. The study has already been used to extract food loss coefficients in the previous version of the model (version 2.0) (1 study), therefore the coefficients were already used by the model.

Table 3. List of screened studies after the first screening step, and reason for exclusion.

Study	Selected/Excluded	Reason (from the list above)
Drofenik et al. (2022)	Excluded	B
Herzberg et al. (2023a)	Excluded	B
Herzberg et al. (2022)	Excluded	C
Herzberg et al. (2023b)	Excluded	C
Łaba et al. (2022)	Excluded	B
O'Connor et al. (2022)	Excluded	D
Strid et al. (2023a)	Excluded	B
Tonini et al. (2022)	Excluded	A
Amicarelli et al. (2022)	Excluded	C
Eičaitė et al. (2022)	Excluded	B
Kör et al. (2022)	Excluded	B
Péra et al. (2023)	Excluded	B
Petrunina et al. (2023)	Excluded	C
Bartezzaghi et al. (2022)	Excluded	C

Lin et al. (2022)	Excluded	B

Source: Authors' own elaboration

As a result, a broader research was conducted using Google Scholar and the materials provided through the EU Platform on Food Losses and Food Waste[14] as data sources. Key words and selection criteria were those previously mentioned. The output of this search lead to the identification of research work done by The Swedish Board of Agriculture[15] on food losses. **Table 4** illustrates the studies selected and the food losses coefficients extracted and used in this model update.

Table 4. Sources and food loss coefficients selected

Study	Country	Food product	Food loss coefficient
Strid et al. (2023b)	Sweden	Potatoes	2.8%
Persson Hovmalm & Lindow, (2023)	Sweden	Wheat	2.6%
Olsson, & Lindow (2023)	Sweden	Carrots*	5.6%
Lindow & Andersson (2022)	Sweden	Milk	0.4%
Lindow & Andersson (2022)	Sweden	Pig	1%
Strid et al. (2022)	Sweden	Beef	0.2%

* Used as a proxy for the item in the model "Vegetables, other".

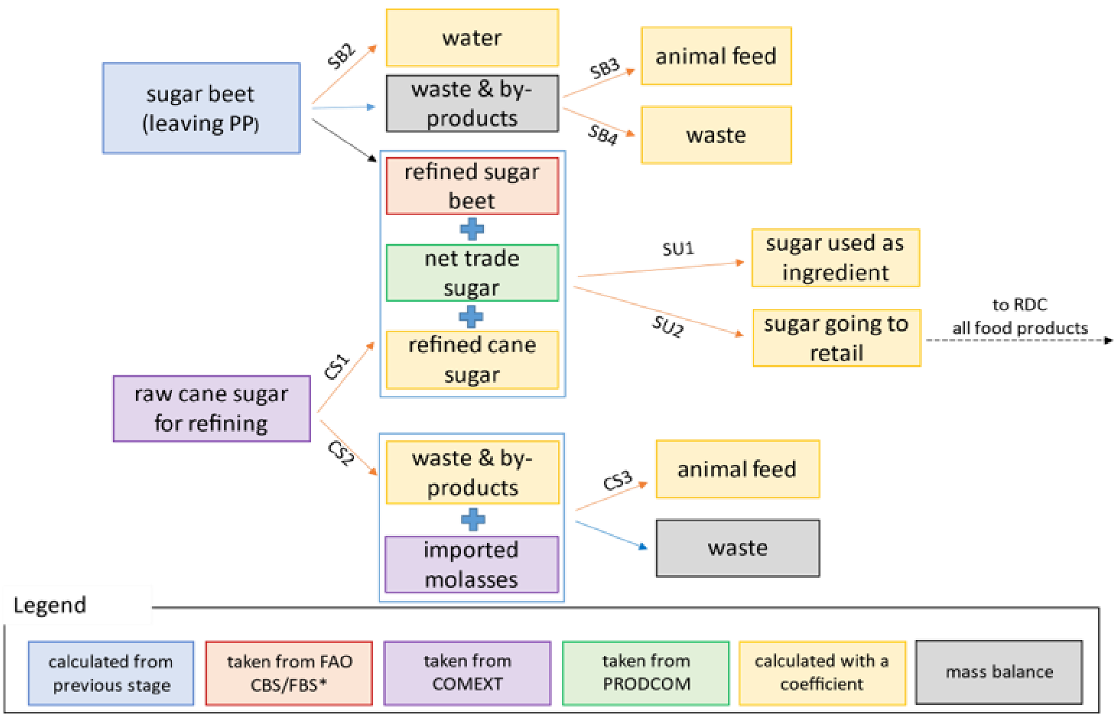
Source: Authors' own elaboration

[14] https://food.ec.europa.eu/safety/food-waste/eu-actions-against-food-waste/eu-platform-food-losses-and-food-waste_en
[15] https://jordbruksverket.se/languages/english/swedish-board-of-agriculture

2.3 Inclusion of additional products

Cane sugar was added to the model to increase its coverage of the food system. In previous versions of the model, only beet sugar was considered, being by far the most consumed type of sugar in the EU. The modelling of cane sugar starts from the import of raw cane sugar entering the P&M stage. The PP stage is not modelled, since sugar cane is not cultivated in EU Member States. Import and export data of cane sugar for refining are retrieved from COMEXT (as reported in Annex 2). Imported raw sugar is covered with a thin coat of molasses, residual plant matter and particles from shipping and handling. It must undergo purification at a cane sugar refinery before it is safe for human consumption. In most instances, raw sugar is not considered an edible food, but it rather represents a bulk commodity (Eggleston et al., 2017). The first step of the raw sugar refining process is the removal of the thin coat of molasses and residual matter from the raw sugar crystals. The efficiency rate from raw cane sugar into refined sugar (CS1 in **Figure 5**) was retrieved from the report of the International Sugar and Sugarcane conference[16]. The aggregated amounts of generated waste and by-products (CS2) are calculated using a coefficient computed by Sugars International[17]. The molasses obtained and those imported as such (taken from COMEXT) are assumed to be entirely used as animal feed (therefore CS3 is taken as equal to 100%) (Ungureanu et al., 2022), which is its predominant use in Europe. After refinement, sugar from cane and from beet are merged in the model (**Figure 5**). The model considers that 70% (SU1) will be used as ingredient in food industry (and is therefore not further considered in the model to avoid double counting), while the remaining 30% (SU2) of total sugar produced (beet and cane sugar) is distributed as such (European Commission, 2006). For retail and distribution and consumption stages the coefficients used and the model architecture are the same used in De Laurentiis et al. (2023). The full list of coefficients is available in Annex 1.

Figure 5. Modelling of the processing and manufacturing stage for cane sugar.



Source: Authors' own elaboration

[16] https://tssct.org/wp-content/uploads/2019/08/0900-0920-E.-M.-I.-Sarir-1.pdf
[17] https://sugarsonline.com/wp-content/uploads/2023/06/refinery.pdf

2.4 Modelling improvements based on market sales data

Sales data proved very useful in the earlier update of the MFA model (leading to version 2.0), as they allowed to fill in gaps in official statistics, such as for instance the differentiation between the amount of a certain product purchased by households and by food services in a given country, which crucially helped refining the quantification of food waste generated by households and food services, respectively. Therefore, the aim of this modelling improvement was to further leverage on the potential of using this data source to complement official statistics, ultimately to refine the estimations of food waste for specific food groups.

Sales data were used to improve the modelling of specific food products, by calculating coefficients fixed in time that are inputted to the model. In this way, while an improvement in the modelling of the relative products can be achieved, it is also guaranteed that future updates of the model do not rely on the availability of sales data. On the other hand, periodic updates of the coefficients would be beneficial to ensure that they do not become outdated. The refinement of the coefficients used in the FW MFA model v3.0 involves the following tasks:

- calculating shares of edible oils used for food purposes;
- calculating shares of eggs distributed fresh and going to manufacturing;
- calculating shares of fresh fish and processed fish products entering the distribution phase;
- further disaggregating processed fruit, processed vegetables, and processed fish products at distribution.

Sales data were obtained from Euromonitor International, which is a business intelligence provider of product sales data and market outlook of the food and beverage sectors including Fresh Food, Packaging Food, Alcoholic Drinks and Soft Drinks (Euromonitor, 2023). Euromonitor publishes sales data for both retail and food service channels organized in different modules. To perform this exercise the following Euromonitor International industry categories were used:

- Cooking ingredients and meals
- Fresh food
- Staple foods
- Ingredients in food products

Data are published in value (both retail selling price and manufacturers selling price) or volume terms in tonnes or litres. For the purpose of this exercise the latter were used. Data were extracted for the 27 EU MSs (current composition) from 2010 to 2022. It is important to stress the difference between the following modules: “Cooking ingredients and meals” and “Ingredients in food products”. The first includes items sold as such through retail channels (i.e., vegetable oil sold in bottles to the final consumer), whereas the second estimates the amount of an ingredient sold in food product formulation (i.e., the estimation of the amount of vegetable oil in a backed cake sold to the final consumer). For instance, the retail volume of vegetable oil sold in supermarkets is captured in “Cooking ingredients and meals”, whereas the volume sold in products such as baked goods is reported in “Ingredients in food products”.

2.4.1 Oilcrops

The aim of this update is to refine the estimation of the amounts of vegetable oils entering the food system, thus differentiating them from the quantities used for non-food uses, e.g. biofuels. Furthermore, it allows to distinguish between vegetable oils distributed as such for food consumption and those contained in processed food products. To this end two coefficients are calculated for each country: the share of the total vegetable oils available in a country (resulting from production and trade statistics) that is distributed for food consumption as such, and the share that is distributed as an ingredient of processed food products.

The MFA model v2.0 distinguishes between the quantities of oilcrops produced for food purposes and for non-food uses (e.g. biofuels production), based on information provided by Transport and Environment (2017) on the average shares of rapeseed, soybeans, sunflower seeds, and cotton seeds produced for the production of biofuels in Europe. All of the olive oil produced and the remaining quantities of the other edible oils mentioned above were assumed to be used exclusively for food purposes. The MFA model considers only these quantities (and neglects the amounts used for biofuels production) as it is focused on the food system.

To tailor this estimation to each MS, the following information was collected from Euromonitor: sales quantities of vegetable oils (i.e. sunflower oil, rapeseed oil, soy oil, and other edible oils) from the "Cooking ingredients and meals" industry (i.e. vegetable oils sold as such), and quantities of the ingredients "vegetable oil" and "hydrogenated vegetable oil" contained in sales of processed food products, extracted from the "Ingredients in food products" industry. Euromonitor reports oil sales data in million litres in the "Cooking ingredients" industry and in thousands of tonnes in the "Ingredients" industry. Therefore, data expressed in volume were converted in mass using density values for each oil type extracted from (Aceite de las valdesas, 2023).

The sum of the amount of vegetable oils distributed as such and as part of processed food products thus obtained was divided by the amount of vegetable oils (rapeseed and mustardseed oil, soybean oil, sunflowerseed oil, and cottonseed oil) available in each country in the MFA model (calculated as the amount produced plus the net trade), to calculate coefficients expressing the share of vegetable oils used for food production (equation 1).

It should be noted that the calculation of these coefficients is affected by a number of limitations. Firstly they are calculated by combining data deriving from two different sources, which may introduce some inconsistencies. Secondly they do not account for waste that occurs during the distribution of both vegetable oils sold as such and processed food products containing them, nor do they consider waste at the manufacturing stage for both groups of products. Nevertheless, these coefficients provide a reasonably fair assessment of the share of vegetable oils used for food production.

The model differentiates between rape and mustard oil, soyabean oil, sunflowerseed oil, cottonseed oil, and palm oil both at primary production and at processing and manufacturing stages, as production and trade data are provided separately for each oil type. Nevertheless, as Euromonitor does not disaggregate to this level (in particular in the "Ingredients" module), when performing this calculation the quantities of vegetable oils available in each country were aggregated, leading to the calculation of one coefficient for each country, across all vegetable oil types. This share was calculated for each MS as the average of the coefficients obtained in the time period 2010-2019. The resulting coefficients (OC1 in Figure 11) are reported in Annex 1.

$$Oilcrops\ for\ food\ purposes\ (\%) = \frac{Vegetable\ oils\ sold\ as\ such + used\ as\ ingredient}{Amount\ of\ oil\ available\ (production + imports - exports)} \qquad [1]$$

The remaining quantities are assumed to be used for non-food purposes. It should be noted that, due to the calculation approach adopted, vegetable oils used by the manufacturing sector but that are not part of the final processed products (e.g. oil used for frying), are accounted for under "non-food uses". Actually, a part of it will be used for energy purposes while the rest will be discarded, and should therefore be considered in the estimation of food waste at manufacturing. However, at the moment there is no data to quantify these flows. This entails that, in countries where not all of the used cooking oil is re-used for energy purposes (i.e. when it is finally collected by a waste treatment facility and further processing is classified as waste treatment), the food waste of vegetable oils at the manufacturing stage is most likely underestimated by the model.

Moreover, the share of vegetable oil sold as such and used as ingredient were derived separately, as illustrated by equations 2 and 3, yielding coefficients OC2 and OC3 in Figure 11. This allows to distinguish between vegetable oils entering the R&D stage as such, and vegetable oils entering it as ingredients of other processed food products.

The modelling of the subsequent stages (i.e. retail and distribution, and consumption) considers only the amount of oils sold as such, whereas the oils used as ingredient are not accounted for as they are assumed to be already considered in the modelling of final processed products belonging to other food categories. For instance, the oil used for biscuits preparation is already accounted in the modelling of the cereals food category.

$$Vegetable\ oils\ sold\ as\ such\ (\%) = \frac{Vegetable\ oils\ sold\ as\ such}{Amount\ of\ oil\ available\ (production+imports-exports)} \quad [2]$$

$$Vegetable\ oils\ used\ as\ ingredient\ (\%) = \frac{Vegetable\ oils\ used\ as\ ingredient}{Amount\ of\ oil\ available\ (production+imports-exports)} \quad [3]$$

The modelling of the R&D and consumption stages of the vegetable oils sold as such was updated compared to version 2.0, as explained in Section 2.5.3.

2.4.2 Eggs

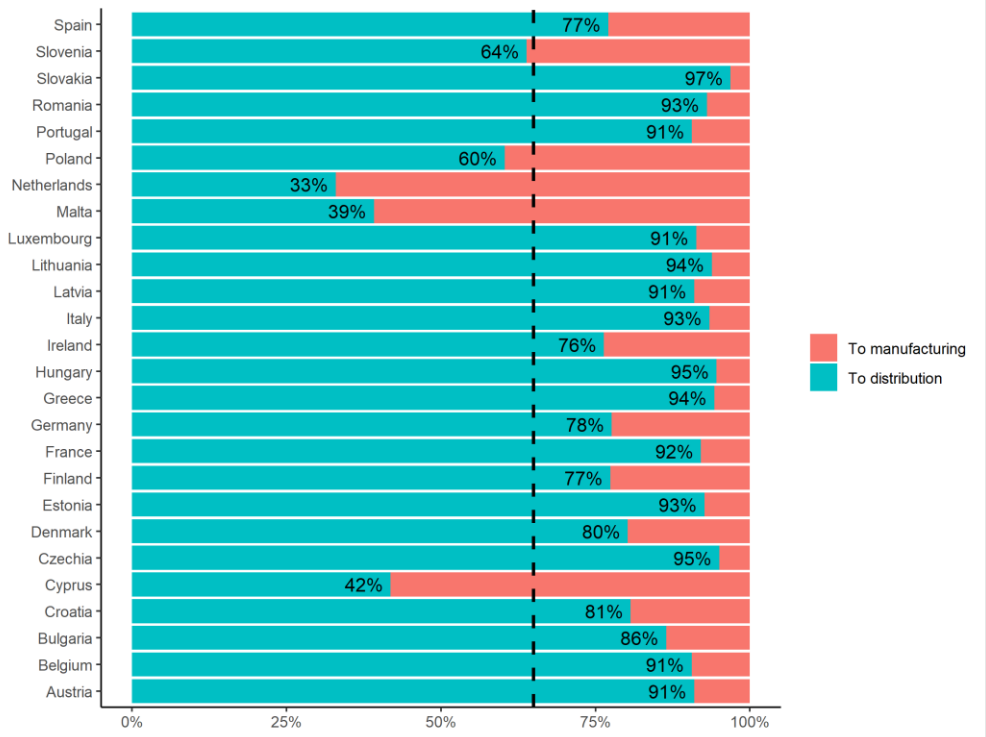
The aim of this update is to refine the distinction between fresh eggs distributed as such and used by the manufacturing sector, to take into account differences across countries in this respect. To this end a coefficient is calculated to express the share of fresh eggs distributed as such out of the total fresh eggs available in a country (resulting from production and trade statistics).

Version 2.0 of the MFA model used an EU average coefficient to distinguish between the amount of eggs distributed fresh and entering the manufacturing stage to be used as ingredient in product formulations, taken from Agra Ceas Consulting (2008). To calculate this coefficient for each MS, the amount of eggs sold as fresh through retail channels was obtained from the “Fresh food” 2023 industry edition of Euromonitor. This quantity was then divided by the total quantity of eggs available for processing and distribution in each country (denoted as “leaving primary production” in the model) following equation 4. The remaining share was assumed to be used by the manufacturing sector.

$$Eggs\ fresh\ for\ distribution\ (\%) = \frac{Fresh\ eggs\ sold}{Amount\ leaving\ primary\ production} \quad [4]$$

As in the previous example, a coefficient was calculated for each MSs as the average of the coefficients obtained in the time range 2010-2019. The resulting coefficients are reported in Annex 1 and illustrated in **Figure 6**.

Figure 6. Share of eggs distributed fresh and entering the manufacturing stage (the dashed line indicates the share applied in version 2.0 of the MFA model). The percentage next to each bar indicates the share of eggs distributed fresh.



Source: Authors' own elaboration based on data from Euromonitor (2023)

2.4.3 Fish

The aim of this update is to allow for the estimation of fresh and processed fish entering the distribution phase, differentiating between the two in order to more accurately estimate food waste generated from this stage onwards. To this end two coefficients are calculated for each country expressing out of the total amount of fish available in a country (expressed in live weight equivalent) the share sold as fresh and the share sold as processed (both expressed in product weight).

In the MFA model v2.0 the modelling of the fish food group differs from the other food groups significantly. As explained in Section 2.2.1.3 of De Laurentiis et al. (2021), this is due to the fact that unlike the other food groups, it is not possible to distinguish between trade of fresh and processed fish products, as part of the processing already takes place at sea (gutting, freezing) and trade statistics report together raw and processed fish products. For this reason, it is not possible to quantify the amount of fish leaving the primary production stage and entering the processing stage after trade, instead, based on FAOSTAT data, it is only possible to quantify directly the amount of fish entering the distribution stage, expressed in live weight equivalent (LWE) (see Figure 4 of the same report). The amount of fish entering the distribution stage is therefore calculated directly from the FAO Commodity Balance Sheets (as illustrated in equation 19 of De Laurentiis et al. (2021).

The refinement here suggested makes use of sales data of fresh seafood (i.e., fish, crustaceans, and molluscs and cephalopods) obtained from the "Fresh food" 2023 industry edition of Euromonitor and of processed seafood, obtained from the "Staple food" 2023 industry edition of Euromonitor, both expressed in product weight (PW), at national level. These quantities are divided by the quantities of fish entering the distribution phase (expressed in live weight equivalent), to calculate coefficients (FI3 and FI4 in **Figure 7**) as illustrated by equations 5 and 6. These coefficients are then used in the model to estimate for each year the quantities of fresh fish and processed fish entering the distribution phase expressed in product weight.

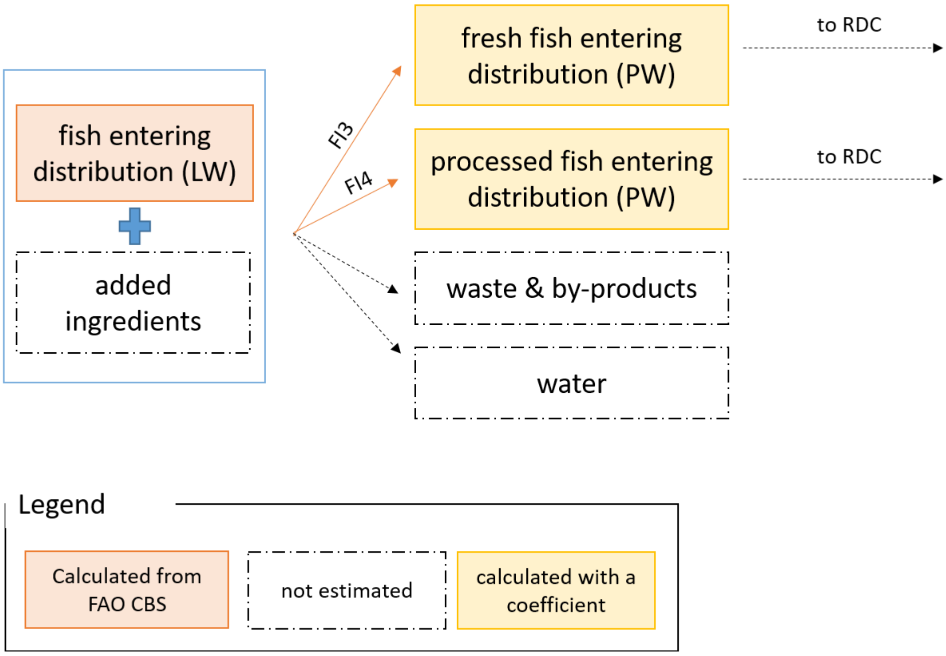
$$Fresh\ fish\ for\ distribution\ (PW)\ (\%) = \frac{Fresh\ fish\ sold\ (PW)}{Fish\ entering\ distribution\ (LWE)} \quad [5]$$

$$Processed\ fish\ for\ distribution\ (PW)\ (\%) = \frac{Processed\ fish\ sold\ (PW)}{Fish\ entering\ distribution\ (LWE)} \quad [6]$$

The two coefficients were calculated for each MSs as the average of the coefficients obtained in the time period 2010-2019. The resulting coefficients are reported in Annex 1.

A number of elements cannot be quantified to close the mass balance (**Figure 7**). These are: the water, waste and by-products leaving the system at the processing stage and the additional ingredients (e.g. potato starch, oil) used in the production of processed fish products. Nevertheless, thanks to this update, the modelling of the distribution and consumption stages is no longer performed expressing fish products in their live weight equivalent, and therefore the risk of double-counting some waste streams (both at the processing stage and at consumption stage), as highlighted as a limitation in De Laurentiis et al. (2021) is reduced. The modelling of waste and by-products at the processing stage is therefore maintained as in the previous versions of the model Section 2.2.2.9 of (De Laurentiis et al., 2021).

Figure 7. Modelling of fish products entering the distribution phase. CBS: commodity balance sheets.



Source: Authors' own elaboration

2.4.4 Further disaggregation of processed products

Version 2.0 of the MFA model considered processed fruit (excluding wine and juices), and processed vegetables (excluding processed tomato products and processed legumes) entering the retail and distribution phase as two items, without further disaggregation. Following the refinement suggested in Section 2.4.3, processed fish products entering the retail and distribution phase are also modelled as an individual item (while in version 2.0 they were considered together with fresh fish). As different typologies of processed products are expected to present different levels of waste at consumption levels, due to varying perishability levels, this task aimed at adding this level of detail to the classification of processed fruit, vegetables and fish products entering the distribution phase, to allow a more precise estimation of the food waste generated from this stage onwards.

This was possible as Euromonitor publishes sales data of processed fish products distinguishing between shelf-stable, chilled, and frozen processed products, while for processed fruit and vegetable products, it distinguishes between shelf-stable and frozen products.

To this end, sales data were obtained from the “Staple Foods” 2023 industry edition of Euromonitor and the share of each type of processed food (chilled, frozen, or shelf stable) was calculated as the ratio between the quantities sold of that type and the total quantities sold. Equations 7, 8 and 9 exemplify this calculation for processed fish products (while only equation 7 and 9 apply to processed fruit and vegetables products as no chilled products are reported). Different shares were calculated for household and food services levels.

$$Share\ of\ frozen\ products\ (\%) = \frac{FR}{FR+CH+SS} \quad [7]$$

$$Share\ of\ chilled\ products\ (\%) = \frac{CH}{FR+CH+SS} \quad [8]$$

$$Share\ of\ shelf\ stable\ products\ (\%) = \frac{SS}{FR+CH+SS} \quad [9]$$

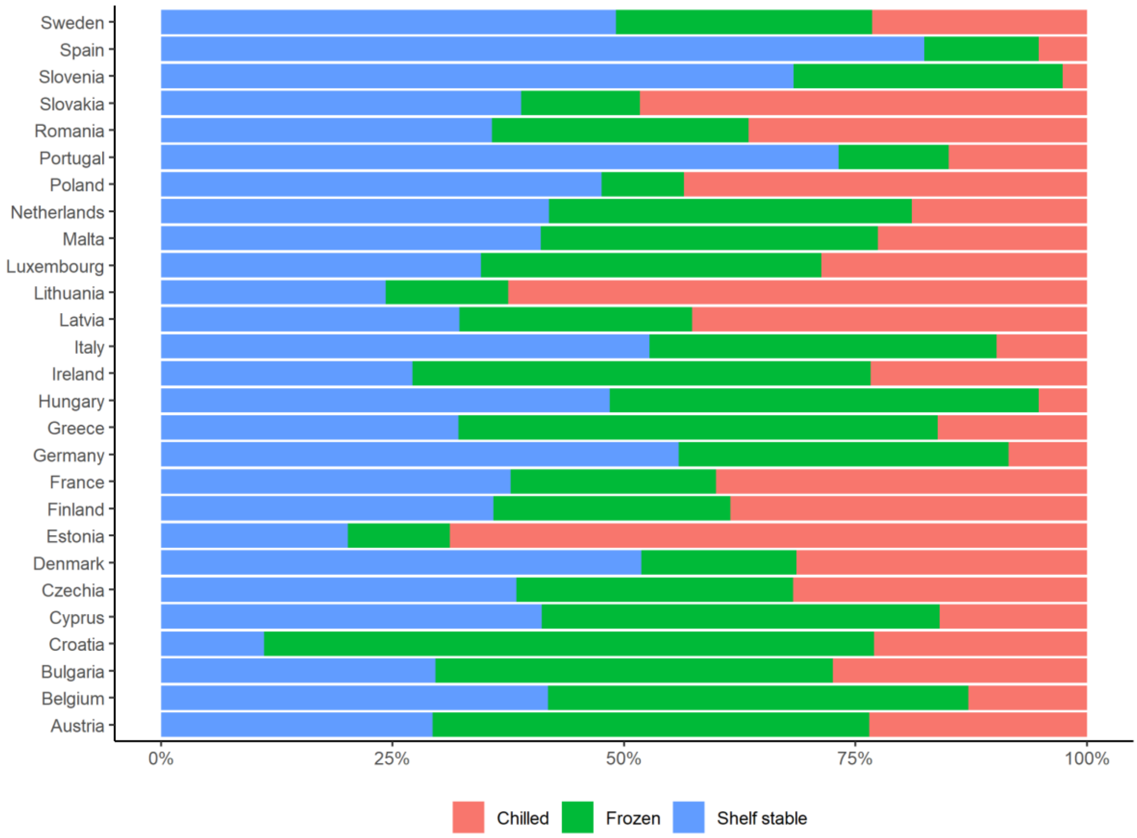
Where:
FR: total amount of frozen processed fish products sold

CH: total amount of chilled processed fish products sold

SS: total amount of shelf-stable processed fish products sold

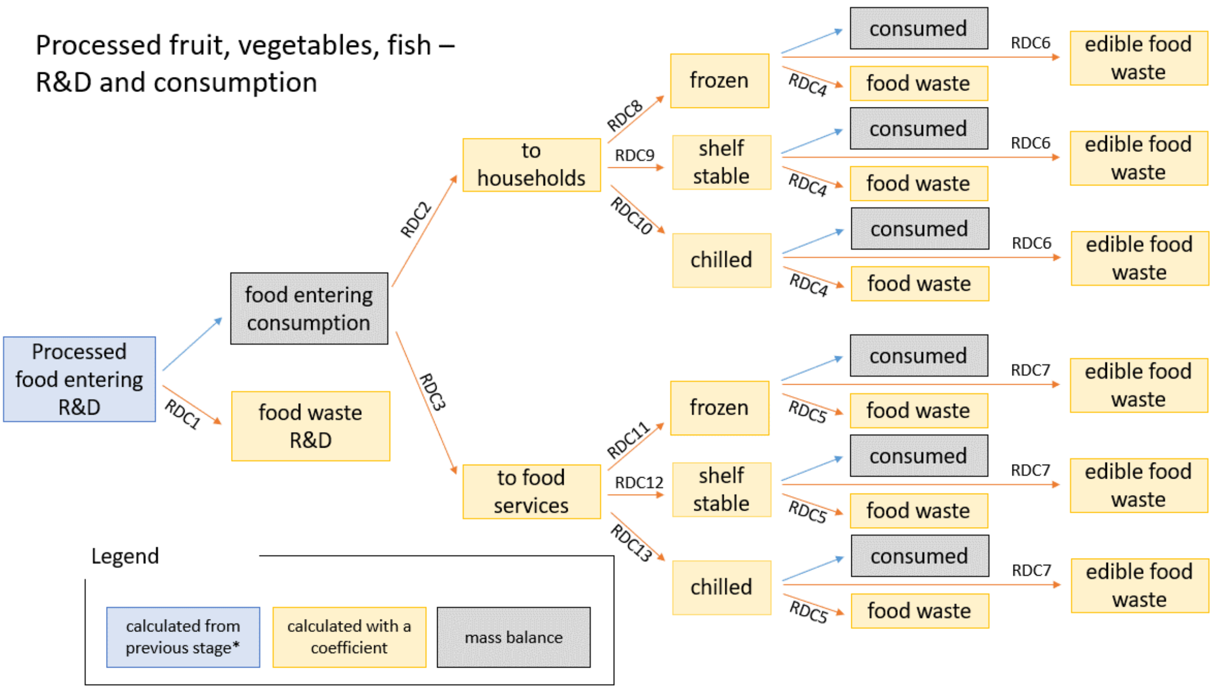
The coefficients were calculated for each MSs as the average of the coefficients obtained in the time period 2010-2019. The resulting coefficients are reported in Annex 1. **Figure 8** illustrates the coefficients obtained for processed fish products, whereas **Figure 9** illustrates how this affects the modelling of the distribution and consumption phases of the MFA model. Food waste coefficients for frozen products (RDC4 in **Figure 9**) have been taken from Martindale & Schiebe, (2017).

Figure 8. Share of chilled, frozen and shelf-stable processed fish products



Source: Authors' own elaboration based on data from Euromonitor (2023)

Figure 9. Distribution and consumption modelling scheme for processed fruit, processed vegetables, and processed fish. R&D: retail and distribution



Source: Authors' own elaboration

2.5 Additional modelling improvements

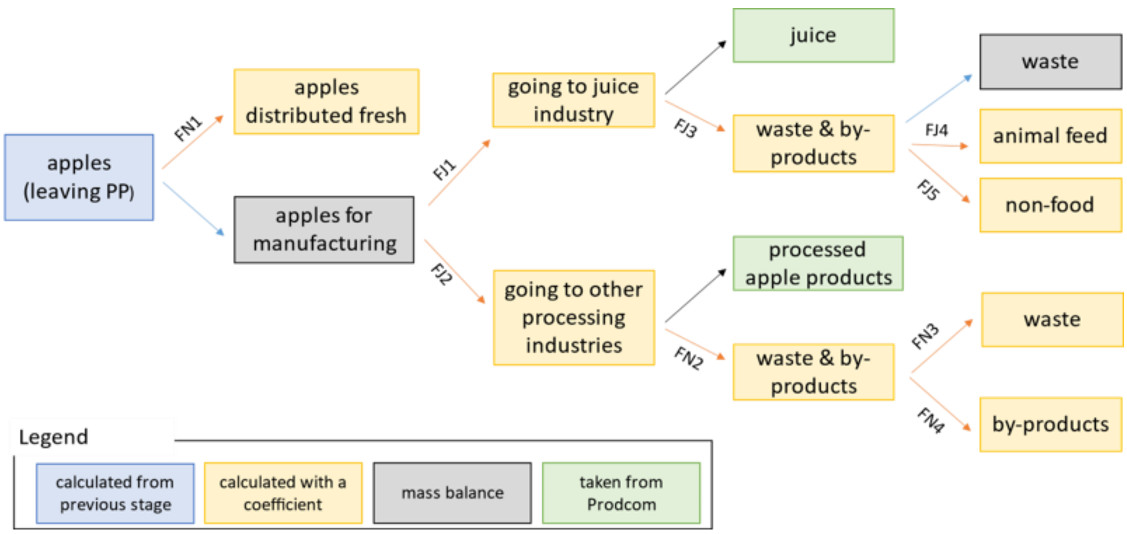
This section presents three updates that were implemented to refine the modelling of the manufacturing stage and consumption stage for selected commodities and, in one case, countries. The first is an update of the modelling of apple juice production in Germany. An update of the modelling of fruit juices was deemed necessary as the MFA model treated fruit juices together with other processed fruit products (a part from wine), due to a lack of data that would allow to distinguish between the amounts of raw materials used for different production purposes. To this end, several industry associations were contacted to retrieve this information for different countries and fruit types. Nevertheless, it was possible to obtain this information only for the production of apple juice in Germany. Future updates of the model would benefit from the capability to retrieve similar data for other major juice-producing countries.

The modelling of oilcrops was improved both at the manufacturing stage, by integrating coefficients to estimate the water leaving the system when extracting vegetable oils, and most importantly at the consumption stage, to take into account for the fact that in certain countries used cooking oils are separately collected and re-used as by-products, therefore no longer contributing to the generation of food waste at this stage. This refinement was deemed necessary to capture the effect of this increasing trend on the generation of liquid food waste at consumption stage.

2.5.1 Modelling of fruit juices (apples)

Data provided by the German Association of the Fruit Juice Industry were used to improve the modelling of apple juice production in Germany. This included information on: the amount of apples used by the juice industry on average at national level, the share of waste and by-products generated in the apples processing stage (FJ3) and the share of waste and by-products going to animal feed (FJ4) and non-food (FJ5). By comparing the amount entering the manufacturing stage estimated by the model with the amount manufactured for juice production, we obtained that in this specific case roughly 100% of the apples are manufactured to produce juices (FJ1), therefore FJ2 is equal to zero in this case (this share might be higher than what happens in reality due to the uncertainty of the two figures). **Figure 10** illustrates the modelling followed for apples in Germany. The remaining fruit products follow the same modelling workflow as in previous version of the MFA model. The modelling at R&D and consumption stage follows the same scheme and uses the same coefficients used in the previous version of the model (De Laurentiis et al., 2023).

Figure 10. Modelling of the processing and manufacturing stage for apples in Germany

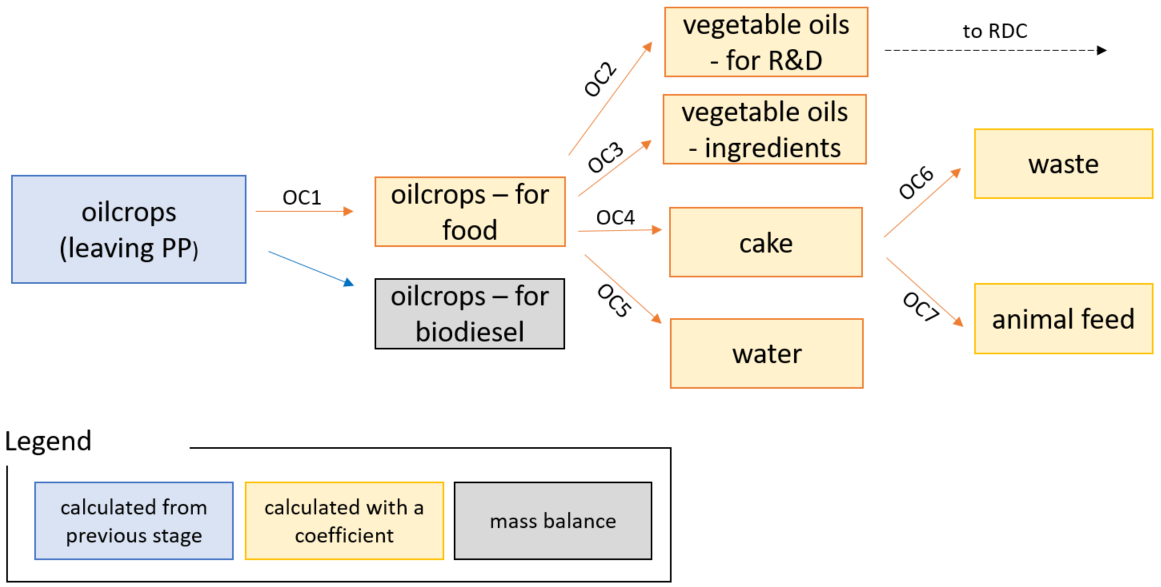


Source: Authors' own elaboration

2.5.2 Modelling of oilcrops at manufacturing stage

The modelling of three out of five edible oilcrops, namely rapeseed and mustard seed, sunflower seed, and soybean has been improved by adding the share of water leaving the process (OC3), as illustrated in **Figure 11**. The process of heating and crushing oilseeds decreases oil viscosity and reduces the water content. The water leaving the process corresponds to 3% of the input flow in the case of rapeseed, 4% in the case of soybean, and 1.7% in the case of sunflower seed (Fine et al., 2015). Although this refinement does not affect the estimation of waste and by-products, it improves the accuracy of the modelling of the processing stage for these three oilcrops, in view of a more precise accounting of the material flow analysis by further considering flows of water leaving the system. **Figure 11** also illustrates the split of vegetable oils going to retail and used as ingredient, as described in Section 2.4.1.

Figure 11. Modelling of the processing and manufacturing stage for oilcrops (rapeseed and mustard seed, sunflower seed, soybean)



Source: Authors' own elaboration

2.5.3 Modelling of oilcrops at consumption stage

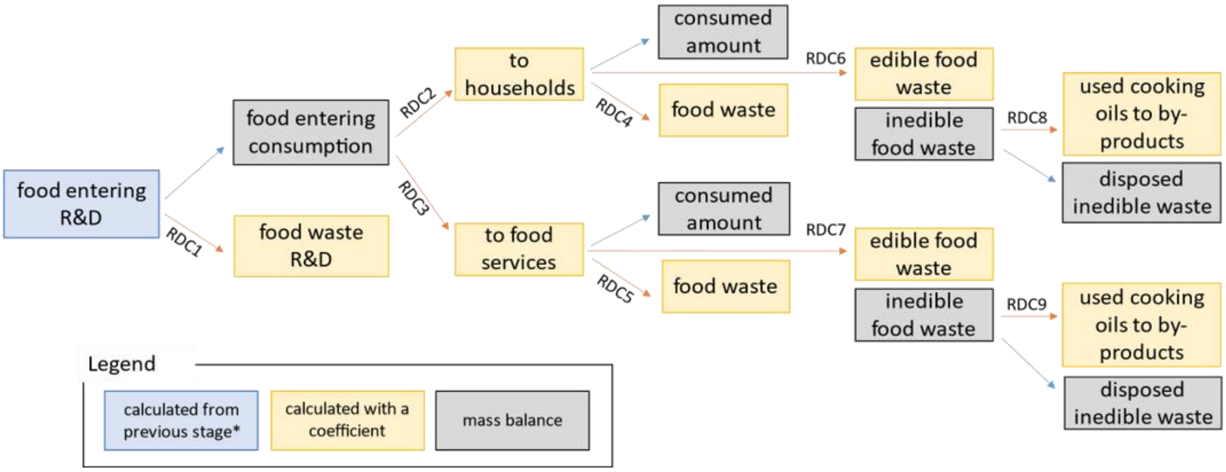
A further refinement of the oilcrops modelling has been carried out at consumption level, for all the edible oils considered (i.e. rape and mustard oil, sunflower seed oil, soybean oil, cottonseed oil and olive oil), in addition to the updates based on sales data presented in Section 2.4.1

For what concerns olive oil and vegetable oils entering the R&D stage as such (as opposed to those entering it as ingredients of processed food products that are not further considered in the model, as explained in Section 2.4.1), a model update allowed to take into account that a part of the oil discarded at consumption (what the model estimates under "inedible food waste", assumed to correspond to used cooking oil) will be collected and used as a by-product.

The collection of used cooking oils (UCOs) is becoming more frequent across MSs, due to blockages caused by UCOs in sewage systems, if not disposed properly, but also because its use for biodiesel production is likely to increase significantly, especially in the light of the Renewable Energy Directive

II[18]. The share of UCOs collected at household (RDC8) and food service (RDC9) levels were taken from Ewaba (2016) and Repsol[19]. In case of UCO collected from household, rates vary significantly across countries, ranging from 0% in 15 countries to 64% (as it happens in Belgium, for instance) (Ewaba, 2016). **Figure 12** illustrates the updated modelling of edible oils from the retail and distribution phase to the consumption phase.

Figure 12. Modelling of the R&D and consumption stage for vegetable oils distributed as such



Source: Authors' own elaboration

2.6 Food waste estimates

This section presents an overview of the results obtained from the model (version 3.0) and a plausibility check of the results of the model performed by comparing one of its outputs (i.e. the consumed amount) with food consumption data. It is important to highlight that the model is affected by uncertainty mostly related to the data gaps, to the inherent uncertainty of the underlying statistical data used, and to the assumptions made in the modelling stage to overcome missing data on food waste percentages for different MSs. Therefore, MSs should not use the data provided by this model to replace their quantification, which should be instead done according to Delegated Decision (EU) 2019/1597.
The model, implemented in R version 4.3.2 (R core team, 2023), produces a range of outputs, presented in Annex 3. For each EU MS and at EU27 level, and for the years 2003-2021, it generates:

- Food waste estimations in fresh mass. Solid food waste, solid edible[20] food waste, and liquid food waste amounts per food category and FSC stage (Table A3.1).
- Food waste amounts per FSC stage (solid component) – dry mass[21] (Table A3.2).
- Food waste estimations per capita by stage of the FSC and by food group (solid component) – fresh mass (Table A3.3).
- Material flow analysis of the food system per food category and across the FSC stage, including: food losses, by-products to animal feed, by-products to non-food, food waste, consumed amount of each food group at household and food services level. All quantities

[18] DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources (recast)
[19] https://www.repsol.com/en/energy-and-the-future/future-of-the-world/oil-culinary-treasure-can-and-should-be-recycled/index.cshtml
[20] The disaggregation between edible and inedible food waste is presented in detail in De Laurentiis et al. (2023) and is based on the edible percentage in each food product as provided in a number of nutritional databases (e.g. CREA, Frida food data).
[21] Defined as the total amount of ingredients in a food exclusive of water (DTU, 2022)

are in fresh mass. Food waste includes both solid and liquid components together (Table A3.4).

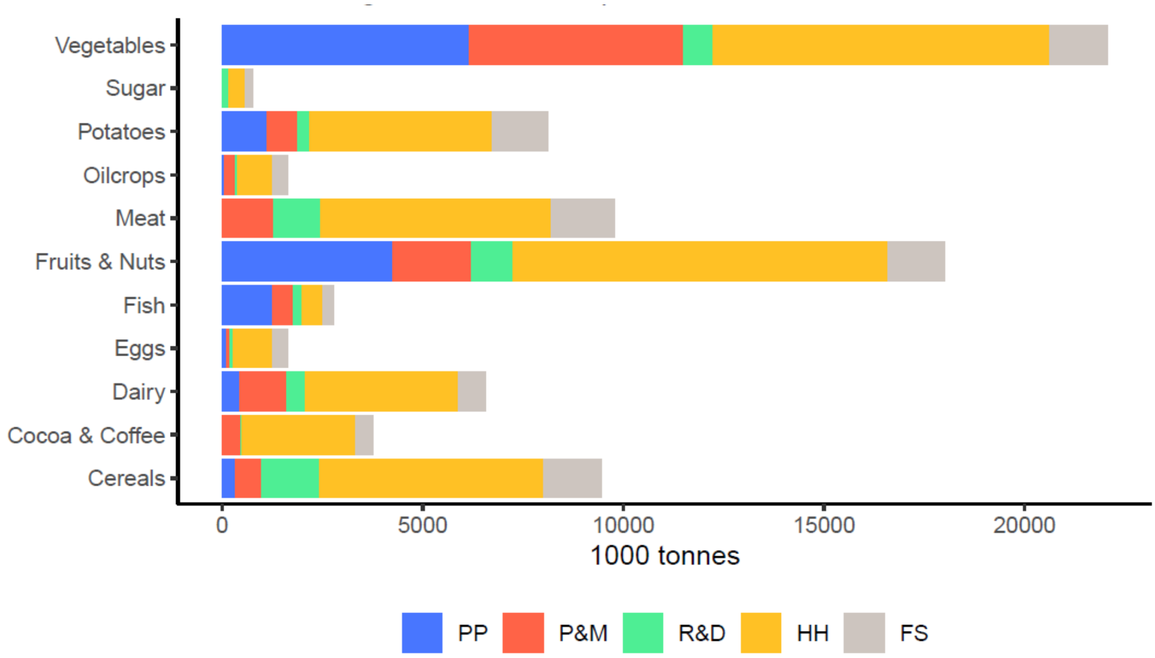
— Comparison between consumed amounts from the MFA model version 3.0 and EFSA food consumption surveys, per food category (Table A3.5).

Annex 4 reports an example of tables and charts provided by the model for each Member State and EU for the year 2021.

Figure 13 illustrates food waste generation (including both solid and liquid components) across food categories and across the different stages of the supply chain estimated for the EU in 2021, while **Figure 14** presents the timeline of the estimated food waste generated in the EU between 2003 and 2021. In line with the previous versions of the model, the consumption stage is the stage of the whole supply chain where most of the food waste is generated.

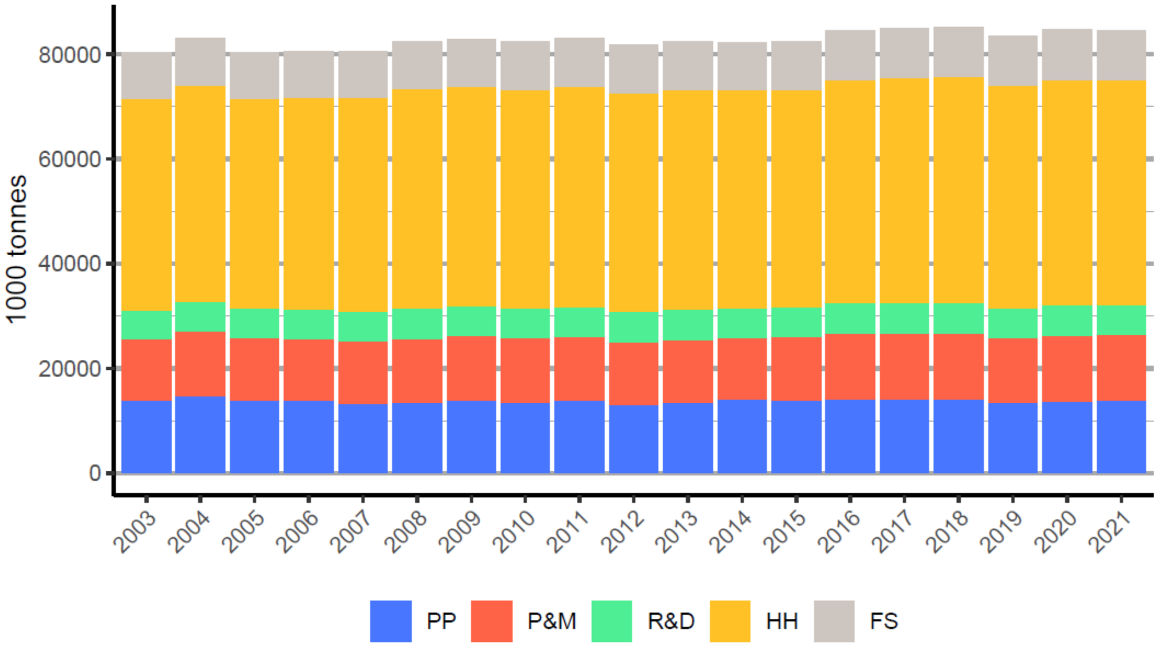
Figure 15 and **Figure 16** offer an overview of the results obtained at MSs level. They show the relative contribution of food supply chain stages and of food groups to the total food waste generated in each MSs, respectively. **Figure 15** shows that household consumption is by far the most important source of food waste across the EU, ranging from 36% in Greece to 66% in Luxembourg. **Figure 16** shows that the contribution of different food groups to the food waste generated varies across countries, with some recurrent patterns. Vegetables and fruit and nuts are frequently amongst the most relevant food groups (e.g. vegetables contribute to 45% of food waste generation in Croatia, while fruit and nuts to 32% of food waste generation in Italy), whereas food from animal origin can also play a dominant role in food waste generation for some MSs, for instance dairy (22%) is responsible for the majority of food waste generated in Ireland and meat contributes to 18% of the total food waste generation estimated for Cyprus. Luxembourg shows a peculiar result with cocoa and coffee (25%) being the most significant contributor to the total food waste estimated.

Figure 13. Food waste generation estimated for the EU27 2021. Solid and liquid components included.



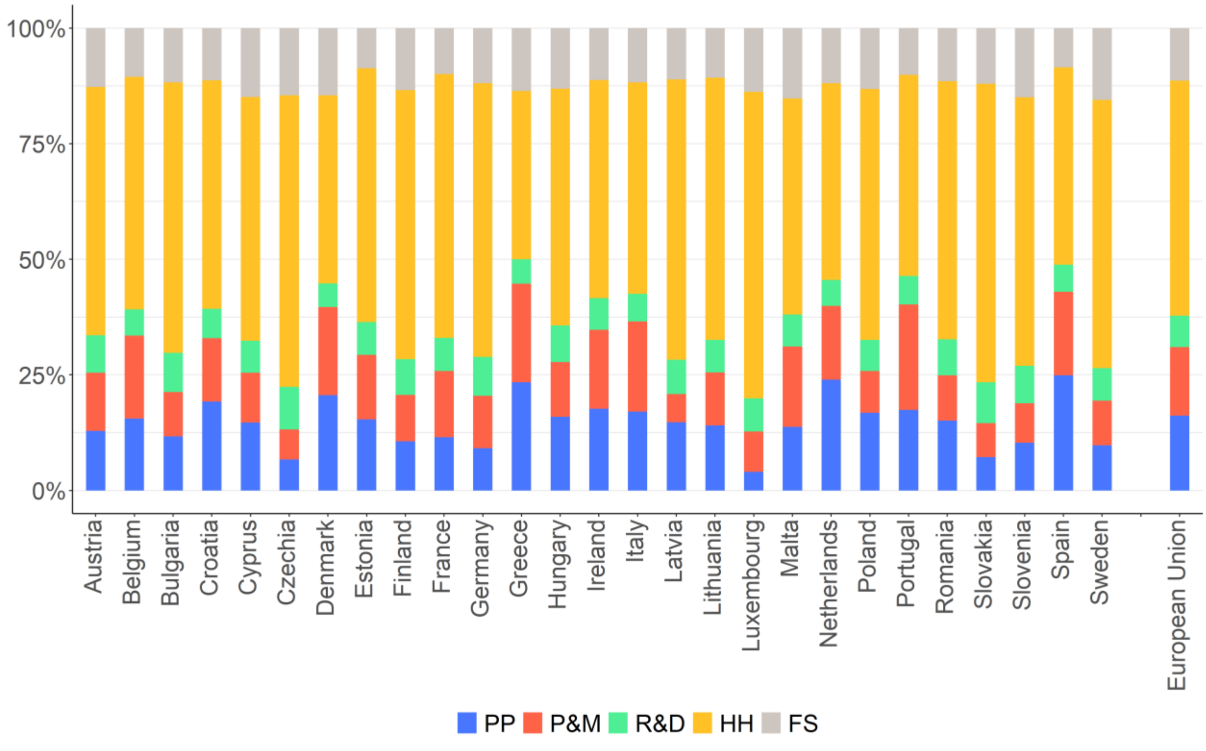
Source: Authors' own elaboration

Figure 14. Food waste timeline, EU27, 2003 – 2021. Solid and liquid components included.



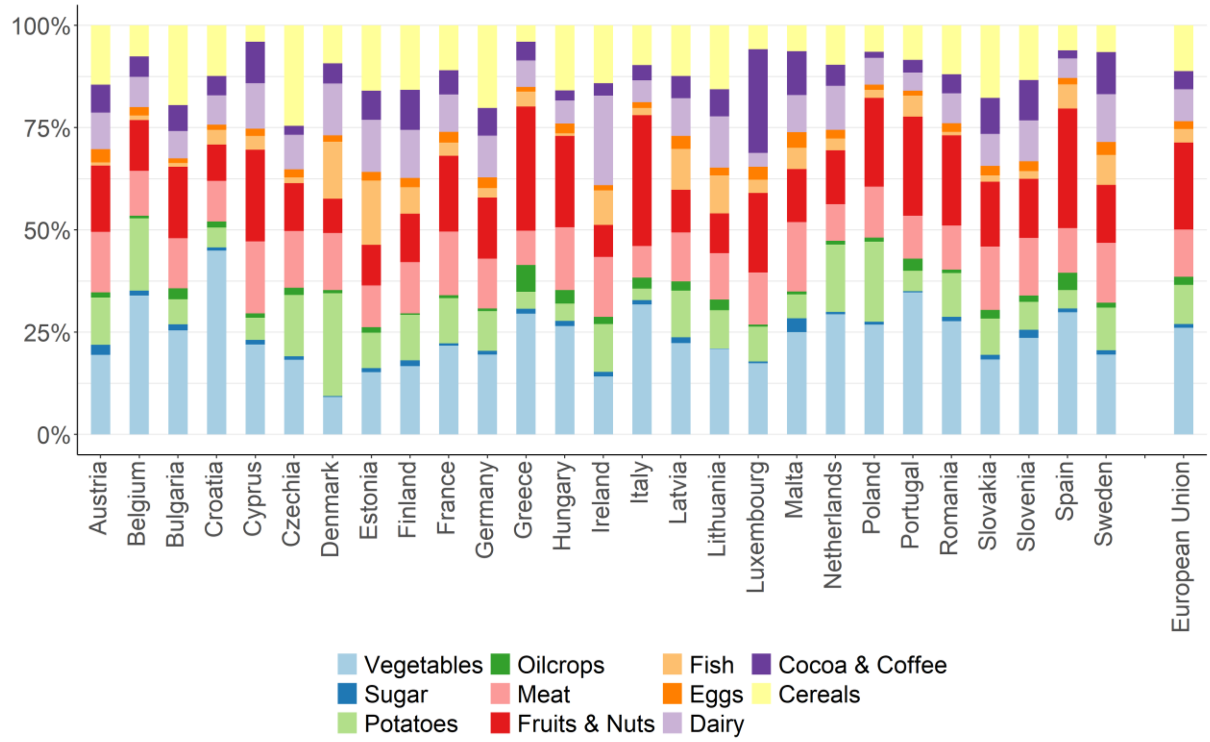
Source: Authors' own elaboration

Figure 15. Relative contribution of food supply chain stages to the total food waste generated (solid and liquid components) in EU MSs in 2021



Source: Authors' own elaboration

Figure 16. Relative contribution of food groups to the total food waste generated (solid and liquid components) in EU MSs in 2021.



Source: Authors' own elaboration

The MFA model estimates a generation of 73 million tonnes (fresh mass) of solid food waste in the EU in 2021 across the food supply chain (**Table 5**). This figure is roughly 25% higher than the total amount estimated by Eurostat based on the quantities reported by MSs in the same year[22].

The total amounts of solid and liquid food waste (the latter is provided separately in brackets) estimated for year 2021, per stage of the supply chain in each MS and at EU level are shown in **Table 5**. **Table 6** reports the per capita amounts of solid food waste generated at the last three stages of the FSC (retail and distribution, household consumption, food services consumption) and provides for each stage the edible share of food waste generated. It should be highlighted that, as most of the food waste coefficients used are the same for all MSs, the variations shown in **Table 6** across MSs are mostly related to the quantities and typologies of food entering the retail and distribution phase as estimated by the model.

[22] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Food_waste_and_food_waste_prevention_-_estimates

Table 5. Solid food waste generated in 2021 at EU and MS level by stage of the food supply chain (kt). Liquid food waste amounts provided in brackets.

Country	Primary production	Processing and manufacturing	Retail and Distribution	Households	Food services	Total
Austria	153 (11)	160 (0)	94 (10)	551 (132)	125 (37)	1083 (189)
Belgium	435 (11)	515 (0)	146 (16)	1249 (202)	265 (38)	2611 (268)
Bulgaria	108 (2)	91 (0)	71 (9)	426 (131)	91 (19)	787 (162)
Croatia	159 (2)	115 (0)	45 (8)	337 (78)	63 (32)	719 (120)
Cyprus	21 (1)	16 (0)	9 (1)	60 (18)	18 (4)	124 (23)
Czechia	90 (10)	95 (0)	120 (17)	790 (146)	170 (45)	1266 (218)
Denmark	292 (14)	283 (0)	69 (8)	487 (117)	195 (21)	1325 (159)
Estonia	32 (3)	31 (0)	14 (2)	91 (33)	16 (4)	184 (41)
Finland	79 (7)	81 (0)	54 (10)	330 (142)	94 (15)	638 (174)
France	1079 (75)	1441 (0)	640 (81)	4787 (959)	809 (188)	8756 (1303)
Germany	1077 (87)	1439 (0)	957 (120)	6071 (1464)	1227 (289)	10771 (1960)
Greece	528 (6)	435 (51)	105 (16)	650 (181)	221 (89)	1939 (343)
Hungary	242 (6)	185 (0)	109 (14)	646 (153)	168 (37)	1349 (210)
Ireland	166 (27)	187 (0)	65 (9)	423 (95)	97 (26)	938 (158)
Italy	2203 (41)	2520 (41)	660 (126)	4305 (1731)	1151 (395)	10840 (2335)
Latvia	44 (3)	19 (0)	21 (3)	157 (36)	30 (5)	271 (46)
Lithuania	72 (3)	62 (0)	31 (7)	223 (83)	44 (13)	432 (107)
Luxembourg	2 (1)	8 (0)	6 (1)	39 (20)	9 (3)	64 (25)
Malta	7 (0)	9 (0)	3 (0)	19 (7)	7 (2)	45 (9)
Netherlands	1047 (27)	713 (0)	233 (20)	1654 (259)	487 (47)	4133 (351)
Poland	1305 (41)	725 (0)	500 (38)	3893 (470)	993 (61)	7414 (610)
Portugal	426 (6)	541 (27)	134 (20)	902 (179)	180 (72)	2183 (304)
Romania	482 (12)	320 (0)	232 (25)	1525 (307)	333 (42)	2892 (386)
Slovakia	40 (3)	44 (0)	48 (5)	296 (87)	62 (9)	490 (103)

Country	Primary production	Processing and manufacturing	Retail and Distribution	Households	Food services	Total
Slovenia	25 (2)	22 (0)	19 (2)	114 (35)	31 (7)	211 (46)
Spain	3036 (24)	2070 (148)	636 (89)	4425 (827)	728 (321)	10895 (1409)
Sweden	115 (7)	122 (0)	77 (12)	534 (200)	170 (25)	1017 (244)
EU27	**13267 (430)**	**12248 (268)**	**5097 (669)**	**34983 (8090)**	**7784 (1847)**	**73380 (11305)**

Source: Authors' own elaboration

Table 6. Per capita solid food waste generation (kg per capita) and edible shares estimated for year 2021 at EU and MS level at retail and distribution and consumption stages

	Retail & Distribution		**Households**		**Food services**	
Country	**Solid food waste**	**Edible share**	**Solid food waste**	**Edible share**	**Solid food waste**	**Edible share**
Austria	10.5	92.2%	61.7	59.0%	14.0	57.1%
Belgium	12.7	90.3%	108.1	58.9%	22.9	63.3%
Bulgaria	10.3	90.8%	61.5	55.7%	13.2	54.5%
Croatia	11.2	90.0%	83.5	50.2%	15.7	57.2%
Cyprus	10.3	85.9%	66.9	49.6%	20.4	49.9%
Czechia	11.4	90.5%	75.3	55.4%	16.2	55.7%
Denmark	11.8	90.2%	83.4	60.6%	33.4	65.9%
Estonia	10.2	91.3%	68.4	57.3%	12.0	52.4%
Finland	9.7	90.1%	59.7	57.0%	16.9	56.3%
France	9.5	89.2%	70.7	55.9%	12.0	58.1%
Germany	11.5	91.8%	73.0	61.7%	14.8	61.9%
Greece	9.8	82.7%	60.9	49.8%	20.7	56.3%
Hungary	11.2	90.4%	66.3	58.0%	17.3	51.5%
Ireland	13.1	92.2%	84.4	66.2%	19.3	58.7%
Italy	11.1	88.1%	72.7	57.8%	19.4	66.9%
Latvia	11.1	89.3%	83.0	50.1%	15.7	50.1%

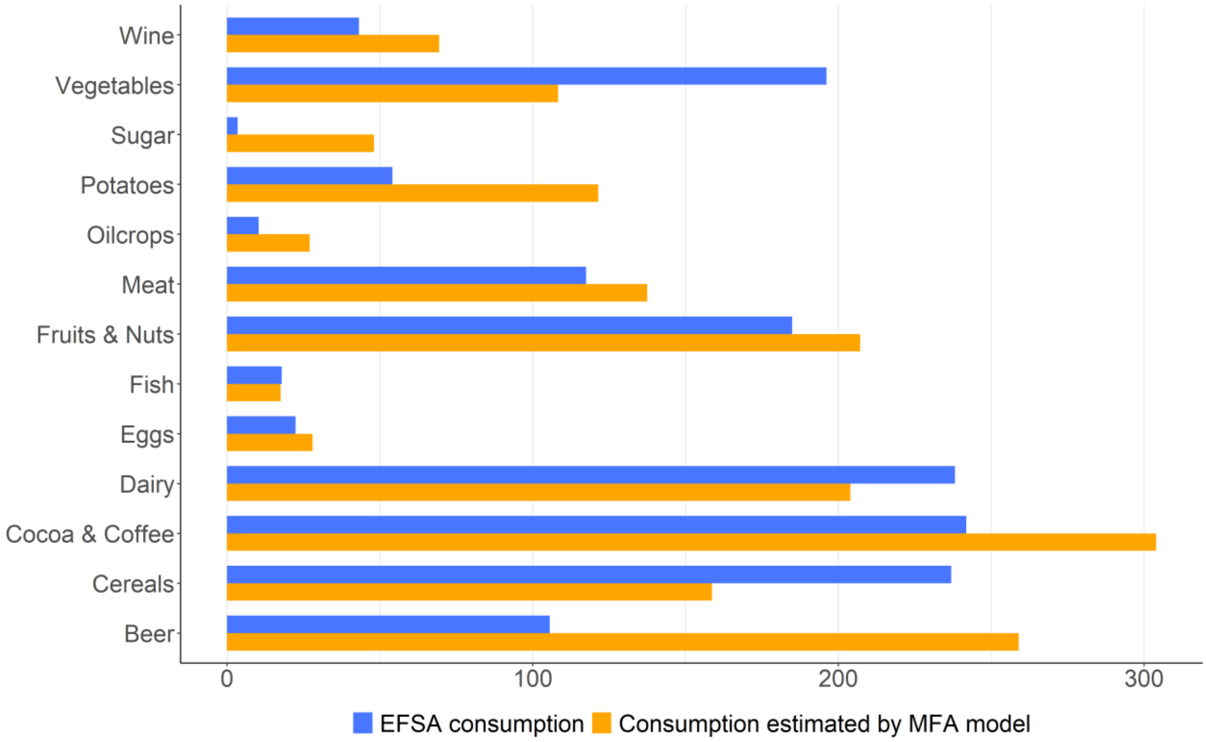
	Retail & Distribution		Households		Food services	
Country	**Solid food waste**	**Edible share**	**Solid food waste**	**Edible share**	**Solid food waste**	**Edible share**
Lithuania	11.1	89.6%	79.8	54.4%	15.8	52.9%
Luxembourg	9.1	82.2%	61.5	49.8%	14.2	49.4%
Malta	6.3	88.3%	36.0	53.9%	12.6	51.5%
Netherlands	13.3	90.3%	94.6	58.1%	27.8	60.0%
Poland	13.2	87.1%	102.9	48.0%	26.2	52.8%
Portugal	13.0	86.1%	87.6	51.8%	17.5	56.5%
Romania	12.1	89.5%	79.4	54.2%	17.3	51.5%
Slovakia	8.8	90.5%	54.2	55.0%	11.4	56.3%
Slovenia	8.8	89.8%	54.1	56.5%	14.9	56.8%
Spain	13.4	83.3%	93.4	51.1%	15.4	58.0%
Sweden	7.4	86.2%	51.4	49.9%	16.4	50.5%
EU27	**11.4**	**88.6%**	**78.2**	**55.6%**	**17.4**	**58.8%**

Source: Authors' own elaboration

2.6.1 Comparison with food consumption data

A plausibility check is performed by comparing the consumed food amounts as estimated by the model with amounts reported in the EFSA food consumption database obtained through surveys (EFSA, 2015) for 21 MSs in different years. In order to perform this comparison, the EFSA hierarchical level 3 has been selected. As for a similar comparison made in the previous MFA model updates, this comparison is affected by some limitations of food consumption surveys, such as: these surveys are notably underestimating the amounts of food consumed (due to social desirability bias people tend to under report their food intake), data are available only for few countries and few years and are not directly comparable between each other (in some cases weight is referred to cooked food, in others to raw food). With all these limitations in mind, it is interesting to see that, with some exceptions that can be explained considering the above mentioned limitations of data collected through food consumption surveys and the limitations of the estimations performed by the MFA model, results are quite aligned. In particular, results for sugar consumption are much more aligned compared to the analysis performed in De Laurentiis et al. (2023). This is mainly due to the refinement of the sugar model (see Section 2.3). A table presenting this comparison for all the countries for which a food consumption survey was available is provided in Annex 3, Table A3.5 and as an example **Figure 17** shows this comparison for Austria in 2014.

Figure 17. Comparison between food consumption amounts (grams per capita per day) estimated by the MFA model and reported by EFSA for Austria in 2014.



Source: Authors' own elaboration

3 Modelling of food packaging: methodology and results

The following sections (3.1, 3.2, 3.3) illustrate the methodology developed to estimate the quantities of packaging materials linked to the consumption of food and beverages, by combining information on packaging sales data with information on the unitary masses of the different packaging typologies considered. Section 3.4 provides an approach to estimate packaging materials that can be used in the absence of a packaging sales database, as it relies on the use of sales data of food and beverage products. Section 3.5 presents the resulting packaging estimates obtained.

3.1 Extraction of packaging sales data

The starting point to estimate the use of packaging materials linked to food consumption is Euromonitor International’s Packaging industry research, a database providing annual information on consumer goods sold by packaging material including food and beverage products. The data provides a deep understanding of packaging demand offering several data sets including the volumes of units sold for each “Product Variant”. A Product Variant (PV) is identified based on attributes like size, closure or material. An example of PV in full is: “milk, HDPE bottle, 1000 ml”. In this report we identify three components of a PV:

1) the food or beverage product contained (e.g. milk),
2) the packaging type defined according to the material and the shape (e.g. HDPE bottle),
3) the packaging size expressed in g or L (e.g. 1000 ml).

A list of definitions (complemented with photographs of examples of packaging types) is provided by Euromonitor to inform the user on the different shapes and typologies of packaging recorded under each type (an example is shown in **Figure 18**). Yearly data are available for 19 EU Member States (Austria, Belgium, Bulgaria, Czechia, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Romania, Slovakia, Spain, and Sweden) which all together cover 96% of EU27 population and the time ranges from reference year 2008 and to reference year 2022[23].

Figure 18. Examples of containers classified as “HDPE bottles”.

Source: Euromonitor documentation (2013), Pack type definition.

Sales data are available at “retail/off-trade” level (i.e., household consumption) for all products. In addition, for alcoholic beverages and soft drinks data are also available at “foodservice/on-trade” level (i.e., foodservice consumption). Both levels are considered when available.

As the Packaging industry research database contains an extensive list of PV (e.g. 7408 distinct PV are recorded for Austria in 2020) the analysis was performed only for the most relevant products and packaging types. The following strategy was followed to perform this selection.

In the database, packaging sales data are provided for 44 different food and beverage products grouped into 12 categories. For instance, the category “Alcoholic beverages” includes three products:

[23] Certain combinations of PV and countries present data gaps for earlier years. Nevertheless missing data correspond to less than 5% of all possible combinations (of PV, country and year).

“Beer”, “Spirits” and “Wine”. Euromonitor International does not research the Fresh Food packaging industry and so does not provide packaging data for the following food categories: fresh eggs, fresh fish and seafood, fresh fruit and vegetables, nuts and dry pulses, fresh/unprocessed meat, and sugar. For each product, the total volume of products sold was derived by multiplying the number of units sold for each PV by the unitary volume of each PV. Then, the contribution of each product to its category in terms of volume sales was derived for each Member State for year 2022 (as this was the most recent year available). When the average contribution across all countries of a food and beverage product to its category was at least 10%, this product was included in the analysis. This led to the selection of 27 food and beverage products. In a future refinement the list of products could be expanded to include also the remaining products.

Table 7 below summarises the results of the products selection, reporting for each food and beverage product the average share of sales volume in its category across the 19 MSs considered, and the number of MSs in which this value was higher than 10%.

Table 7. Selection of products, showing for each food and beverage product the average share of sales volume in its category across the 19 MSs, and the number of MSs in which this value was higher than 10%.

Food category	**Food and beverage product**	**Contribution to the food category**	**Countries with a contribution >10%**	**Product included in the analysis**
Alcoholic beverages	Beer	71%	19	X
	Spirits	5%	0	
	Wine	24%	17	X
Baby food	Baby food	100%	19	X
Baked	Baked goods	83%	19	X
	Breakfast cereals	17%	14	X
Condiments	Condiments	8%	6	
	Dips	20%	16	X
	Sauces	72%	19	X
Confectionery	Chocolate	69%	19	X
	Gum	3%	0	
	Sugar confectionery	28%	19	X
Dairy	Butter	4%	0	
	Cheese	6%	2	
	Ice cream	7%	2	
	Milk	64%	19	X
	Other dairy	7%	3	

	Plant-based dairy	2%	0	
	Yoghurt	11%	5	X
Edible oils	Edible oils	100%	19	X
Meals	Pizza	29%	19	X
	Prepared salads	8%	5	
	Ready kits	5%	2	
	Ready meals	43%	19	X
	Soup	16%	15	X
Pasta, rice and noodles	Noodles	4%	2	
	Pasta	52%	19	X
	Rice	44%	18	X
Processed products	Meat alternatives	2%	0	
	Processed beans	3%	0	
	Processed fruit	5%	1	
	Processed meat	40%	19	X
	Processed potatoes	11%	9	X
	Processed seafood	13%	12	X
	Processed vegetables	26%	19	X
Snacks	Savoury snacks	39%	19	X
	Sweet snacks	48%	19	X
	Sweet spreads	13%	15	X
Soft drinks	Bottled water	48%	19	X
	Carbonates	31%	19	X
	Coffee and tea	4%	0	
	Concentrates	1%	0	
	Energy drinks	4%	0	
	Juice	12%	12	X

Source: Authors' own elaboration based on data from Euromonitor (2023)

At a second step, for each food and beverage product selected, total sales were extracted for each combination of food/beverage product and packaging type. Packaging types were excluded from the analysis if the average across the 19 MSs of their contribution to sales volumes of the food and beverage product to which they belonged was below 1%. An exception was made for plastic-based packaging types that were always included in the analysis, because of their high policy relevance. When a packaging type was included, all the PV belonging to it (i.e. all the packaging sizes) were also included. This led to the inclusion of 5330 PV, belonging to the 27 food products selected and 35 different types of packaging with varying sizes.

3.2 Collection of packaging unitary mass values

Euromonitor International's Packaging research does not capture information on the average mass of each PV (e.g. the mass in grams of 1 PET bottle containing 1000 ml of drinking milk, once empty), an online search was performed to collect unitary mass (UM) coefficients for the PV included in the database. One of the main sources of data were websites of packaging suppliers. However, due to time constraints, it was not possible to perform this search for each of the 5330 PV included in the analysis. Therefore, the search was performed with the aim of collecting data for at least one PV for each packaging type. Being food and beverage containers highly variable among countries and retailers, more UM values were collected for the same PV when available, and three values were recorded: the median, minimum and maximum UM value, respectively UM_{med}, UM_{min}, and UM_{max} (when only one value was found the three elements coincide).

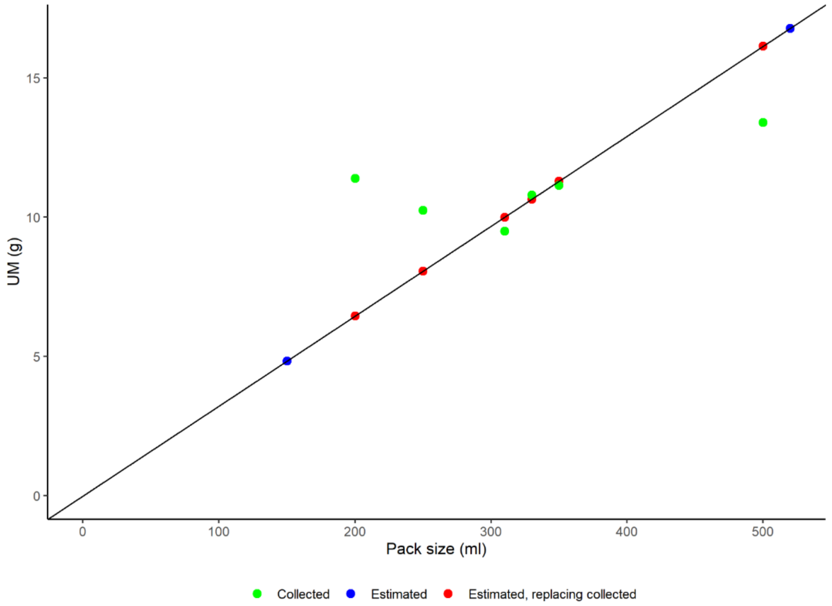
This led to the collection of UM_{med}, UM_{min}, and UM_{max} values for 511 PV. In the remaining cases the unitary mass coefficients were estimated by following three alternative approaches (from the most preferable to the least preferable).

<u>Approach 1:</u>

When one or more UM_{med} values were available for a PV associated with the same food product and packaging type but different packaging size, a linear regression of the UM_{med} values available plotted against their size was performed. The linear regression was performed for all packaging materials, with the exception of glass. In presence of glass packaging, a logarithmic regression was preferred as it was deemed that the linear regression led to overestimate the UM values for large pack sizes. In doing so, the axes origin was included as one of the points for the regression (i.e., UM = 0 when size = 0) for both linear and logarithmic regressions. This was done to avoid situations in which extrapolating the UM value for a small packaging size this would result in a negative value. The UM_{med} values of the missing PV were then extrapolated based on their size. Collected UM values were replaced with regression predicted values, in order to ensure that for the same packaging type and food product a larger size always resulted in a larger UM value. This was not always the case in the original data collected due to the large variety of data sources used. The same operation was repeated with UM_{min}, and UM_{max} values. In total, 2556 PV were assigned a UM_{med}, UM_{min} and UM_{max} value with this approach.

To provide an example (**Figure 19**), there are 8 PV associated to the food product "Juice" and packaging type "Metal beverage cans". Of these, primary data on UM values was found for 6 packaging sizes: 200 ml, 250 ml, 310 ml, 330 ml, 350 ml, and 500 ml (green dots). A linear regression through the origin of axes of the 6 data points (considering the median value for each PV – UM_{med}) was performed and the 2 missing UM_{med} values were extrapolated based on their packaging size (i.e., 150 ml and 520 ml) (blue dots). The 6 UM_{med} values collected (in green in **Figure 19**) were also replaced by the values predicted (in red in **Figure 19**) by the linear regression to avoid situations such as the ones visible in the figure, where the collected value for size 200 ml the UM value is higher than the collected one for sizes 250 ml and 310 ml. The same operation was repeated with the collected UM_{min} and UM_{max} values. In this way, each UM_{med} value is associated an uncertainty rage, shown by the shaded area in **Figure 20**.

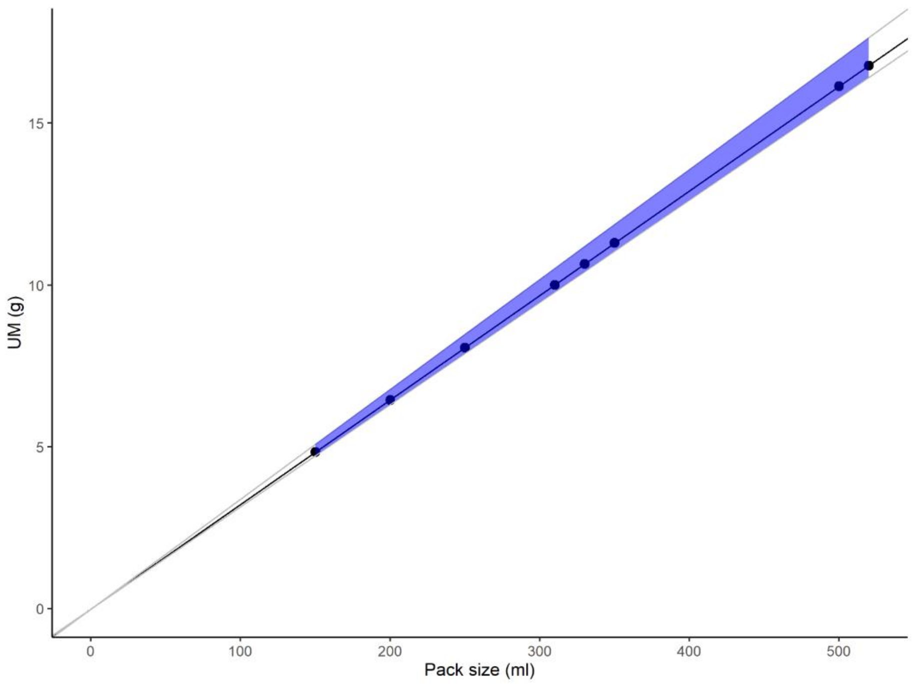
Figure 19. Visual representation of collected (green dots) and estimated (red and blue dots) UM median values for PV associated to different sizes of juice metal beverage cans



Source: Authors' own elaboration

Note: the black line represents the linear regression used to perform the estimation.

Figure 20. Estimation of uncertainty ranges in UM values (UM_{min}-UM_{max}) for the PV reported in Figure 19



Source: Authors' own elaboration

Note: the lines represent the regression models for the median values (black line), and the minimum and maximum values (grey lines), the shaded blue area represents the uncertainty range between estimated minimum and maximum values.

Approach 2:

When no UM_{med} values were available for a PV associated with the same food product and packaging type, the UM_{med} values were estimated by using 5 alternative sub-methods, based on data availability, from 1 (most preferable) to 5 (least preferable).

Sub-method 1: median value of the UM_{med} values collected for all PV associated with the same food product, packaging material, and packaging size.

Sub-method 2: median value of the UM_{med} values collected for all PV associated with the same food category, packaging type, and packaging size.

Sub-method 3: median value of the UM_{med} values collected for all PV associated with the same food category, packaging material, and packaging size.

Sub-method 4: median value of the UM_{med} values collected for all PV associated with the same packaging type and packaging size.

Sub-method 5: median value of the UM_{med} values collected for all PV associated with the same packaging material and packaging size.

The same operation was repeated with UM_{min}, and UM_{max} values. In this way 380 PV were associated a UM_{med}, UM_{min}, and UM_{max} value.

Approach 3:

For the remaining PV that were not assigned UM values with approach 1 or approach 2, approach 1 was repeated with the PV added after performing approach 2. Therefore, the only difference between approach 3 and approach 1 is that, in the former, the input data are not collected values but values that were estimated with approach 2. In total 1773 PV were assigned UM_{med}, UM_{min}, and UM_{max} value with this approach.

A remaining list of 110 PV from the initial 5330 selected for the analysis was not assigned UM values, as none of the approaches presented above allowed to estimate their UM values. These PV were therefore left out of this analysis. Packaging types within this group are either extremely generic, such as “Other packaging types”, or used in very low amounts, such as “30 L other rigid container for beer” used only for 0.03% of beer sale volumes.

3.3 Estimation of packaging materials linked to food consumption

The total mass of materials associated to each combination of packaging type and food and beverage product is calculated per country and per year as follows:

$$M_{x,y} = \sum_i N_{PVi} \times UM_{PVi} \times 0.001 \qquad [10]$$

Where:

- $M_{x,y}$ is the mass associated with packaging type x and food and beverage product y expressed in kg
- N_{PVi} is the number of units of the i-th PV sold belonging to packaging type x and food and beverage product y
- UM_{PVi} is the unitary mass of the i-th PV belonging to packaging type x and food and beverage product y expressed in g
- 0.001 is the conversion factor to transform the mass from g to kg.

The calculation is performed with the UM_{med} values and then repeated with the UM_{min} and UM_{max} values to provide uncertainty intervals.

The resulting quantities are provided in Annex 6 (for 19 MSs and years between 2008 and 2022) at different levels of aggregation: total mass of each packaging material associated with each food and beverage product distinguishing by packaging type, total mass of each packaging material associated with each food and beverage product (aggregating across packaging types), total mass of each packaging material distinguishing by packaging type (aggregating across food and beverage products), total mass of each packaging material (aggregating across both packaging types and food and beverage products).

3.4 Calculating coefficients to estimate packaging quantities linked to food and beverages sales

The results of the estimation presented in Section 3.3 were combined with information on total sales of each food and beverage product in the countries/years considered, so to obtain a set of coefficients (one for each packaging type) that can be used in the absence of a packaging sales database to estimate packaging material use from sales data of food and beverage products. The coefficients are valid under the hypothesis that the unitary mass coefficients collected for each PV are a good proxy for the average unitary mass of that PV in all countries.

The coefficients estimated with this approach are referred to as Consumption-Weight Conversion Factors (CWCFs). CWCFs are calculated at two levels of aggregation. At the more disaggregated level, they are specific per packaging type, country and product, and are calculated as the ratio between the total mass of packaging associated to a product, calculated for each packaging type (obtained in Section 3.3) – as expressed by the numerator in equation 11 - and the total volume or mass sold of the same product - as expressed by the denominator in equation 11.

$$CWCF_{x,y} = \frac{\sum_i N_{PVi} \times UM_{PVi} \times 0.001}{\sum_i N_{PVi} \times V_{PVi}} \qquad [11]$$

Where:

- $CWCF_{x,y}$ is the coefficient associated to packaging type x and food product y (e.g. PET bottles, milk)
- N_{PVi} is the number of units of the i-th PV sold belonging to packaging type x and food product y
- UM_{PVi} is the unitary mass of the i-th PV belonging to packaging type x and food product y
- V_{PVi} is the volume or mass of product y contained in the i-th PV belonging to packaging type x (i.e., the packaging size)
- 0.001 is the conversion factor to transform the mass from g to kg.

At the more aggregated level CWCFs are specific for packaging material, country and product and are calculated following equation 12.

$$CWCF_{z,y} = \frac{\sum_i N_{PVi} \times UM_{PVi} \times 0.001}{\sum_i N_{PVi} \times V_{PVi}} \qquad [12]$$

Where:

- $CWCF_{z,y}$ is the coefficient associated to packaging material z and food product y (e.g. PET, milk)
- N_{PVi} is the number of the i-th PV sold belonging to packaging material z and food product y
- UM_{PVi} is the unitary mass of the i-th PV belonging to packaging material z and food product y
- V_{PVi} is the volume or mass of product y contained in the i-th PV belonging to packaging material z (i.e., the packaging size)
- 0.001 is the conversion factor to transform the mass from g to kg.

The coefficients are calculated for all years between 2008 and 2022. Users of these coefficients can choose whether to use the ones calculated for the most recent year, or whether to calculate an average of the last 2 or more years (to reduce the effect of yearly fluctuations). Depending on the product considered, CWCFs are expressed in kg-packaging/kg-product or kg-packaging/L-product. For example, the CWCFs obtained for glass bottles used for drinking milk sold in Italy in 2022 will express the average mass of glass associated to the sale of 1 L of drinking milk in Italy during that year.

These coefficients should be used in combination with sales data of each food and beverage product to estimate the related quantity of each packaging type consumed. Nevertheless, in case of lack of sales data, the coefficients can be used in combination with estimates of food consumption data obtained from modelling (e.g. if the total amount of drinking milk sold in country x in year y is not known, an estimation of the total amount of drinking milk consumed – obtained via an alternative modelling approach - can be used instead). It should be stressed that in this case the uncertainty of the estimation would be higher than if sales data were used.

The resulting CWCF coefficients are provided in Annex 7 at the two levels of aggregation mentioned.

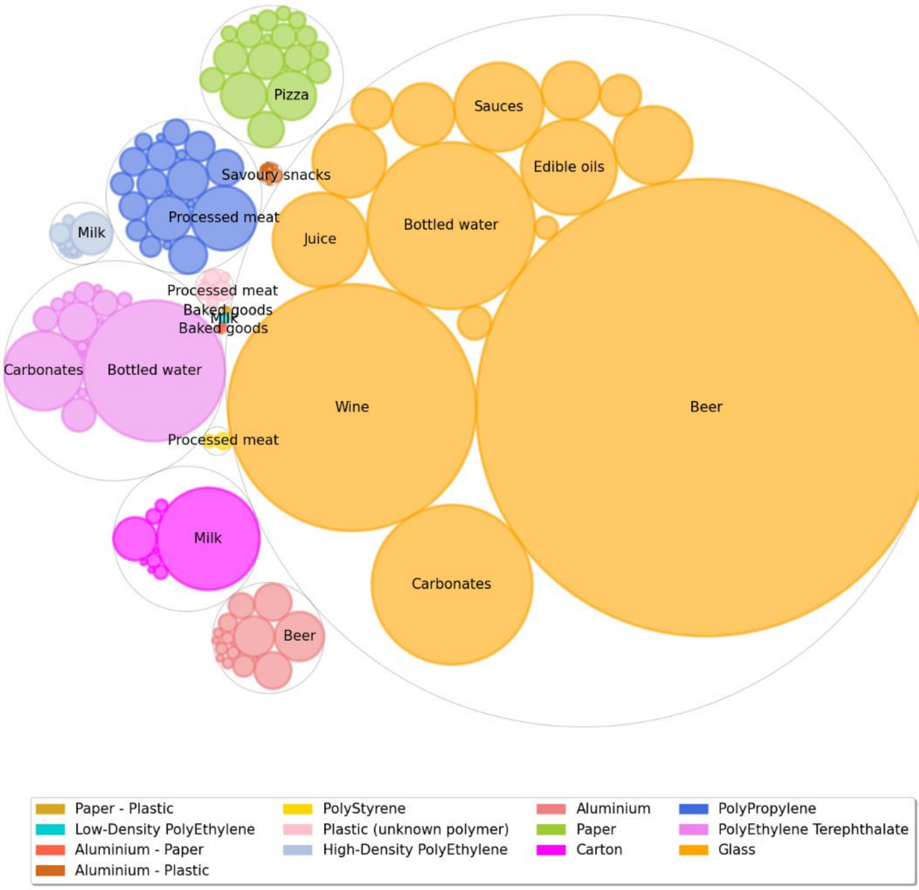
3.5 Estimated packaging amounts

This section illustrates the results obtained for the estimation of packaging amounts associated with food consumption. Packaging amounts have been estimated for 19 MSs (covering 96% of EU population) in the time range 2008-2022. Results are available at different level of detail, as presented in Section 3.1: food category (e.g., dairy), food product (e.g. yoghurt), packaging type (e.g., glass jar), and packaging material (e.g. glass). Packaging amounts estimations are available in Annex 6 (see Table 6.1 for the full data and Table 6.2 for an extract for year 2022 aggregated at the level of packaging materials). For each data point, median, minimum and maximum values are provided.

Figure 21 graphically identifies the food products which are responsible for the largest amounts of packaging (in weight), per packaging material. The bigger the size of the bubble the larger the amount. The colour legend indicates the packaging material. It shows that glass, due to its high density, accounts for the largest amount of packaging weight in the food and beverage sector, followed by PET. Liquid foods account for most of the packaging total weight. Alcoholic beverages (mainly beer and wine) are responsible for the largest amount of glass packaging, soft drinks (mostly bottled water and carbonates) for PET packaging, while milk for the carton[24] and the HDPE packaging. Beer is also responsible for the largest amount of aluminium packaging, followed by canned seafood. **Table 8** reports the amounts of packaging estimated for the total of the considered 19 MSs in 2022 distinguishing between food categories and packaging materials. In this way it is possible to further explore food categories and packaging materials that are not clearly visible in **Figure 21**. It confirms that glass packaging is by far the most relevant packaging material in terms of mass.

[24] Including also liquid cartons (mainly tetrapack®)

Figure 21. Amounts of estimated packaging in 19 MSs in 2022, by packaging material and food product



Source: Authors' own elaboration

Table 8. Tonnes of estimated packaging quantities in 19 MSs in 2022, per food category and packaging material. The largest contributor for each row is highlighted.

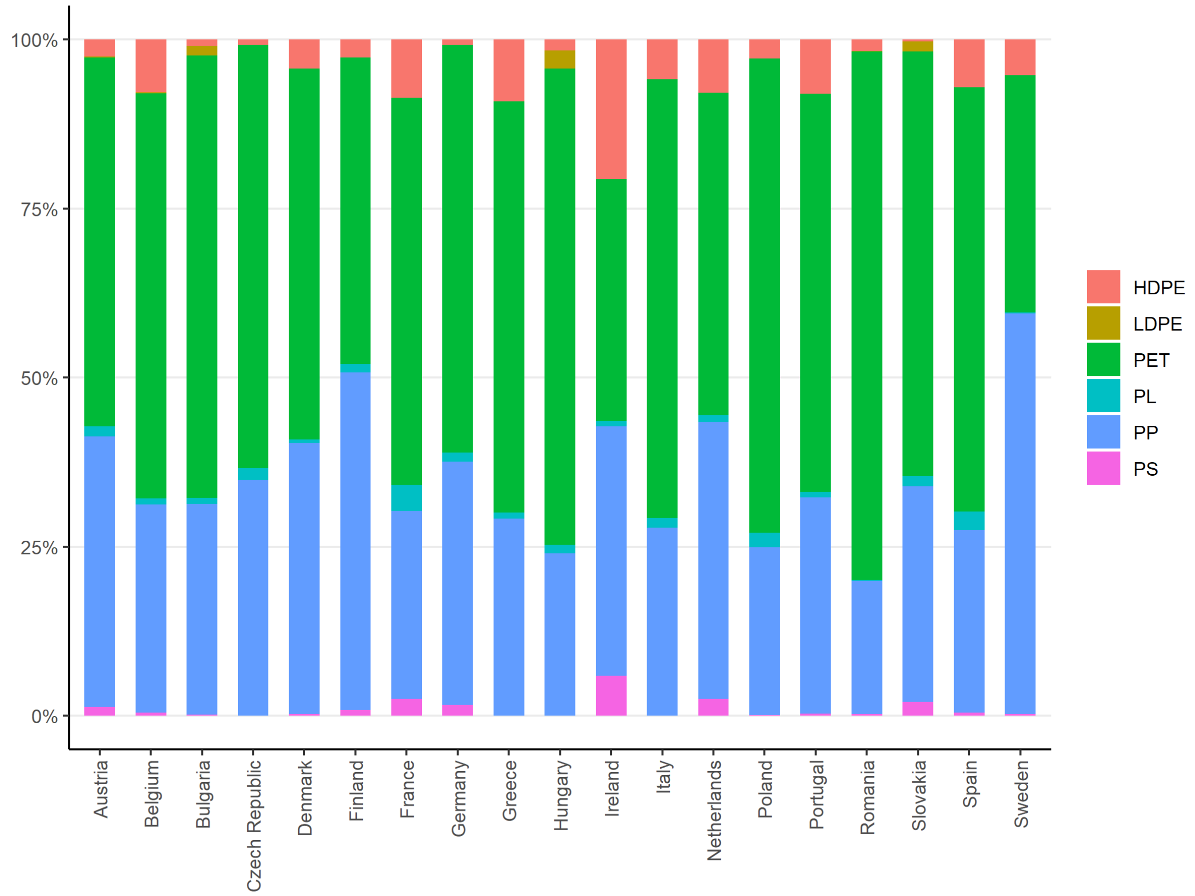
Material	Alcoholic beverages	Baby food	Baked	Condiments	Confectionery	Dairy	Edible oils	Meals	Pasta, rice and noodles	Processed products	Snacks	Soft drinks	Total
AL	197590	4389		30801	9834		12339	49423		296457	2111	130696	733639
AL_PA			2258	1110	2416			860					6645
AL_PL	556	2390	585	1830	499	714		3300		1147	12814	9049	32884
CA	18578	3363		17146		1016893	1742	13732		3962		177694	1253109
GL	21838572	135473		1071339		271708	733032	41734		535704	490988	5032577	30151125
HDPE		2795	3876	16090	1411	192240	590	848	2415	529	2788	5620	229201
LDPE						5068							5068
PA	54768	25034	178156	17607	36340	2144		410917	150137	145415	178689		1199209
PA_PL		132	1774		1343						285		3534
PET	57014	1300	17179	15483	10280	153365	37817	15212		487	67039	2502214	2877388
PL				21799	26611			464		38975	1351		89200
PP		4403	96093	9719	132617	169706		84143	201126	500000	226395		1424201
PS										48294			48294

Source: Authors' own elaboration

Note: AL: Aluminium, AL_PA: Aluminium-Paper, AL_PL: Aluminium-Plastic, CA: Carton, GL: Glass, HDPE: High-Density PolyEthylene, LDPE: Low-Density PolyEthylene, PA: Paper, PA_PL: Paper-Plastic, PET: PolyEthylene Terephtalate, PL: Plastic (unknow polymer), PP: PolyPropylene, PS: PolyStyrene

Regarding plastics, estimations are available at polymer level. The total amount of plastic packaging is 4.67 million tonnes, resulting from the sum of amounts of all plastic polymers (excluding mixed packaging materials including plastic such as “aluminium-plastic” and “paper-plastic” and “cartons”). **Table 9** and **Figure 22** show the share of each plastic polymer to the total amount of plastic contained in packaging for food and beverage products placed on the market in each MS in 2022. In addition, **Table 9** provides also total quantities. PET is often the largest contributor (ranging from 35% in Sweden to 78% in Romania), followed by PP (from 20% in Romania to 59% in Sweden). Finland, Ireland, and Sweden are the only MSs where the amount of estimated PP is higher than PET. PET is used mainly for “Soft drinks”, whereas PP for a broader variety of food and beverage products. The remaining polymers types are less relevant across MSs. It is worth noticing the high contribution of HDPE in Ireland (21%), which is used only for dairy products (“Milk” and “Yoghurt”).

Figure 22. Share of plastic polymers per MSs in 2022



Source: Authors’ own elaboration

Note: HDPE: High-Density PolyEthylene, LDPE: Low-Density PolyEthylene, PET: PolyEthylene Terephtalate, PL: Plastic (unknown polymer), PP: PolyPropylene, PS: PolyStyrene

Table 9. Total estimates (in tonnes) of plastic polymers in packaging placed on the market and relative share of each type of polymer per MS in 2022 (minimum, maximum, median and average shares across the 19 MSs considered are provided at the bottom of the table)

	HDPE		**LDPE**		**PET**		**PL**		**PP**		**PS**	
AT	1922	2%	148	0%	42184	55%	1178	2%	30943	40%	981	1%
BE	10148	8%	169	0%	77937	60%	1121	1%	40045	31%	590	0%
BG	664	1%	976	1%	45236	65%	626	1%	21552	31%	83	0%
CZ	669	1%	52	0%	55621	63%	1561	2%	30992	35%		
DE	7456	1%			581621	60%	13171	1%	346774	36%	15468	2%
DK	1956	4%			24827	55%	230	1%	18171	40%	99	0%
EI	12310	21%			21311	36%	498	1%	22039	37%	3493	6%
EL	6586	9%			43952	61%	621	1%	21079	29%		
ES	38578	7%			344510	63%	15363	3%	147776	27%	2643	0%
FI	1043	3%			18026	45%	525	1%	19861	50%	316	1%
FR	68714	9%			457499	57%	30793	4%	222314	28%	19631	2%
HU	1687	2%	2777	3%	73898	70%	1283	1%	25192	24%		
IT	43650	6%			486630	65%	10981	1%	208285	28%		
NL	9685	8%			58823	48%	1163	1%	50580	41%	3001	2%
PL	11449	3%			290566	70%	8909	2%	102844	25%	258	0%
PT	6753	8%	1	0%	49667	59%	716	1%	26958	32%	273	0%
RO	3295	2%	251	0%	155735	78%	251	0%	39283	20%	432	0%
SE	3084	5%			20692	35%	75	0%	34900	59%	119	0%
SK	122	0%	694	2%	28729	63%	678	1%	14613	32%	907	2%
MIN	**0%**		**0%**		**35%**		**0%**		**20%**		**0%**	
MAX	**21%**		**3%**		**78%**		**4%**		**59%**		**6%**	
MEDIAN	**4%**		**0%**		**60%**		**1%**		**32%**		**0%**	
AVERAGE	**5%**		**1%**		**58%**		**1%**		**34%**		**1%**	

Source: Authors' own elaboration

Note: HDPE: High-Density PolyEthylene, LDPE: Low-Density PolyEthylene, PET: PolyEthylene Terephtalate, PL: Plastic (unknown polymer), PP: PolyPropylene, PS: PolyStyrene

4 Conclusions

This report presents the outcome of two activities: the refinement of the food waste model and the estimation of packaging waste.

The material flow analysis (MFA) model presented in De Laurentiis et al. (2021) and in De Laurentiis et al. (2023) underwent several updates, leading to model version 3.0. Firstly, a review of the scientific and grey literature (information produced outside of traditional publishing and distribution channels) was performed to identify studies providing updated coefficients for food waste and losses at country level (based on primary data). The availability of studies was significantly limited by the timeframe considered and by the fact that for food losses there is still no agreement on a single definition in the scientific community (partly because such a definition is also lacking in EU legislation), and therefore only few works providing data compatible with the definition adopted by the model could be retrieved. Secondly, a new product (cane sugar) was added to the sugar product group. Thirdly, the model was improved by making use of Euromonitor International data. These data were used to refine the estimation of the vegetable oils used for food purposes, the eggs distributed fresh and used by the manufacturing sector, to distinguish between the quantities of fresh and processed fish products entering the distribution phase, and to perform a disaggregation of processed fruit, processed vegetables and processed fish products distributed in sub-categories (i.e. chilled, shelf-stable and frozen). Lastly, additional model improvements allowed to refine the modelling of fruit juices and oilcrops at manufacturing and consumption.

In the first two years of mandatory reporting of food waste quantities by MSs, the model results were used by Eurostat to cross check whether the quantities reported were in the correct range, allowing them to identify potential errors, for instance in the unit of measure used. In the coming years, the model will continue to be used to benchmark the quantities reported by the MSs, in order to identify potential outliers, and to assess the quality of data in the years in which in depth-methods are not used (i.e. when the reported food waste quantities are estimated using Annex IV instead of Annex III of Delegated Decision (EU) 2019/1597).

As a result of the second activity, a methodology to estimate the mass of different packaging materials linked to the consumption of food and beverage products is presented and the total quantities of packaging materials are estimated for 19 MSs for the years between 2008 and 2022. In addition, coefficients are provided, to be used in combination with food sales data in the absence of a packaging database like the one used in this analysis to perform an estimation of related packaging materials.

These estimates of amounts of packaging placed on the market can support Member States in the process of reporting packaging waste quantities, and can be used by Eurostat to benchmark the quantities of packaging waste reported.

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List of abbreviations and definitions

CBS	Commodity balance sheet
CWCF	Consumption-Weight Conversion Factors
DG	Directorate General
DSQ	Domestic supply quantity
EC	European Commission
EU	European Union
FAO	Food and Agriculture Organization
FBS	Food balance sheet
FS	Food services
FSC	Food supply chain
FWI	Food waste index
HDPE	High Density Poly Ethylene
HH	Households
JRC	Joint Research Centre
LWE	live weight equivalent
MFA	Material flow analysis
MS	Member State
P&M	Processing and manufacturing
PET	polyethylene terephthalate
PP	Primary production
PV	Product variant
PW	Product weight
R&D	Retail and distribution
RDC	Retail, distribution, consumption
SDG	Sustainable Development Goal
UCO	used cooking oil
UM	unitary mass

List of Definitions

Bone-free-meat – Weight of meat products ready for human consumption.

By-products - surplus food used as animal feed and for non-food uses.

Commodity balance sheets – FAOSTAT statistical database providing for a list of commodities their sourcesof supply (i.e. production, import and stock variation) and utilisation (i.e. export, feed, seeds, other uses, losses, processing, food supply).

Commodity primary equivalent - the amount of primary commodity input that would be required to produce a given amount of derived product output (e.g. the amount of wheat necessary to produce a certain quantity of flour).

Domestic supply quantity – element of the CBS, calculated as production plus imports and stock variation minus exports.

Dry mass - the total amount of ingredients in a food exclusive of water (DTU, 2022)

Edible parts of food – fraction of food intended to be eaten by humans, calculated based on the edible percentage of food products as provided in nutritional databases

Food – defined in Regulation 178/2002 as *"food as a whole, along the entire food supply chain from production until consumption. Food also includes inedible parts, where those were not separated from the edible parts when the food was produced, such as bones attached to meat destined for human consumption."* Feed, live animals (unless they are prepared for placing on the market for human consumption) and plants prior to harvesting are excluded from the definition of food.

Food balance sheets – as commodity balance sheets but providing additional information (e.g. per capita food supply quantity, protein supply quantity).

Food losses – Food crops left on field and ploughed in, mortality of the animals ready for slaughter, both during transport to slaughterhouse and rejects at slaughterhouse.

Food supply quantity – element of the CBS, calculated as domestic supply quantity minus feed, seeds, losses, processing and other uses.

Food waste – All food (defined according to Regulation 178/2002), including both edible and inedible parts, that has become waste (defined according to Directive 2008/98/EC).

Food waste coefficient – coefficient taken from the scientific and technical literature providing, at a certain stage of the food supply chain, the share of food waste generated of the amount entering that stage of the supply chain.

Live weight equivalent - the live weight of an animal (fish or livestock) needed to produce a given amount of a derived animal product (e.g. fish fillets).

Product variant – a typology of packaging identified based on attributes like size, closure or material.

Raw commodity – any food in its raw or natural state, presenting no degree of processing.

Side flow - portion of crops ready for harvest/animals ready for slaughter that is either wasted, lost, transformed in animal feed or in other by-products.

Technical coefficient – coefficient taken from the technical literature used to estimate the quantity of the considered flow from the quantity of a related flow (e.g. pomace and pits generated in the production of olive oil from the amount of olives processed).

Waste – defined in Directive 2008/98/EC as "*any substance or object which the holder discards or intends or is required to discard"*.

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Annexes

Annex 1. Coefficients used in the model and respective data sources

The worksheet is publicly available on the JRC Data Catalogue at the following URL:

http://data.europa.eu/89h/1f450ba2-d844-4873-8161-7f210a70474e

Annex 2. Sources of data used in the model and respective classification

The worksheet is publicly available on the JRC Data Catalogue at the following URL:

http://data.europa.eu/89h/1f450ba2-d844-4873-8161-7f210a70474e

Annex 3. Food waste estimates resulting from the model version 3.0

The worksheet is publicly available on the JRC Data Catalogue at the following URL:

http://data.europa.eu/89h/1f450ba2-d844-4873-8161-7f210a70474e

Annex 4. Visualisation of the estimates as output of the model version 3.0 for the year 2021 for all Member States and EU

The document is publicly available on the JRC Data Catalogue at the following URL:

http://data.europa.eu/89h/1f450ba2-d844-4873-8161-7f210a70474e

Annex 5. Collected and estimated unitary mass values, in grams

The document is publicly available on the JRC Data Catalogue at the following URL:

http://data.europa.eu/89h/f9c65f14-2bea-4b3d-a13d-d7eb2b8fb1c2

Annex 6. Packaging amounts estimates by country, year, type of food product and packaging material type, in kilograms

The document is publicly available on the JRC Data Catalogue at the following URL:

http://data.europa.eu/89h/f9c65f14-2bea-4b3d-a13d-d7eb2b8fb1c2

Annex 7. Consumption-weight conversion factors

The document is publicly available on the JRC Data Catalogue at the following URL:

http://data.europa.eu/89h/f9c65f14-2bea-4b3d-a13d-d7eb2b8fb1c2

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