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Ecodesign preparatory study for product specific measures on scarce, environmentally relevant and critical raw materials and on recycled content

Final Study Report

Phase 2: Preparatory Study Refrigeration appliances

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Phase 2: Preparatory study

Computers

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Acronyms

A	Allocation factor in the CFF (section 5.4)
ABS	Acrylonitrile butadiene styrene
AEC	Annual Electricity Consumption
Ag	Silver
Au	Gold
BoM	Bill of Materials
CFF	Circular Footprint Formula
CR	Commission Regulation
CRM	Critical Raw Material
CRMA	Critical Raw Materials Act
Cu	Copper
EC	European Commission
EEE	Electric and Electronic Equipment
EEI	Energy Efficiency Index
EIA	Ecodesign Impact Accounting
EFSA	European Food Safety Authority
EoL	End-of-Life
EPR	Extended Producer Responsibility
EPREL	European Product Registry for Energy Labelling
Erec	Environmental impact of recycled raw material
ERT	EcoReportTool
ESPR	Ecodesign for Sustainable Products Regulation
Ev	Environmental impact of virgin raw material
FCA	Food Contact Article
FCM	Food Contact Material
GMP	Good Manufacturing Practice
GPPS	General Purpose Polystyrene
GWP	Global Warming Potential
HIPS	High-Impact Polystyrene
HIPS ESCR	high impact polystyrene with enhanced environmental stress cracking resistance
IA	Impact Assessment
MDI	Methylene diphenyl diisocyanate (used for PUR foam)
NIAS	Non-intentionally added substances
ODP	Ozone depletion
PCB	Printed Circuit Board
PCR	Post-consumer recycled
Pd	Palladium
PET	Polyethylene Terephthalate
PP	Polypropylene
PPWR	Packaging and Packaging Waste Regulation
Pt	Platinum
PU(R)	Polyurethane (Rigid)
R1	Recycled content in the CFF (section 5.4)
R2	Recycling output rate in the CFF (section 5.4)
RC	Recycled Content
RF	Refrigerating appliance covered by regulations 2019/2019 and 2019/2016
R&M	Repair and Maintenance
r-HIPS	Recycled HIPS
SAN	Styrene acrylonitrile resin
WEEE	Waste Electric and Electronic Equipment

EXECUTIVE SUMMARY

This document is part of the '*Ecodesign preparatory study for product specific measures on scarce, environmentally relevant and critical raw materials and on recycled content*' [1] and specifically regards phase 2 of the study, on (household) refrigerating appliances [2].

Refrigerators and freezers (RF) were identified as a priority product group in phase 1 of the study mainly for their potential to use recycled plastics, and consequently that was the focus of the study.

The phase 2 study on RF products was a mini-preparatory study with limited budget. It performed data collection on fridge components, their material use, current end-of-life collection and recycling practices, existing legislation, etc. and performed a first analysis (for a single base case product) on the reduction of environmental impacts due to an increase in recycled material content. The recommendations of the study will feed into the review study on refrigerating appliances that started in December 2024. That study will further complete the data collection, the analyses (for additional base products) and the stakeholder consultation, and propose recycled content and recyclability requirements for RF products in ESPR context.

Mass distribution over material types and components

The analysis is based on a Bill-of-Materials (BoM) for a refrigerator-freezer combi of a major European manufacturer, for a model still on the market in January 2025 (section 5.3). Combis represent more than 50% of the annual RF sales, and the percentual material distribution for the specific BoM is similar to the one for the average refrigerator in APPLiA statistical reports. Hence, analysis results are retained representative.

As shown in Figure 1, 41% of the fridge mass is plastic, 45% ferrous metal, 3.4% non-ferrous metal (2.1% aluminium, 1.3% copper), 9.6% glass, 0.5% electronic components, and 0.7% others (adhesives, refrigerant, lubrication oil).

More specifically for the plastics, 23% of the fridge mass is polystyrene (high-impact HIPS or general purpose GPPS), 11% polyurethane foam (PU), 4% polypropylene (PP), 1% polyvinylchloride (PVC), 0.6% acrylonitrile butadiene styrene (ABS) and 0.8% other plastics.

Viewing the mass distribution from the point of view of fridge components:

- 55% is in the body and the doors
- 20% is in internal components (shelves, drawers, baskets, accessories)
- 11% is in the hermetic compressor
- 10% is in the rest of the cooling system (condenser, evaporator)
- The rest are airflow components (fans, ducts, covers) and electronics.

[1] www.ecodesignmaterials.eu

[2] Refrigerators and freezers in scope of Ecodesign regulation 2019/2019 and Energy Labelling regulation 2019/2016.

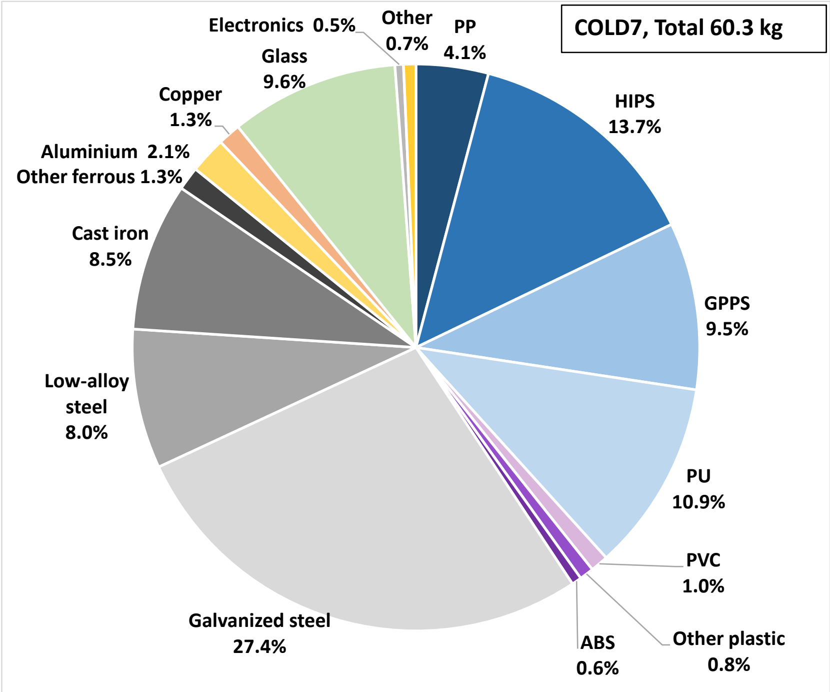

Figure 1: Masses per material type for base case COLD7 (combi)

End-of-life collection and recycling rates

It is estimated that 60% of RF products reaching end-of-life is currently being separately collected [3], and an additional 18% complementarily collected (section 2.1.5).

Recycling rates (share recycled compared to collected) depend on the type of material and on the collection method. Based on various sources and on interviews with recyclers, for separately collected fridges the recycling rates are 70-90%, except for plastics other than PP, PS and ABS. For complementary collection, the recycling rates are uncertain, but (much) lower (Table 1, details in section 5.4.4).

As regards the recycled content in input to fridge production, for metals 30-37% has been assumed, for flat glass 5%, and for plastics and electronics 0% (Table 1, details in section 5.4.3) [4]. A major factor limiting the use of recycled plastics inside fridges are the food contact material regulations (FCM, section 1.5.7), which set severe limits on the migration of a large number of substances from the fridge materials to the food. Electrolux, which is using 70% recycled high-impact polystyrene (rHIPS) for the inner liner of one of its fridge models, resolved this by organizing a dedicated fridge-to-fridge PS recycling chain, applying a virgin HIPS barrier layer on top of the recycled material (section 4.2.1) [5], and performing continuous quality monitoring. Anyway, the PRIMUS project has shown that, if the collection, sorting, transportation and recycling process is well managed, recycled HIPS can also meet FCM requirements without such a barrier (section 4.2.2).

The amount of rigid polyurethane insulation foam (PUR) in fridges has increased over the last decades because of the increasing energy efficiency requirements of Ecodesign regulations.

[3] Percentage of generated WEEE, from APPLiA and Eurostat statistical data. Separate collection is organized by manufacturers, or by third parties for them, in the context of Extended Producer Responsibility, and covers the entire recycling chain: collection, pre-sorting, transport and recycling.

[4] One manufacturer, for one fridge model, is already using recycled polystyrene for the inner liner of the body, so recycled content is not exactly 0%, but close to it.

[5] Electrolux filed a patent on the design and technology.

However, PUR from fridges is now mainly being incinerated with heat recovery. Chemical recycling (recovery of polyols) is not economically viable on a large scale (yet) (section 4.2.3). Top-of-the-range fridges increasingly use vacuum insulation panels (VIPs, with glass fibres and silica cores), often combined with PUR foam. VIPs bring energy consumption benefits but complicate fridge recycling (section 0).

Table 1: Collection rates for fridges, recycling rates for fridge materials and recycled content

	Mass share in fridge	Separate collection rate	Comple-mentary collection rate	Recycling rate for separate collection	Recycling rate for complementary collection	Recycling output rate (R2 of CFF) [6]	Recycled content (R1 of CFF)
PP, PS and ABS	27.9%	60%	18%	80%	4%	49%	0%
PUR foam	10.9%			0%	0%	0%	0%
Other plastics	1.8%			0%	0%	0%	0%
Steel	45.2%			98%	98%	76%	30%
Aluminium	2.1%			90%	90%	70%	30%
Copper	1.3%			95%	95%	74%	37%
Glass	9.6%			70%	35%	48%	5%
PCBs and LEDs	0.3%			75%	37.5%	52%	0%
Cables, wiring	0.2%			90%	45%	62%	0%
Other materials	0.7%			0%	0%	0%	0%

Fridge recycling practice

Fridge recycling consists in three main steps:

- Removal of components before shredding
- Shredding of the rest of the fridge
- Post-shredder separation, cleaning and refinement processes.

The fridge recycling practice can be summarized as follows (section 6.3.2):

- The WEEE directive prescribes the removal before shredding and the separate treatment of certain types of components and materials (section 1.5.6). This means that e.g. refrigerants, lubrication oil, and capacitors are removed by recyclers before shredding.
- Although not required, hermetic compressors and most glass parts (shelves, some transparent doors), are removed before shredding and sent to specialized recyclers.
- For the rest, the decision on separation before shredding is made by recyclers mainly on economic grounds. If a component or material is valuable and easy to access and separate, this will be done, otherwise it will be shredded together with the rest, and the materials will be recovered from post-shredder separation processes as far as possible.
- Another reason to choose separation before shredding can be that the component (potentially) causes problems in the shredder (e.g. high-energy Li-ion batteries, increasingly found in fridges, can cause fires).
- Electronic boards in fridges are low-value and not always removed before shredding (but their flakes are anyway recovered later during separation). Recyclers are in favour

[6] Factor R2 of the Circular Footprint Formula (CFF) used in the EcoReportTool, calculated as the sum (over separate and complementary collection) of collection rates multiplied by recycling rates.

of requirements facilitating identification and removability of electronic boards, but more for process safety reasons than for increasing recyclability.

- The components for which Ecodesign regulation 2019/2019 requires spare parts availability (section 1.5.1), and which should thus be accessible and removable, are usually not removed before shredding.
- Mobile components like shelves, drawers, baskets and accessories are usually not removed before shredding (except glass).
- The common shredding and separation processes work quite satisfactorily, separation before shredding is therefore often not economically advantageous.
- Recyclers do not have the time to scan labels, check online model information, and then separate components accordingly. Recyclers are also sceptic on the usefulness (for them) of information in the Digital Product Passports introduced by the ESPR.
- Recyclers do not have time to carefully unscrew components, preferably they are cut away or broken away. Dismantling is not a reverse assembly.

Potential requirements

Table 2 presents a survey of potential recycling-related requirements on fridges. The sections of the report where these requirements are further discussed are indicated, and a first judgement is provided whether to continue considering the requirement or not.

Remarks on recycled content requirements:

- Requirements regarding the recycled plastic content of fridges can be set on 5 levels (Table 2). Each of the options has advantages, disadvantages, and associated minimum required recycled content percentages (section 6.2.1.4). The options and the percentages are open for discussion. Option 2 is recommended by the study team. The requirements could be e.g. [7]:
  - By 1 January 2030, any fridge placed on the market shall contain at least 10% of recycled plastic content recovered from post-consumer waste.
  - By 1 January 2033, any fridge placed on the market shall contain at least 30% of recycled plastic content recovered from post-consumer waste.
  - The recycled content share shall be computed as the mass of post-consumer recycled plastics contained in the product divided by the total plastics mass contained in the fridge as sold, excluding packaging.
- Glass is near 10% of the fridge mass, current recycled content is low (5%), and flat glass recyclers are trying to promote flat-to-flat glass recycling (section 2.2.4) [8]. Hence, it is recommended setting minimum recycled content requirements, e.g.:
  - By 1 January 2030, any fridge placed on the market shall contain at least 15% of recycled flat glass recovered from post-consumer waste.
  - By 1 January 2033, any fridge placed on the market shall contain at least 35% of recycled flat glass recovered from post-consumer waste.

[7] The chosen +10% and +30% are based on the estimated maximum realistic recycled plastic content, see section 6.2.1.5. With this type of requirements, the manufacturer would be free to choose for which type of plastic the recycled content is increased, i.e. for HIPS, GPPS, PP, ABS, PVC, or even chemically recycled PUR (if available).

[8] This is mainly intended for windows in the building sector.

  - The share shall be computed as the mass of post-consumer recycled flat glass contained in the product divided by the total flat glass mass contained in the fridge.

Remarks on recyclability requirements:

- 55% of the fridge mass is in the body and the doors, which are mainly sandwich structures (e.g. HIPS + PUR foam + steel sheet). Considering the structural and thermal functions, and economical aspects, requirements aiming at ease of separation are not opportune.

  However, with an eye on the future, it would be relevant to identify the presence of vacuum insulation panels (compare the APPLiA code of conduct).

  Transparent doors can have spacers and frames in different materials, which can pose recycling problems. Ease of separation is an issue here.
- 20% of the fridge mass is in internal components (shelves, drawers, baskets, accessories). These can already be easily removed, but recyclers often do not do this. Imprinting the type of plastic on the components could help. Avoiding a mix of different materials in the same component should be avoided.
- 10% of the fridge mass is in the hermetic compressor, which is already being removed before shredding and processed separately. The CRM act already addresses the presence of permanent magnet motors.
- Shredding (almost) all fridge materials together and separating afterwards is economical and leads to high recycling rates. The possible benefit of requirements facilitating separation before shredding therefore seems limited.
- Recyclers are in favor of requirements facilitating the identification and separation of electronic boards before shredding, mainly for process safety reasons.
- Stakeholders have indicated few recycling problems due to additives or fillers in plastic. Further restriction of halogenated flame retardants (compare the electronic displays regulation) is a debated issue that needs further study. Limits could be set on fillers in polypropylene. In addition, or alternatively, require a density of 1.2 g/cm3 or higher for plastics with fillers or additives that give recycling problems.
- A recyclability index for fridges is expected to have a limited impact but anyway deserves further study.

Remarks on CRMs:

- No recycled content (RC) requirements are proposed for CRMs.
- For copper and aluminium, recycling rates are already high. The amount of recycled material could be increased mainly by improving the separate collection rates for fridges, which is outside the scope of the study. Recycled Cu and Al content in fridges depends on the general recycled metals market, which is well established and would not benefit from requirements.
- For other CRMs and SRMs, stakeholders pointed out e.g. difficulties in establishing the RC thresholds, uncertainties if RC requirements would have the desired effects, economic viability issues, verification issues and the small CRM quantities present in fridges versus the administrative and verification efforts.

  Recyclability and information requirements for CRMs in fridges need further study and discussion in the follow-up study. Fridge recyclers have stated that the recycling rate of printed circuit boards and other electronic components is already high, but other stakeholders believe that more CRMs can be captured during fridge recycling by separating CRM-containing parts before shredding. Recyclability requirements could include design-for-recyclability criteria, development of high-quality recycling standards, and ensuring ease of access and removability for CRM-containing parts. Information requirements could include a compulsory dismantling manual, e.g. as part of the Digital Product Passport.

Main stakeholder comments on potential requirements (further details in section 7.3):

- Organizations of home appliance manufacturers judge the setting of minimum recycled content requirements as premature. They prefer to start with information requirements on recycled material content. Recycler organizations and environmental NGOs are in general in favor of setting minimum recycled content requirements, considering only post-consumer recyclates.
- There is wide support from stakeholders for measures like 2.7.1 and 2.7.2 that require the removal of electronic boards (and other CRM-containing parts) before shredding.
- Chemical industry organizations and organizations of home appliance manufacturers are not in favor of a ban on halogenated flame retardants.
- Stakeholders generally agree not to set recycled content requirements for CRMs.

Table 2: Survey of potential requirements on fridges

	Potential requirement	reference	recommendation
1	**Recycled content requirements**		
1.1	Minimum recycled content for entire fridge. > 25% in 2030, > 45% in 2033	6.2.1.4, option 1	no
1.2	Minimum recycled content for entire plastics fridge mass. > 10% in 2030, > 30% in 2033	6.2.1.4, option 2	YES
1.3	Minimum recycled content for sum of PS, PP, ABS mass in fridge. > 20% in 2030, > 40% in 2033	6.2.1.4, option 3	Alternative to 1.2
1.4.1	Minimum recycled content per type of plastic in a fridge. PS > 30% in 2030, > 50% in 2033 PP > 20% in 2030, > 40% in 2033 ABS > 20% in 2030, > 40% in 2033	6.2.1.4, option 4	Alternative to 1.2
1.4.2	Minimum recycled content per type of plastic in a fridge PUR > X% in 2033	6.2.1.4, option 4	To be decided in 2030.
1.5	Minimum recycled content per (plastic) fridge component. Body inner liner > 30% in 2030, > 50% in 2033 Door inner liner > 30% in 2030, > 50% in 2033 Shelves, drawers, etc. > 30% in 2030, > 50% in 2033	6.2.1.4, option 5	no
1.6	Minimum recycled content for ferrous metals in fridges	6.2.2	no
1.7	Minimum recycled content for aluminium in fridges	6.2.2	no
1.8	Minimum recycled content for copper in fridges	6.2.2	no
1.9	Minimum recycled content for flat glass in fridges > 15% in 2030, > 35% in 2033	6.2.3	YES
1.10	Minimum recycled content for electronics in fridges	6.2.4	no
1.11	Minimum recycled content for other fridge materials	6.2.5	no
2	**Recyclability requirements**		
2.1	Main structure: marking for the presence or not of vacuum insulation panels, and of the type of core material used	6.3.4.1	YES
2.2	Transparent doors: design for ease of separation of glass from other door materials (e.g. spacers, frames)	6.3.4.2	YES, but needs further study
2.3	Shelves, drawers, etc.: require a marking on the shelves, drawers, baskets and accessories that indicates the type of plastic, like what is done for packaging.	6.3.4.3	YES
2.4	Shelves, drawers, etc.: design for ease of separation of different material types used in a single component.		YES, but needs further study
2.4	Hermetic compressor: require separation before shredding and separate processing by specialists	6.3.4.4	no
2.5	Cooling system: no potential requirements identified	6.3.4.5	void

	Potential requirement	reference	recommendation
2.6	Internal air flow: require spare parts availability for fans, fan motors, and controls	6.3.4.6	YES, but needs further study
2.7.1	Electronics: boards larger than 10 cm² and boards containing batteries or wet capacitors should be easily removable for recyclers, without the use of screwdrivers	6.3.4.7	YES, but needs further study
2.7.2	Electronics: position all printed circuit boards in a box on top of the fridge, or if that is not possible use a standardized marking, recognizable from 2-meter distance, to indicate the location of the box	6.3.4.7	YES, but needs further study
2.7.3	Electronics, for printed circuit boards in fridges, use any of the four types of plastics that are recycled from fridges today (GPPS, HIPS, PP, ABS), as bare board material	6.3.4.7	no
2.8	Other components: require a label indicating the type of refrigerant being used in the fridge, clearly visible from a distance during the recycling process	6.3.4.8	no
2.9.1	Additives and fillers: forbid the use of halogenated flame retardants, and require a marking for plastics containing flame retardants, like the regulation for electronic displays	0	Needs further study
2.9.2	Additives and fillers: set a maximum 10% mass content for chalk, talcum, or fibre glass filler in polypropylene	0	maybe
2.9.3	Plastics with additives or fillers giving recycling problems: require density 1.2 g/cm3 or higher to facilitate separation	0	maybe
2.10	Recyclability index: develop a recyclability index for fridges	6.3.6	Needs further study
3	**Requirements for CRMs**		
3.1	Recycled content requirements	6.4	no
3.2	Recyclability requirements	6.4	Needs further study
3.3	Information requirements	6.4	Needs further study

Environmental impacts for the baseline scenario

For the reference refrigerator-freezer combi, environmental impacts have been calculated using the 2024 EcoReportTool v1.7. Impacts from materials and from end-of-life (EoL, impacts and benefits) have been considered and compared to those from lifetime electricity consumption (see sections 5.3, 5.4 and 5.6 for details).

Figure 2 shows that a large share of the impacts comes from plastics (purple bars).

Figure 3 shows that, for most environmental categories, material and EoL impacts are relatively small compared to lifetime use-phase impacts from electricity consumption. The main exceptions are ‘resource use, minerals and metals’, and ‘ozone depletion’.

Figure 4 shows that for plastics, the largest environmental impacts come from HIPS, GPPS, and PP (grey and cyan bars). For this reason, these plastic types have been targeted for recycled content requirements. Impacts from rigid PU foam (purple) are also high, but recycling of PU is currently not economically viable (recommended to reassess in 2030).

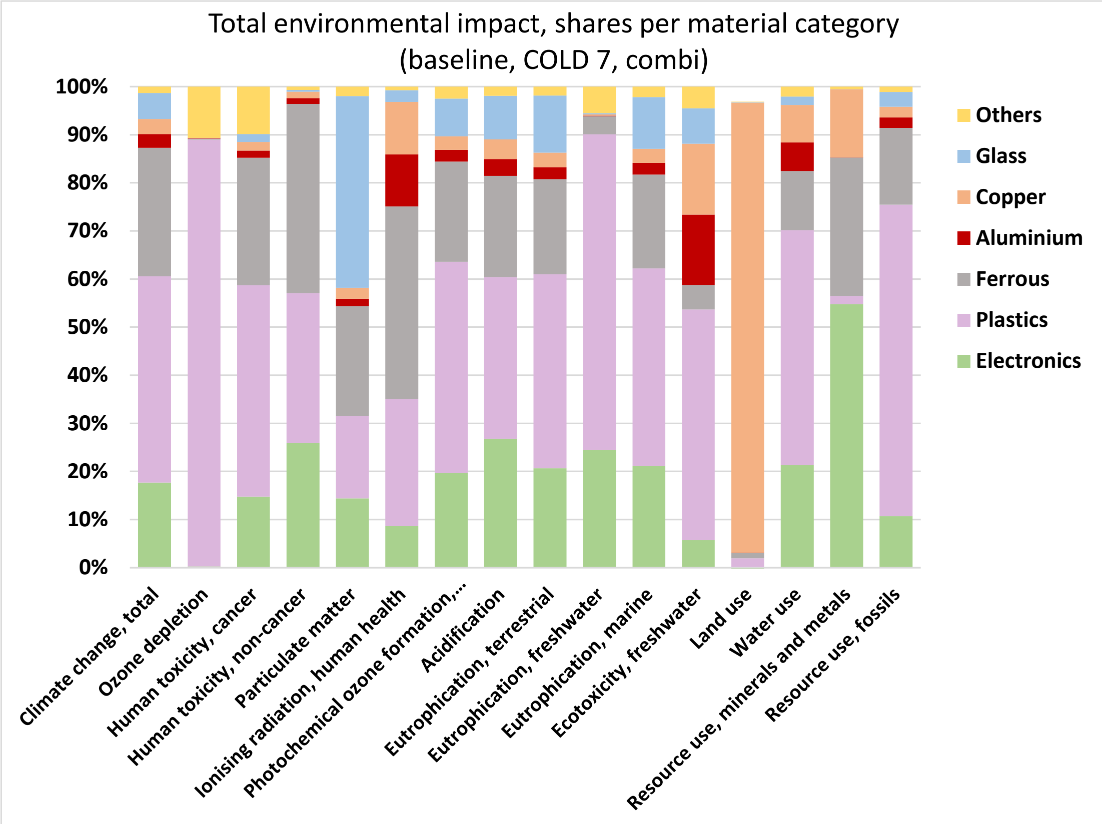

Figure 2: Shares per material category in the total environmental impacts from materials and end-of-life, per environmental impact category, for base case COLD 7 (combis), for the baseline scenario.

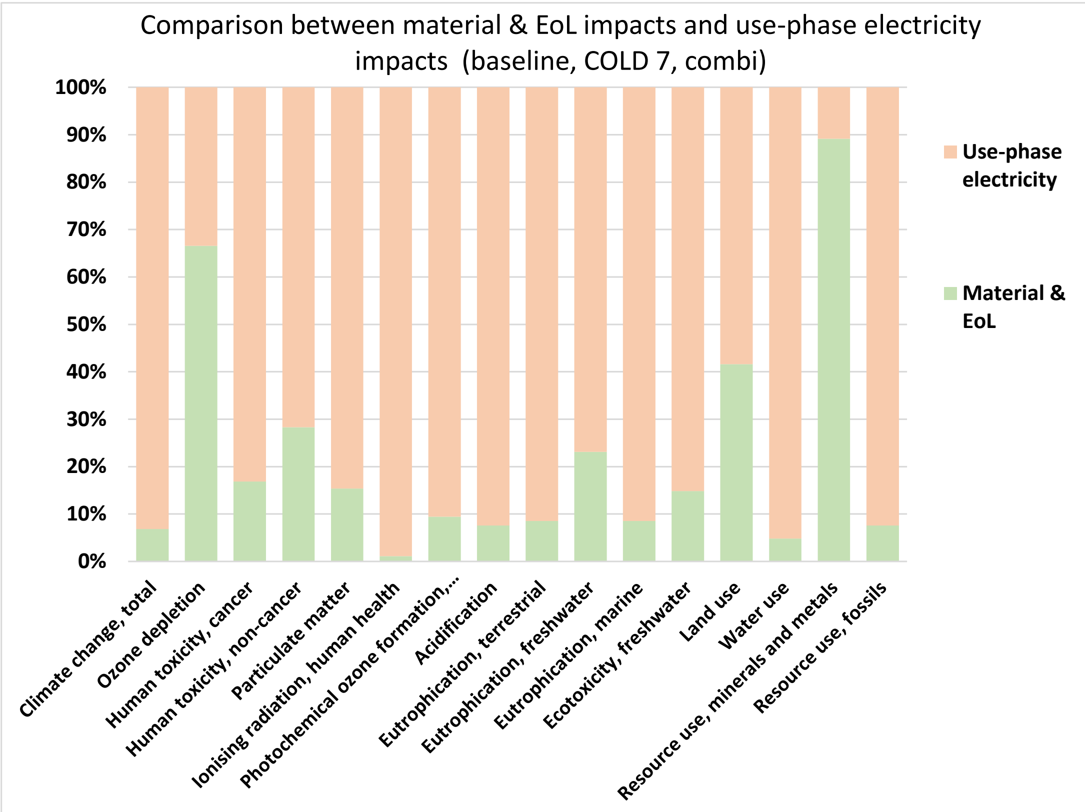

Figure 3: Impact shares from materials & end-of-life (green) and from lifetime use-phase electricity consumption (orange), per environmental impact category, for base case COLD 7 (combis), for the baseline.

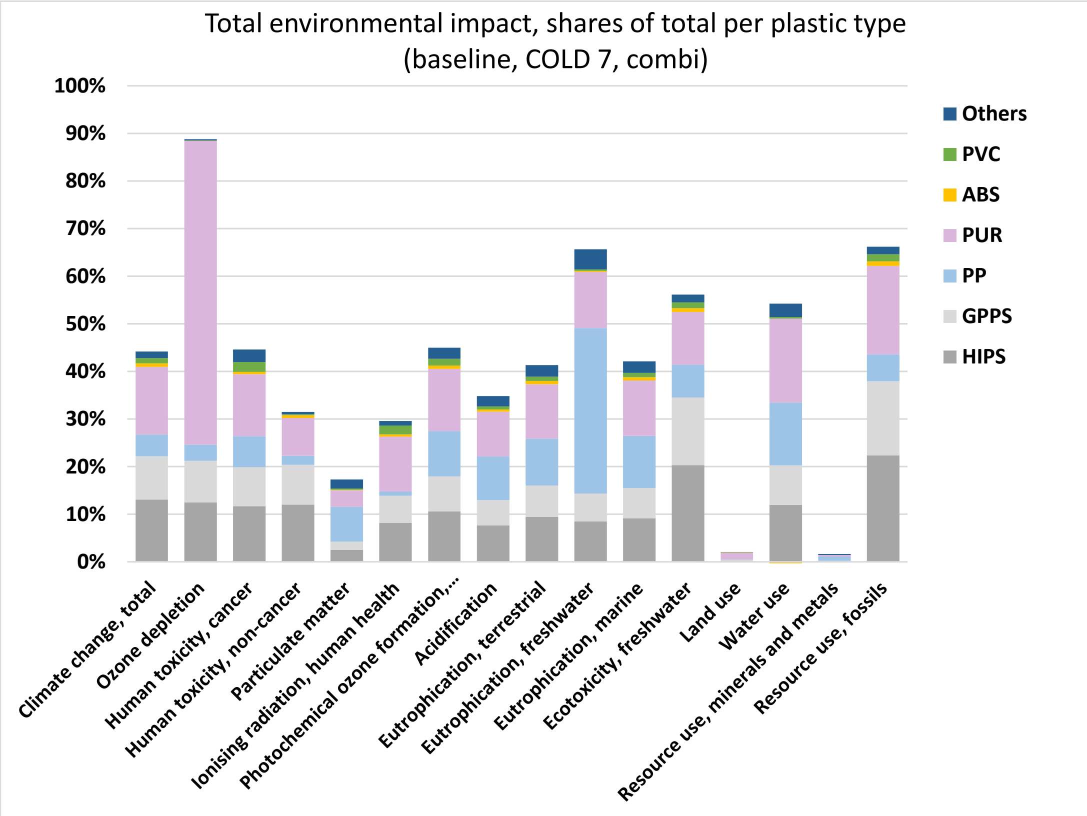

Figure 4: Shares per plastic type in the total environmental impacts from materials and end-of-life, per environmental impact category, for base case COLD 7 (combis), for the baseline scenario.

Reduction of environmental impacts due to recycled content requirements

The reduction of impacts compared to the baseline has been performed for the following minimum post-consumer recycled content (RC) requirements:

PS	> 30% in 2030, > 50% in 2033
PP	> 20% in 2030, > 40% in 2033
ABS	> 20% in 2030, > 40% in 2033
Flat glass	> 15% in 2030, > 35% in 2033

In Table 2 this corresponds to the combination of rows 1.4.1 for plastics and row 1.9 for glass. For plastics, requirements of 1.4.1 have been chosen for analysis because they contain specific limits per plastic type. For the requirements of 1.2 and 1.3, manufacturers have more freedom of choice, which would complicate the analyses. The recommended requirement for plastics is 1.2, but the results for 1.4.1 are retained indicative also for requirements 1.2 and 1.3.

The results of the analysis are shown in Table 3 for the tier 2 requirements of 2033, for RF products projected to be sold in 2033 (17.4 million units) [9] [10].

The table is split in two parts, covering different environmental impact categories. The top four rows show the baseline materials and end-of-life impacts, for plastics only, for glass only, and for all fridge materials, and the latter when adding impacts from use phase electricity consumption over the product lifetime [11]. The bottom four rows show the impact reduction shares versus the baseline impacts. For some categories, the EU27 total impact in 2020 is also shown for reference.

As regards the environmental impact reduction:

- For ‘ozone depletion’ and ‘ionising radiation’, the impact reduction is negative, indicating that the recycled content requirement creates additional impacts. This is due to the datasets used for HIPS and GPPS, see remarks in sections 5.6 and 5.7.
- For other environmental impact categories, the reduction due to plastics recycled content compared to the baseline impacts for plastics varies from 1.6% for ‘eutrophication, freshwater’ to 23.0% for ‘human toxicity, non-cancer’. Other high reduction shares are found for ‘eco toxicity, freshwater’ (22.3%), ‘human toxicity, cancer’ (17.7%) and ‘resource use, fossils’ (17.6%).
- The impact reduction due to glass recycled content compared to the baseline impacts for glass varies from 0.2% for ‘acidification’ to 7.5% for ‘eco toxicity, freshwater’. Other high reduction shares are found for ‘particulate matter’ (7.2%), ‘ionising radiation’ (7.0%), ‘ozone depletion’ (6.9%) and ‘eutrophication, freshwater’ (6.8%).
- The impact reduction due to plastics and glass recycled content compared to the baseline impacts for all fridge materials varies from 0.0% for ‘land use’ and 0.3% for ‘resource use, minerals and metals’ to 11.7% for ‘resource use, fossils’ and 13.1% for ‘eco-toxicity, freshwater’. The percentage impact reduction depends on the baseline impacts from plastics and glass compared to those from other materials (Figure 2), and on the baseline impacts of PS, PP and ABS compared to those from other plastics, e.g. PUR foam (Figure 4).

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[9] Section 7.2.1 provides the results also for tier 1 (2030), and the results per unit product (not multiplied by the sales).

[10] This implies the assumption that the reference BoM for the refrigerator-freezer combi is representative for the average of all refrigerators and freezers.

[11] impacts from electricity use over the lifetime of the fridge-freezer combi (for 235 kWh/year, 15.7 years lifetime, electricity grid mix dataset 243)

- Compared to the baseline impacts including those from lifetime electricity use, the largest impact reductions occur for 'human toxicity, non-cancer (2.1%) and 'ecotoxicity, freshwater' (2.0%).
- For 'climate change', 'water use', and 'resource use, fossils' a comparison has also been made with the EU27 total impacts in 2020 [12]. For these parameters, the tier 2 (2033) recycled content requirements decrease the impacts by 0.004% to 0.014%.

As regards the reduction in use of virgin materials in input to fridge production:

- The virgin material mass reduction compared to the baseline is 33% for plastics, 32% for glass, and 19% for all fridge materials.
- The 141.6 kton plastic reduction is 0.27% of the 53.3 Mton total consumed plastics in EU27 in 2022, and 3.5% of the 4.0 Mton plastics used in EEE (section 2.2.3).
- The 122 kton reduction for HIPS and GPPS is 4.5% of the 2.7 Mton total PS consumed in EU27 in 2022, and 46% of the EU27 recycling capacity for PS of 264 kton.
- The 17.3 kton reduction for PP is 0.2% of the 8.8 Mton total PP consumed in EU27 in 2022, and 1.0% of the EU27 recycling capacity for PP of 1.7 Mton.
- The 2.3 kton reduction for ABS is 0.31% of the 0.8 Mton total ABS consumed in EU27 in 2022.

Between 2022 and 2033, the plastics recycling capacity in the EU27 is expected to further increase. However, for use in fridges the recycled PS needs to be food-contact-approved and cannot be bought just anywhere on the recycled PS market. Current use of recycled PS in fridges relies on specially developed fridge-to-fridge collection and recycling processes (sections 4.2.1 and 4.2.2).

Table 3: Reduction of material and end-of-life impacts compared to the baseline, for fridges projected to be sold in 2033, when using 2033 minimum proposed recycled content percentages for PS, PP, ABS and flat glass, for base case COLD 7 (combi).

RF sales in 2033 Tier 2, 2033	Virgin Mass in input [kton]	Climate change, total [kton CO2 eq]	Ozone depletion [kg CFC-11 eq]	Human toxicity, cancer [CTUh]	Human toxicity, non-cancer [CTUh]	Particulate matter [disease incidence]	Ionising radiation, human health [ton Bq U235 eq]	Photo-chemical ozone formation, human health [ton NMVOC eq]	Acidifi-cation [k mol H+ eq]
Baseline impact Material & EoL									
Plastics only	427	868	17.6	0.4	11.2	26.9	37985	2063	2330
Glass only	96	109	0.0	0.0	0.1	62.9	3539	368	627
All materials	890	1964	19.9	0.9	35.5	155.3	128335	4583	6688
All materials & Electricity use		28821	29.8	5.4	125.4	1011.6	11540810	48567	88412
EU27 total 2020		3311000							
Impact reduction									
PP (R1=40%)	17.3	18.1	1.7E-01	1.3E-02	1.6E-01	2.1E+00	285	105.8	139.3
HIPS (R1=50%)	72.0	56.2	-2.5E+00	3.4E-02	1.4E+00	2.2E-02	-636	80.9	20.8
GPPS (R1=50%)	50.0	39.1	-1.8E+00	2.4E-02	9.7E-01	1.5E-02	-442	56.2	14.5
ABS (R1=40%)	2.3	3.2	3.3E-05	1.2E-03	4.9E-02	4.3E-02	59	6.5	6.5
Glass (R1=35%)	30.2	3.2	1.8E-04	-7.5E-04	2.9E-03	4.5E+00	248	4.0	1.1
Sum reduction	**172**	**119.8**	**-4.1**	**0.1**	**2.6**	**6.7**	**-487**	**253**	**182**

[12] Source: EIA 2024 Materials and Environmental impacts report, VHK October 2024, Table 50. See further references there. The EU27 total value for 'resource use, fossils' is for 'primary energy', but for the calculation of the shares this does not make any difference.

Share reduction vs. baseline									
Plastics only	33%	13.4%	-23.3%	17.7%	23.0%	8.1%	-1.9%	12.1%	7.8%
Glass only	32%	3.0%	6.9%	-5.0%	2.1%	7.2%	7.0%	1.1%	0.2%
All materials	19%	6.1%	-20.7%	7.8%	7.2%	4.3%	-0.4%	5.5%	2.7%
All materials & Electricity use		0.4%	-13.8%	1.3%	2.1%	0.7%	0.0%	0.5%	0.2%
Share EU27 total 2020		0.004%							

RF sales in 2033 Tier 2, 2033	Eutrophi-cation, terrestrial [k mol N eq]	Eutrophi-cation, freshwater [kg P eq]	Eutrophi-cation, marine [ton N eq]	Ecotoxicity, freshwater [k CTUe]	Land use [k pt]	Water use [Mm3 water eq. of deprived water]	Resource use, minerals and metals [kg Sb eq]]	Resource use, fossils [TJ]
Baseline impact Material & EoL								
Plastics only	6348	10.8	609	11978	1696	241	949	25440
Glass only	1868	0.04	160	1839	86	9	6	1196
All materials	15354	16.4	1445	21327	82427	464	56327	38427
All materials & Electricity use	179676	71.2	16945	143625	198076	9633	63168	505537
EU27 total 2020						158640		(51749000)
Impact reduction								
PP (R1=40%)	364	1.4	38.5	376	-10.5	14.7	115.8	540
HIPS (R1=50%)	141	-0.7	15.3	1325	20.6	6.1	16.4	2262
GPPS (R1=50%)	98	-0.5	10.6	921	14.3	4.2	11.4	1572
ABS (R1=40%)	24	0.0	2.3	44	4.9	-2.9	0.5	91
Glass (R1=35%)	23	0.0	1.3	138	1.2	0.2	0.4	17
Sum reduction	**650**	**0.2**	**68.1**	**2803**	**30.4**	**22.2**	**144**	**4483**
Share reduction vs. baseline								
Plastics only	9.9%	1.6%	11.0%	22.3%	1.7%	9.1%	15.2%	17.6%
Glass only	1.2%	6.8%	0.8%	7.5%	1.4%	2.2%	5.9%	1.5%
All materials	4.2%	1.1%	4.7%	13.1%	0.0%	4.8%	0.3%	11.7%
All materials & Electricity use	0.4%	0.3%	0.4%	2.0%	0.0%	0.2%	0.2%	0.9%
Share EU27 total 2020						0.014%		(0.009%)

1. MEErP Task 1, Scope

1.1. Scope

The product scope for this study is the same as the scope of the 2019 Ecodesign and Energy Labelling regulations for (household) refrigerating appliances [1][2]:

Electric mains-operated refrigerating appliances with a total volume of more than 10 litres and less than or equal to 1500 litres, not including:

(a) professional refrigerated storage cabinets and blast cabinets, with the exception of professional chest freezers

(b) refrigerating appliances with a direct sales function

(c) mobile refrigerating appliances

(d) appliances where the primary function is not the storage of foodstuffs through refrigeration.

The focus of the study is on the material content of refrigerating appliances and the associated environmental impacts, in particular on the presence of scarce, environmentally relevant and critical raw materials (CRM) and on the recycled materials content.

1.2. Categories of refrigerating appliances

The EPREL database [3] distinguishes the following types of refrigerating appliances [13]:

Based on the number of compartments:

- One compartment
- Combi

Based on the type of compartments:

- pantry (unfrozen, target 17°C, 14-20°C)
- cellar (unfrozen, target 12°C, 2-14°C)
- fresh food (unfrozen, target 4°C, 0-8°C)
- chill (target 2°C, -3 to +3°C)
- 0 star (ice-making) (frozen, max 0°C)
- 1 star (frozen compartment, max -6°C)
- 2 star (frozen compartment, max -12°C)
- 3 star (frozen compartment, max -18°C)
- 4 star (freezer compartment, -18°C) [14]

Special design characteristics:

[13] The EPREL product group designation is: ‘Household, hotel and wine refrigerators’

[14] 4 star must also meet freezing capacity requirement: > 4.5 kg per 24 h per 100 l of freezer volume but not less than 2.0 kg

- Wine storage dedicated appliance
- Low-noise (such as minibars)
- Transparent doors [15]

Design types:

- Built-in
- Freestanding

Minibars (with volume < 60 litres) are mentioned in the regulations [1][2] but do not have specific Ecodesign requirements and are not explicitly declared in EPREL. However, minibars are often low-noise, and low-noise appliances have specific requirements and are explicitly declared. In EPREL, minibars are easily identified by their total volume < 60 litres, and they have characteristics that differ from the other refrigerators (see Annex B). Several of them will use ammonia absorption cycles instead of vapor compression cycles. Hence, it seems opportune to consider them separately.

The 2016 review study [4] used the following category designations:

1 Refrigerator with one or more fresh-food storage compartments

2 Refrigerator-cellar, cellar and wine storage appliances

3 Refrigerator-chiller and refrigerator with a 0-star compartment

4 Refrigerator with a 1-star compartment

5 Refrigerator with a 2-star compartment

6 Refrigerator with a 3-star compartment

7 Refrigerator-freezer

8 Upright freezer

9 Chest freezer

10 Multi-use and other refrigerating appliances

For scenario analysis purposes, the review study [4] simplified this to five categories:

COLD 1:single-door refrigerators of categories 1-5 (see above), except wine coolers

COLD 2: wine storage appliances

COLD 7: fridge-freezers, incl. refrigerators with 3-star compartment (category 6)

COLD 8: upright freezers

COLD 9: chest freezers

The above category 10 was split over COLD7 and COLD1.

[15] This is not distinguished in EPREL, but it is a relevant parameter in the 2019 regulations.

Considering the availability of data in the review study [4] and in the impact assessment [5], it is convenient for this study to use the latter five categories, with the addition of COLD 0: minibars.

1.3. Definitions

For refrigerating appliances, this study uses the definitions of the 2019 regulations [1][2], article 2 and Annex I.

See also the general, horizontal part of the report on recycled content and CRMs.

To be completed in follow-up study as far as necessary [16].

1.4. Standards

See also the general, horizontal part of the report on recycled content and CRMs.

To be completed in follow-up study as far as necessary [17].

1.5. Legislation

1.5.1 Ecodesign regulation on refrigerating appliances

The 2019 Ecodesign regulation for RFs [1] specifies the following resource efficiency requirements in Annex II, point 3, applicable from 1 March 2021:

(a) Availability of spare parts:

(1) manufacturers, importers or authorised representatives of refrigerating appliances shall make available to professional repairers at least the following spare parts: thermostats, temperature sensors, printed circuit boards and light sources, for a minimum period of seven years after placing the last unit of the model on the market;

(2) manufacturers, importers or authorised representatives of refrigerating appliances shall make available to professional repairers and end-users at least the following spare parts: door handles, door hinges, trays and baskets for a minimum period of seven years and door gaskets for a minimum period of 10 year, after placing the last unit of the model on the market;

(3) manufacturers shall ensure that these spare parts can be replaced with the use of commonly available tools and without permanent damage to the appliance;

[16] A stakeholder asked to consider: nomenclature & definitions used in the European Sustainability Reporting Standards (ESRS) - particularly ESRS E5 -, as well as the technical screening criteria defined for the respective economic activities subject to the phase 2 studies and lined out in the Annex II to the Commission Delegated Regulation on the sustainable finance taxonomy (C(2023) 3851/2. For the selected product groups, a mapping to the respective NACE codes and the TSC as well as DNSH criteria should be included

[17] APPLiA's SG Plastics is currently working on assessing what minimum technical requirements could be introduced for recycled plastics in appliances. So far, the group is focusing on vacuum cleaners and washing machines. The choice of these products corresponds to standardisation activities such as a Dutch Technical Agreement (NTA) on demand-driven recyclates as well as CEN/TC 249's work on developing a series of standards with 'Quality requirements for application of plastic recyclates in products'.

(4) the list of spare parts concerned by point (1) and the procedure for ordering them shall be publicly available on the free access website of the manufacturer, importer or authorised representative, at the latest two years after the placing on the market of the first unit of a model and until the end of the period of availability of these spare parts;

(5) the list of spare parts concerned by point (2) and the procedure for ordering them and the repair instructions shall be publicly available on the manufacturer's, the importer's or authorised representative's free access website, at the moment of the placing on the market of the first unit of a model and until the end of the period of availability of these spare parts.

(b) Access to repair and maintenance information:

After a period of two years after the placing on the market of the first unit of a model or of an equivalent model, and until the end of the period mentioned under (a), the manufacturer, importer or authorised representative shall provide access to the appliance repair and maintenance information to professional repairers in the following conditions:

(1) the manufacturer's, importer's or authorised representative's website shall indicate the process for professional repairers to register for access to information; to accept such a request, manufacturers, importers or authorised representative may require the professional repairer to demonstrate that:

(i) the professional repairer has the technical competence to repair refrigerating appliances and complies with the applicable regulations for repairers of electrical equipment in the Member States where it operates. Reference to an official registration system as professional repairer, where such system exists in the Member States concerned, shall be accepted as proof of compliance with this point;

(ii) the professional repairer is covered by insurance covering liabilities resulting from its activity, regardless of whether this is required by the Member State;

(2) the manufacturers, importers or authorised representatives shall accept or refuse the registration within 5 working days from the date of request by the professional repairer;

(3) manufacturers, importers or authorised representatives may charge reasonable and proportionate fees for access to the repair and maintenance information or for receiving regular updates. A fee is reasonable if it does not discourage access by failing to take into account the extent to which the professional repairer uses the information;

Once registered, a professional repairer shall have access, within one working day after requesting it, to the requested repair and maintenance information. The available repair and maintenance information shall include:

- *the unequivocal appliance identification;*
- *a disassembly map or exploded view;*
- *list of necessary repair and test equipment;*
- *component and diagnosis information (such as minimum and maximum theoretical values for measurements);*
- *wiring and connection diagrams;*
- *diagnostic fault and error codes (including manufacturer-specific codes, where applicable); and*
- *data records of reported failure incidents stored on the refrigerating appliance (where applicable).*

(c) Maximum delivery time of spare parts:

(1) during the period mentioned under point 3(a)(1) and point 3(a)(2), the manufacturer, importer or authorised representatives shall ensure the delivery of the spare parts for refrigerating appliances within 15 working days after having received the order;

(2) in the case of spare parts available only to professional repairers this availability may be limited to professional repairers registered in accordance with point b.

(d) Requirements for dismantling for material recovery and recycling while avoiding pollution:

(1) manufacturers, importers or authorised representatives shall ensure that refrigerating appliances are designed in such a way that the materials and components referred to in Annex VII to Directive 2012/19/EU can be removed with the use of commonly available tools [18];

(2) manufacturers, importers and authorised representatives shall fulfil the obligations laid down in Point 1 of Article 15 of Directive 2012/19/EU [19].

The information requirements in the 2019 Ecodesign regulation [1], Annex II, point 4, are not relevant for this study: there are no reporting requirements on CRMs, specific materials or components, nor on end-of-life processing.

[18] See full list in section 1.5.6. Components potentially relevant for fridges include:

- mercury containing switches or lamps
- batteries
- printed circuit boards > 10 cm2
- plastic containing brominated flame retardants
- chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) or hydrofluorocarbons (HFC), hydrocarbons (HC)
- liquid crystal displays (together with their casing where appropriate) of a surface > 100 cm2
- external electric cables
- equipment containing gases that are ozone depleting or have a global warming potential (GWP) above 15, such as those contained in foams and refrigeration circuits

[19] Directive 2012/19/EU, Article 15 Information for treatment facilities, point 1. In order to facilitate the preparation for re-use and the correct and environmentally sound treatment of WEEE, including maintenance, upgrade, refurbishment and recycling, Member States shall take the necessary measures to ensure that producers provide information free of charge about preparation for re-use and treatment in respect of each type of new EEE placed for the first time on the Union market within one year after the equipment is placed on the market. This information shall identify, as far as it is needed by centres which prepare for re-use and treatment and recycling facilities in order to comply with the provisions of this Directive, the different EEE components and materials, as well as the location of dangerous substances and mixtures in EEE. It shall be made available to centres which prepare for re-use and treatment and recycling facilities by producers of EEE in the form of manuals or by means of electronic media (e.g. CD-ROM, online services).

Main take-aways

Based on existing regulations, it should be relatively easy to remove from the fridges during end-of-life processing:

- thermostats and temperature sensors,
- printed circuit boards (especially those > 10 cm2),
- light sources (including any containing mercury),
- batteries,
- mercury-containing switches,
- door handles,
- door hinges,
- door gaskets,
- trays and baskets,
- liquid crystal displays > 100 cm2,
- external electric cables,
- refrigerants with GWP > 15 or ozone depleting,
- foaming agents with GWP > 15 or ozone depleting.

Not specifically mentioned in existing regulations are:

- motors, compressors and VSDs (hermetic compressor)
- motors and fans
- capacitors
- lubricating oil
- magnets other than magnetic door gaskets
- parts containing Aluminium (CRM)
- parts containing Copper (CRM)

1.5.2 Energy labelling regulation on refrigerating appliances

The 2019 Energy Labelling regulation for RFs [2] specifies the labels shown below. There are no references to CRM content, special materials or components, recycled content, recyclability, dismantlability, etc.

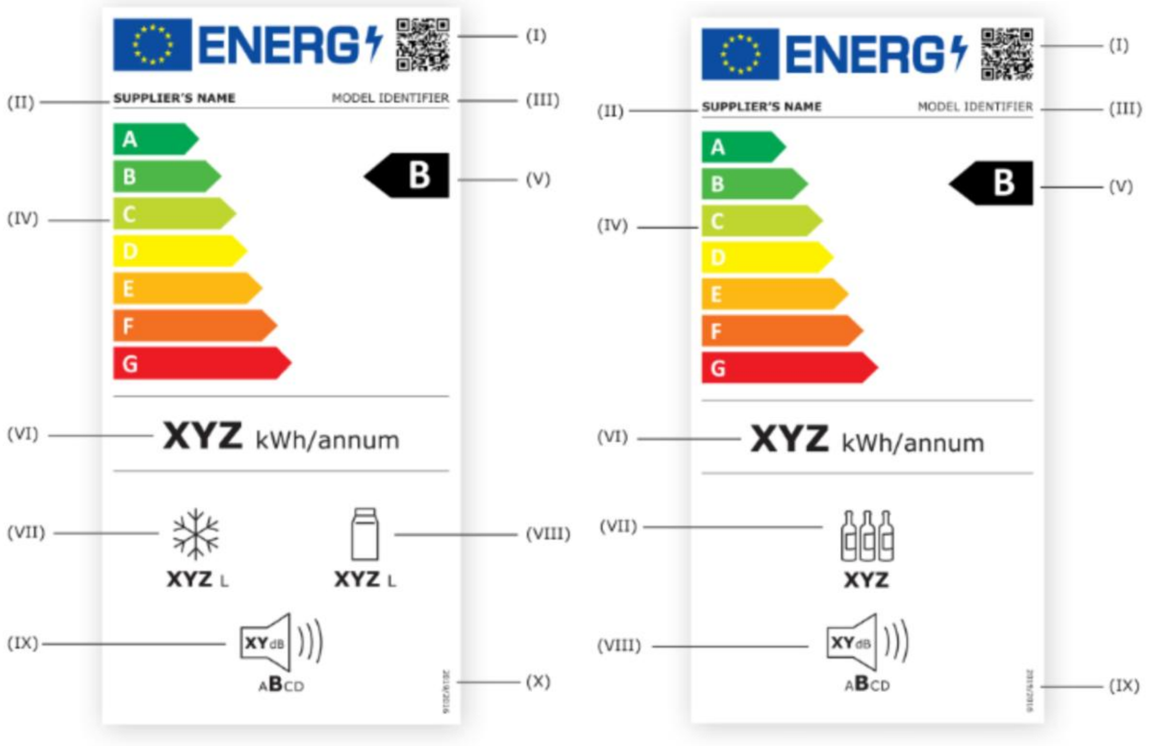

Figure 5: Energy labels for refrigerating appliances according to CDR 2019/2016, for wine storage appliances (right) and for all other RFs (left).

The product information sheet and the technical documentation required by the 2019 Energy Labelling regulation for RFs [2] in its Annex V and VI do not include reporting requirements on CRMs, specific materials or components, nor on end-of-life processing. The following information could be marginally relevant for this study:

- Supplier identification
- Model identification
- Type of refrigerating appliance (see section 1.2 on EPREL categories)
- Overall dimensions (height, width, depth)

1.5.3 Ecodesign Directive

The Ecodesign Directive 2009/125/EC [20] [6] is assumed to be known and not further described here, except for recalling Article 15, point 5:

[20] DIRECTIVE 2009/125/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (recast) (OJ L 285, 31.10.2009, p. 10), consolidated version with amendments of Directive 2012/27/EU

5. Implementing measures shall meet all the following criteria:

(a) there shall be no significant negative impact on the functionality of the product, from the perspective of the user;

(b) ***health, safety and the environment shall not be adversely affected****;*

(c) there shall be no significant negative impact on consumers in particular as regards the affordability and the life cycle cost of the product;

(d) there shall be no significant negative impact on industry's competitiveness;

(e) ***in principle, the setting of an ecodesign requirement shall not have the consequence of imposing proprietary technology on manufacturers****; and*

(f) no excessive administrative burden shall be imposed on manufacturers.

Main take-aways

Sub (b) on health is particularly relevant for fridges for the application of food contact materials in relation to the use of recycled plastic (see sections 1.5.7 and 4.2.1)

Sub (e) on proprietary technology could be relevant, in relation to the patent filed by Electrolux for the use of recycled HIPS under functional barrier in the inner liner of refrigerators or freezers (section 4.2.1, in particular 4.2.1.1).

1.5.4 ESPR

The Ecodesign for Sustainable Products Regulation (ESPR [7]) replaces the Ecodesign Directive 2009/125/EC [6] starting from 18 July 2024, and for some products / articles from 31 December 2026, or 31 December 2030 (ESPR art.79).

Just like the Ecodesign Directive, the ESPR is a framework regulation under which ecodesign, performance and information requirements can be set per product group (or horizontally over various product groups) in delegated acts.

ESPR art.5.11 gives the same criteria for setting ecodesign requirements as art.15.5 of Directive 2009/125/EC (previous section), including e.g. that 'health, safety and the environment shall not be adversely affected', and that the setting of an ecodesign requirement 'shall not have the consequence of imposing proprietary technology on manufacturers'.

The ESPR refers to recycled content and critical raw materials in various points:

- ESPR Recital (6) mentions that the regulation inter alia aims '*to increase the energy and resource efficiency of products, including with regard to the* ***possibility of recovery of strategic and critical raw materials****, reduce their expected generation of waste and* ***increase the recycled content in products***'.
- ESPR Recital (24) states that performance requirements could e.g. specify *limits on […] the quantities of a given material incorporated in the product, a* ***requirement for minimum quantities of recycled content****, or a limit on a specific environmental impact category or on an aggregation of all relevant environmental impacts*.
- ESPR Recital (100) on specific green public procurement requirements and related award criteria gives an example that it *would be mandatory for contracting authorities and contracting entities* ***to give the recycled content of the products in question a***

minimum weighting between 20 % and 30 % or that *contracting authorities and contracting entities should* ***award at least 50 % of their annual procurement of certain products to those with more than 70 % of recyclable material.***

- According to ESPR art.5.1, ecodesign requirements in the delegated acts shall be such as to improve e.g. *resource use and resource efficiency,* ***recycled content****, the possibility of remanufacturing, recyclability, the possibility of the recovery of materials*.
- Among the product parameters listed in Annex I is ***the use or content of recycled materials and recovery of materials, including critical raw materials.***
- The definition of 'substances of concern' in ESPR art.2.27(d) includes ***substances that negatively affect the reuse and recycling*** *of materials in the product in which it is present*, and ESPR art.5.14 states:

  For each product group concerned by ecodesign requirements, the Commission shall determine, where relevant, which substances fall under the definition in Article 2(27), point (d), taking into account, at least, whether:

  (a) based on standard technologies, the substances make the reuse, or recycling process more complicated, costly, environmentally impactful, or energy- or resource-demanding

  (b) the substances impair the technical properties or functionalities, ***the usefulness or the value of the recycled material coming from the product or products manufactured from that recycled material***

  (c) the substances negatively impact aesthetic or olfactory properties of the recycled material.
- According to ESPR art.7.2(b), information requirements shall, as appropriate, also require products to be accompanied by:

  (i) information on the performance of the product in relation to one or more of the product parameters referred to in Annex I, including a repairability score, a durability score, a carbon footprint or an environmental footprint

  (ii) information for customers and other actors on how to install, use, maintain and repair the product, in order to minimise its impact on the environment and to ensure optimum durability, on how to install third-party operating systems where relevant, as well as on collection for refurbishment or remanufacture, and on ***how to return or handle the product at end-of-life***

  (iii) ***information for treatment facilities on disassembly, reuse, refurbishment, recycling, or disposal at end-of-life***

  (iv) other information that could influence sustainable product choices for customers and the way the product is handled by parties other than the manufacturer in order to facilitate appropriate use, value-retaining operations and ***correct treatment at end-of-life****.*

The ESPR further introduces a Digital Product Passport (DPP)

- According to ESPR Recital (32), the *information requirements should include the requirement to* ***make a digital product passport available****. The digital product passport is an important tool for* ***making information available to actors along the entire value chain*** *and the availability of a digital product passport is expected to significantly enhance end-to-end traceability of a product throughout its value chain. Among other things, the digital product passport is expected to help customers make informed choices by improving their access to relevant information, allow economic operators, namely manufacturers, authorised representatives, importers, distributors,* *dealers and fulfilment service providers, and other value chain actors, such as customers, professional repairers, independent operators, refurbishers, remanufacturers, recyclers, market surveillance and customs authorities, civil society organisations, researchers, trade unions, and the Commission, or any organisation acting on their behalf, to access, introduce or update relevant data, and enable competent national authorities to perform their duties, without endangering the protection of confidential business information. To that end, it is important that the digital product passport be user-friendly, and that the data contained therein be accurate, complete and up to date. The digital product passport should, where necessary, be complemented by non-digital forms of transmitting information, such as information in the product manual or on a label. In addition, it should be possible for the digital product passport to be used for providing information concerning the relevant product group pursuant to other Union law*.

- According to ESPR art.9.1: *The information requirements shall provide that* ***products can only be placed on the market or put into service if a digital product passport is available*** *in accordance with the applicable delegated acts […]. The data in the digital product passport shall be accurate, complete and up to date*.
- ESPR art.10 specifies that a DPP *shall be connected through a* ***data carrier*** *to a persistent unique product identifier, the data carrier shall be physically present on the product, its packaging or on documentation accompanying the product, as specified in the applicable delegated act.*
- Related to the DPP information and verification of compliance, ESPR recital (77) states that *the Commission should be empowered to require, where duly justified, that* ***supply chain actors provide, free of charge, information on what they supply, such as the quantity and type or chemical composition of materials used or the production process employed*** and *to* ***allow manufacturers to have access to the documents containing such information*** *or to the actual facilities of the supply chain actors so that they can access directly the necessary information if the supply chain actors do not provide the information requested within a reasonable time*.

In comments after phase 1 of the current study, stakeholders have commented that:

The phase II preparatory study should also include references and detailed examples on what type of DPP data points need to be included at what value chain stage - so that it becomes clear that all actors involved in the value chain will be required to provide mandatory disclosures, i.e. on recycled raw materials, similar to the requirements on embodied carbon, as currently implemented in the CBAM regulation.

In comments after phase 2 (4^{th} SH meeting) of the current study, several stakeholders have suggested information to be reported in the DPP for fridges. This includes e.g. details on the use of VIPs, information on the use of CRMs (where they are to be found and how they can be removed responsibly, details on lubrication oil, refrigerants, propellants, etc. as far as relevant under legislation.

Main take-aways

The ESPR explicitly mentions the use or content of recycled materials and recovery of materials, including critical raw materials, as a product parameter for which requirements can be set.

The ESPR explicitly mentions substances that negatively affect the reuse and recycling of materials as a point to be addressed in studies.

The ESPR introduces a Digital Product Passport that is intended to contain all relevant product information throughout the entire supply chain.

Supply chain actors need to provide, free of charge, information on what they supply, such as the quantity and type or chemical composition of materials used or the production process employed.

1.5.5 Critical Raw Materials Act

Annex I of the Critical Raw Materials Act [8] lists the strategic raw materials, and Annex II the critical raw materials. The list is presented in Table 4.

Aluminium and Copper are strategic and critical raw materials that are used in fridges.

Coking coal is used in the production of steel and thus also (indirectly) relevant for fridges.

Other CRMs can occur in fridges as alloying elements in metal parts, in electronic parts, in magnets or in batteries. See section 4.1.3 for fridge components potentially using CRMs.

Table 4: List of strategic and critical raw materials (source: Critical Raw Materials Act [8], annex I and II)

Raw material / element	critical	strategic
Antimony	x	
Arsenic	x	
Bauxite/alumina/aluminium	x	x
Baryte	x	
Beryllium	x	
Bismuth	x	x
Boron	x	x (metallurgy grade)
Cobalt	x	x
Coking coal	x	
Copper	x	x
Feldspar	x	
Fluorspar	x	
Gallium	x	x
Germanium	x	x
Hafnium	x	
Helium	x	
Heavy rare earth elements [21]	x	

[21] The CRM Act does not further define this, but heavy rare earth elements should include Y (Yttrium), Gd (Gadolinium), Tb (Terbium), Dy (Dysprosium), Ho (Holmium), Er (Erbium), Tm (Thulium), Yb (Ytterbium), and Lu (Lutetium)

Light rare earth elements [22]	x	
Rare earth elements for permanent magnets (Nd, Pr, Tb, Dy, Gd, Sm, and Ce)		x
Lithium	x	x (battery grade)
Magnesium	x	x (metal)
Manganese	x	x (battery grade)
Graphite	x	x (battery grade)
Nickel – battery grade	x	x
Niobium	x	
Phosphate rock	x	
Phosphorus	x	
Platinum group metals [23]	x	x
Scandium	x	
Silicon metal	x	x
Strontium	x	
Tantalum	x	
Titanium metal	x	x
Tungsten	x	x
Vanadium	x	

Among the provisions of the CRM Act most relevant for the current study [24]:

- **Article 26, National measures on circularity**

  1. Each Member State shall, […], adopt […] measures designed to:

     (c) increase the collection, sorting and processing of waste with relevant critical raw materials recovery potential [25], including metal scraps, and ensure their introduction into the appropriate recycling system, with a view to maximising the availability and quality of recyclable material as an input to critical raw material recycling facilities.

     (d) increase the use of secondary critical raw materials, including through measures such as taking recycled content into account in award criteria related to public procurement or financial incentives for the use of secondary critical raw materials.

     (e) increase the technological maturity of recycling technologies for critical raw materials and promote circular design, materials efficiency and substitution of critical raw materials in products and applications, at least by including support actions to that effect under national research and innovation programmes.

  5. Member States shall identify separately, and report, the quantities of components containing relevant amounts of critical raw materials removed from waste electrical and electronic equipment and the quantities of critical raw materials recovered from such equipment.

[22] The CRM Act does not further define this, but light rare earth elements should include La (Lanthanum), Ce (Cerium), Pr (Praseodymium), Nd (Neodymium), Pm (Promethium), Sm (Samarium) and Eu (Europium).

[23] The CRM Act does not further define this, but platinum group metals (PGM) should include: Pd (Palladium), Pt (Platinum), Rh (Rhodium), Ru (Ruthenium), Ir (Iridium) and Os (Osmium).

[24] The following are extracts or summaries of the legal text. See the act itself for the precise text.

[25] The Commission has to define by May 2025 which products, components and waste streams shall at least be considered as having a relevant critical raw materials recovery potential.

- **Article 28, Recyclability of permanent magnets**

  For cooling generators, and for electric motors with permanent magnets, article 28 of the CRM Act requires a labelling indicating whether those products incorporate one or more permanent magnets, and if so, whether those permanent magnets belong to any of the following types:

  (i) neodymium-iron-boron;

  (ii) samarium-cobalt;

  (iii) aluminium-nickel-cobalt;

  (iv) ferrite.

  In future, there will also be a data carrier providing access to information on the weight, location and chemical composition of all individual permanent magnets included in the product, and on the presence and type of magnet coatings, glues and any additives used, and to information enabling access and safe removal of all permanent magnets incorporated in the product, at least including the sequence of all removal steps, tools or technologies required for the access and removal of the permanent magnet.

  For products where permanent magnets are exclusively contained in one or more electric motors, the information may be replaced by information on the location of those electric motors, and on the access and removal of the electric motors, at least including the sequence of all removal steps, tools or technologies required.

  The natural or legal person placing a product on the market shall ensure that the information is complete, up-to-date, and accurate and remains available for a period at least equal to the product's typical lifetime plus 10 years, including after an insolvency, a liquidation or a cessation of activity in the Union.

  For products for which a product passport is required pursuant to another Union legal act [26], the information shall be included in that product passport.

- **Article 29, Recycled content of permanent magnets**

  1. By 24 May 2027 […] any natural or legal person that places on the market products […] which incorporate one or more permanent magnets […], and for which the total weight of all such permanent magnets exceeds 0,2 kg shall make publicly available on a free-access website the share of neodymium, dysprosium, praseodymium, terbium, boron, samarium, nickel and cobalt recovered from post-consumer waste present in the permanent magnets incorporated in the product.
  2. By 24 May 2026, the Commission shall establish rules for the calculation and verification of these shares.
  3. […] By 31 December 2031, the Commission shall lay down minimum shares for neodymium, dysprosium, praseodymium, terbium, boron, samarium, nickel and cobalt recovered from post-consumer waste that must be present in the permanent magnet incorporated in the products […].
  4. Where requirements relating to the recycled content of permanent magnets are established in Union harmonisation legislation for any of the products […], those requirements shall apply to the products concerned in place of this Article.

[26] See section 1.5.4 on the Digital Product Passport

Main take-aways

Aluminium and Copper are strategic and critical raw materials that are used in fridges.

Coking coal is used in the production of steel and thus also (indirectly) relevant for fridges.

Other CRMs can occur in fridges as alloying elements in metal parts, in electronic parts, in magnets or in batteries.

The CRM Act already has provisions for permanent magnets used in products. By May 2026, the Commission shall establish rules for the calculation and verification of the shares of post-consumer recycled CRMs used in permanent magnets. By December 2031, the Commission shall lay down minimum shares for selected CRMs recovered from post-consumer waste that must be present in permanent magnets.

1.5.6 WEEE directive

The WEEE Directive [9] lays down measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste from electrical and electronic equipment (WEEE) and by reducing overall impacts of resource use and improving the efficiency of such use in accordance with Articles 1 and 4 of Directive 2008/98/EC (this is the 'general' waste directive [10]).

Among the provisions of the WEEE Directive most relevant for the current study [27]:

- **Article 4 Product design**

  Member States shall, […], encourage cooperation between producers and recyclers and measures to promote the design and production of EEE, notably in view of facilitating re-use, dismantling and recovery of WEEE, its components and materials. In this context, Member States shall take appropriate measures so that the ecodesign requirements facilitating re-use and treatment of WEEE established in the framework of Directive 2009/125/EC are applied and producers do not prevent, through specific design features or manufacturing processes, WEEE from being re-used […].

- **Article 5 Separate collection**

  1. Member States shall adopt appropriate measures to minimise the disposal of WEEE in the form of unsorted municipal waste, to ensure the correct treatment of all collected WEEE and to achieve a high level of separate collection of WEEE, notably, and as a matter of priority, for temperature exchange equipment containing ozone-depleting substances and fluorinated greenhouse gases, fluorescent lamps containing mercury, photovoltaic panels and small equipment […] [28].

[27] The following are extracts or summaries of the legal text. See the act itself for the precise text.

[28] Definitions from Directive 2008/98/EC, article 3:

'municipal waste' means: (a) mixed waste and separately collected waste from households, including paper and cardboard, glass, metals, plastics, bio-waste, wood, textiles, packaging, waste electrical and electronic equipment, waste batteries and accumulators, and bulky waste, including mattresses and furniture; (b) mixed waste and separately collected waste from other sources, where such waste is similar in nature and composition to waste from households;

2. For WEEE from private households, Member States shall ensure that:
   (a) systems are set up allowing final holders and distributors to return such waste at least free of charge. […]
   (b) when supplying a new product, distributors are responsible for ensuring that such waste can be returned to the distributor at least free of charge on a one-to-one basis as long as the equipment is of equivalent type and has fulfilled the same functions as the supplied equipment […].
   (d) […] producers are allowed to set up and to operate individual and/or collective take-back systems for WEEE from private households provided that these are in line with the objectives of this Directive;

- **Article 7 Collection rate**

  From 2019, the minimum collection rate to be achieved annually shall be 65 % of the average weight of EEE placed on the market in the three preceding years in the Member State concerned, or alternatively 85 % of WEEE generated on the territory of that Member State.

- **Article 11 Recovery targets**

  1. Regarding all WEEE separately collected in accordance with Article 5 (see above) and sent for treatment […], Member States shall ensure that producers meet the minimum targets set out in Annex V (see below).
  2. The achievement of the targets shall be calculated, for each category, by dividing the weight of the WEEE that enters the recovery or recycling/preparing for re-use facility, after proper treatment [29] […] with regard to recovery or recycling, by the weight of all separately collected WEEE for each category, expressed as a percentage.

- **ANNEX III and IV, Categories of WEEE**

  Refrigerators and Freezers fall in Category 1: Temperature exchange equipment

- **Annex V Minimum recovery targets**

  From 15 August 2018, minimum targets applicable to refrigerators and freezers (category 1) [30]:

  — 85 % shall be recovered [31], and

‘collection’ means the gathering of waste, including the preliminary sorting and preliminary storage of waste for the purposes of transport to a waste treatment facility

‘separate collection’ means the collection where a waste stream is kept separately by type and nature so as to facilitate a specific treatment;

[29] Proper treatment, other than preparing for re-use, and recovery or recycling operations shall, as a minimum, include the removal of all fluids and a selective treatment in accordance with Annex VII.

[30] The 85% and 80% are shares from the separately collected WEEE (see article 7), not from all the WEEE produced.

[31] Definitions from Directive 2008/98/EC, article 3:

— 80 % shall be prepared for re-use and recycled [32];

- **ANNEX VII, Selective treatment for materials and components of WEEE**

  1. As a minimum the following substances, mixtures and components have to be removed from any separately collected WEEE:

     — polychlorinated biphenyls (PCB) containing capacitors […] [33],

     — mercury containing components, such as switches or backlighting lamps,

     — batteries,

     — printed circuit boards of mobile phones generally, and of other devices if the surface of the printed circuit board is greater than 10 square centimetres,

     — toner cartridges, liquid and paste, as well as colour toner,

     — plastic containing brominated flame retardants,

     — asbestos waste and components which contain asbestos,

     — cathode ray tubes,

     — chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) or hydrofluorocarbons (HFC), hydrocarbons (HC),

     — gas discharge lamps,

     — liquid crystal displays (together with their casing where appropriate) of a surface greater than 100 square centimetres and all those back-lighted with gas discharge lamps,

     — external electric cables,

     — components containing refractory ceramic fibres […],

     — components containing radioactive substances […],

     — electrolyte capacitors containing substances of concern (height > 25 mm, diameter > 25 mm or proportionately similar volume).

'recovery' means any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy. Annex II sets out a non-exhaustive list of recovery operations.

'material recovery' means any recovery operation, other than energy recovery and the reprocessing into materials that are to be used as fuels or other means to generate energy. It includes, inter alia, preparing for re-use, recycling and backfilling.

[32] Definitions from Directive 2008/98/EC, article 3:

'preparing for re-use' means checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing.

'recycling' means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.

'backfilling' means any recovery operation where suitable non-hazardous waste is used for purposes of reclamation in excavated areas or for engineering purposes in landscaping. Waste used for backfilling must substitute non-waste materials, be suitable for the aforementioned purposes, and be limited to the amount strictly necessary to achieve those purposes.

[33] Single phase induction motors used in fridges need capacitors for starting (and some use them also for running). The capacitors are usually electrolytic, and the older ones can contain polychlorinated biphenyls (PCBs). PCBs were banned in Europe in 1987, so by now, very few fridges should arrive to recyclers with PCB containing capacitors.

Electrolytic capacitors can contain CRMs depending on the type: aluminium, tantalum, niobium, manganese oxide or titanium oxide, silver, graphite, paper, rubber, electrolyte e.g. ethylene glycol (EG) or γ-butyrolactone (GBL). For motor starting, aluminium electrolytic capacitors with non-solid electrolyte seem to be most frequently used.

These substances, mixtures and components shall be disposed of or recovered in compliance with Directive 2008/98/EC.

2. The following components of WEEE that is separately collected have to be treated as indicated:

— cathode ray tubes: the fluorescent coating has to be removed,

— equipment containing gases that are ozone depleting or have a global warming potential (GWP) above 15, such as those contained in foams and refrigeration circuits: the gases must be properly extracted and properly treated. Ozone-depleting gases must be treated in accordance with Regulation (EC) No 1005/2009,

— gas discharge lamps: the mercury shall be removed.

3. Taking into account environmental considerations and the desirability of preparation for re-use and recycling, points 1 and 2 shall be applied in such a way that environmentally-sound preparation for re-use and recycling of components or whole appliances is not hindered.

Main take-aways

The minimum collection rate (for all WEEE together) is 65 % of the average weight of EEE placed on the market in the three preceding years (in the Member State).

For category 1 WEEE (including refrigerators and freezers), 85% shall be recovered, and 80% prepared for re-use and recycled. The percentage is calculated, dividing the weight of the WEEE that enters the recovery or recycling/preparing for re-use facility, after proper treatment, by the weight of all separately collected WEEE for the category.

Components to be removed from separately collected WEEE potentially relevant for fridges include:

- capacitors (especially when containing PCBs)
- mercury containing switches or lamps
- batteries
- printed circuit boards > 10 cm2
- plastic containing brominated flame retardants
- chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) or hydrofluorocarbons (HFC), hydrocarbons (HC)
- liquid crystal displays (with casing where appropriate) of a surface > 100 cm2
- external electric cables
- equipment containing gases that are ozone depleting or have a global warming potential (GWP) above 15, such as those contained in foams and refrigeration circuits

1.5.7 Food Contact Materials Regulations

1.5.7.1 Introduction

Materials used inside refrigerators and freezers potentially come into contact with food and thus might contaminate it due to the migration of constituents from the fridge construction materials to the food, especially when using recycled materials. This may affect the health of people and consequently the EU has (stringent) regulations on food contact materials (FCMs):

- Regulation (EC) No 1935/2004 on materials and articles intended to come into contact with food [34] [35].
- Regulation (EC) No 2023/2006 on good manufacturing practices (GMP) for materials and articles intended to come into contact with food [36] [37].
- Regulation (EU) No 10/2011 on plastic materials and articles intended to come into contact with food [38] [39].
- Regulation (EU) 2022/1616 on recycled plastic materials and articles intended to come into contact with food [40] [41].

These regulations are described in the following subsections.

As an introduction to the topic [42]:

Plastic food contact materials may be used only subject to Regulation (EU) No 10/2011. This Regulation is to ensure that substances present in newly manufactured plastic cannot be transferred to food in amounts that can harm human health. Broadly that regulation sets out two groups of substances:

- Starting substances and additives, which are to be authorised before they can be used, and which must be used subject to restrictions, such as a specific migration limit.
- Non-intentionally added substances (NIAS), which include impurities present in authorised substances, as well as reaction and degeneration products that are formed during production of the plastic. These substances do not require authorisation, but they must be risk assessed according to internationally accepted standards.

The risk assessment either during authorisation or by the producers needs to ensure that the resulting new plastic material is safe.

However, when plastics are recycled, they can contain microbiological and chemical contaminants. Microbiological contamination is usually not a problem due to the high

[34] Regulation (EC) No 1935/2004 of the European Parliament and of the Council of 27 October 2004 on materials and articles intended to come into contact with food and repealing Directives 80/590/EEC and 89/109/EEC (OJ L 338, 13.11.2004, pp. 4–17): https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02004R1935-20090807
as amended by Regulation (EC) No. 596/2009

[35] Summary of Regulation 1935/2004:
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM:l21082a&frontOfficeSuffix=%2F

[36] COMMISSION REGULATION (EC) No 2023/2006 of 22 December 2006 on good manufacturing practice for materials and articles intended to come into contact with food (OJ L 384, 29.12.2006, p. 75), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02006R2023-20080417 , as amended by Commission Regulation (EC) No 282/2008

[37] Summary of Regulation 2023/2006:
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM:l12076&frontOfficeSuffix=%2F

[38] COMMISSION REGULATION (EU) No 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food (OJ L 12, 15.1.2011, p.1): https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02011R0010-20230831 , consolidated text with amendments up to Commission Regulation (EU) 2023/1627 of 10 August 2023.

[39] Summary of Regulation 10/2011: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM:sa0028

[40] COMMISSION REGULATION (EU) 2022/1616 of 15 September 2022 on recycled plastic materials and articles intended to come into contact with foods, and repealing Regulation (EC) No 282/2008 (OJ L 243 20.9.2022, p. 3):
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02022R1616-20220920 consolidated text with corrigendum

[41] Summary of Regulation 2022/1616:
https://eur-lex.europa.eu/EN/legal-content/summary/recycled-plastic-packaging-in-contact-with-food.html:

[42] The text has been taken from:
https://food.ec.europa.eu/food-safety/chemical-safety/food-contact-materials/plastic-recycling_en

temperatures used during recycling of plastics, but chemical contaminants may occur from several sources. Such sources may include:

- The original production of the plastic: for instance, the amount and the identity of NIAS will typically not be known for collected plastic, and may have changed, for instance due to further degradation.
- The use of the plastic: the plastic should in most cases have been used in contact with food and substances from the food may have contaminated the plastic; however, it is usually unavoidable to collect plastics that were used in contact with other substances, such as detergents, or in rare cases more hazardous substances such as pesticides.
- Potential misuse of the plastics: users may have used food packaging to store other substances in it. Examples include paint and paint thinner, fuels, detergents, and other household products that require temporary storing.
- Cross contamination in waste collection: depending on the way the plastic is collected substances originating from other waste may contaminate the collected plastic, for instance if large amounts of waste not suitable for recycling are present in the collected material.

Contaminants differ in one important way from impurities present in substances used for the manufacturing of new plastics. It is not possible to know the identity of all possible contaminants and they are typically present in a random amount in the collected plastic. Therefore, it is not possible to perform a similar assessment as is done for NIAS under Regulation (EU) 10/2011.

The safety of recycled plastic is therefore ensured in a different manner. The European Food Safety Authority ('EFSA') has established a level at which nearly all chemicals are not expected to affect human health if present in the food. On this basis it is possible to calculate a maximum safe level at which chemicals that have not been risk assessed could be tolerated in plastic material without doing harm. They also characterised the maximum level at which chemicals can be present in collected and pre-processed plastic that has not been decontaminated. During recycling the plastic must thus be decontaminated with an operation capable of reducing that contaminant level in the input to the maximum tolerable safe level. EFSA refers to this capability as the decontamination efficiency of the recycling process, its full approach is published online.

The nature of contaminants has another problem. The composition of recycled plastic cannot be easily subjected to official controls. Conversely, the composition of new plastics can be enforced for instance against specific migration limits (SMLs) in a laboratory operated by the enforcing authorities. However, if it is not known what substances to look for, and there are no applicable limits, as is the case for contaminants, this approach is not possible. Therefore, controls focus on the production of the recycled plastic. The production must apply good manufacturing practices that are to ensure the correct input material, the correct equipment and the correct operating condition are applied during production. Official controls thus focus at auditing the production installations of recycled plastics.

1.5.7.2 Regulation (EC) No 1935/2004 (Framework Regulation)

Regulation (EC) No 1935/2004 lays down common rules for the placing on the market of food contact materials (FCMs), including food packaging, kitchenware, tableware and food-processing equipment, that are intended or likely to come into contact with food, or transfer their constituents (substances they may contain) into food [43].

Key points:

- FCMs must be manufactured in compliance with good manufacturing practice (GMP) so that, under normal or foreseeable conditions of use, they do not transfer their constituents to food in quantities that could:
  - endanger human health;
  - bring about an unacceptable change in the composition of the food; or
  - bring about a deterioration in the flavour or texture of the food.
- The legislation includes 17 groups of materials and articles for which specific measures may be adopted.
- These specific measures may include a list of authorised substances permitted to be used at EU level in the manufacture of FCMs and restrictions, such as specific limits on migration (transfer of constituents).
- The regulation also sets out the process for an application for the use of a new substance where such a list exists, such as for plastic FCMs. A dossier must be submitted to the relevant national authority, which then forwards it to the European Food Safety Authority.
- FCMs not already in contact with food when sold to consumers, such as kitchenware and tableware, must be identified as 'for food contact' or accompanied by the wine and fork symbol set out in Annex II to the regulation, if the intended use of the article as an FCM is not clear. Other information to ensure the safe use of the FCM article must also be provided where relevant.
- Traceability measures must be in place to make it possible to recall any defective products or provide the public with specific information.
- The rules do not apply to:
  - antique materials and articles;
  - coatings covering, for example cheese rinds, prepared meat products or fruit, which form part of the food or may be eaten with it.

The Regulation has applied since 3 December 2004, except for the traceability measures, which have applied from 27 October 2006.

Regulation (EC) No 1935/2004 has the character of a framework regulation.

Article 3 requires the application of good manufacturing practices, which are further detailed in Regulation 2023/2006 (see section 1.5.7.3).

Article 5 indicates how more specific measures for groups of materials and articles listed in Annex 1 can be developed [44] (see sections 1.5.7.4 and 1.5.7.5).

[43] A large part of the text in this paragraph comes from the summary published by the EU, see footnote 35

[44] Annex 1 lists: 1. Active and intelligent materials and articles, 2. Adhesives, 3. Ceramics, 4. Cork, 5. Rubbers, 6. Glass, 7. Ion-exchange resins, 8. Metals and alloys, 9. Paper and board, 10. Plastics, 11. Printing inks, 12. Regenerated cellulose, 13. Silicones, 14. Textiles, 15. Varnishes and coatings, 16. Waxes, 17. Wood

1.5.7.3 Regulation (EC) No 2023/2006 (Good Manufacturing Practice)

Regulation (EC) No 2023/2006 lays down the rules on good manufacturing practice (GMP [45]) for the groups of materials and articles intended to come into contact with food listed in Annex I to Regulation (EC) No 1935/2004 and combinations of those materials and articles or recycled materials and articles used in those materials and articles.

Key points [46]:

- The legislation applies to all sectors and all stages of manufacture, processing and distribution of materials and articles.
- Businesses must:
  - conform with good manufacturing practice;
  - establish, implement and apply an effective and documented quality assurance system [47];
  - establish and maintain an effective quality control system;
  - establish and maintain appropriate records, either in paper or electronic form, on specifications, formulae and processing on the safety of the individual product and the various manufacturing operations.
- Good manufacturing practice covers objects such as containers, packaging, paper, cardboard, ink and adhesives which could come into contact with food.
- Quality assurance systems take account of:
  - the staff's knowledge and skills and the organisation of the premises and equipment;
  - the size of the business to prevent them being an excessive burden.
- Quality control systems include:
  - monitoring the implementation of good manufacturing practice; and
  - identifying and correcting any measures that fall short of the required standards.
- An addition and amendment (Regulation (EC) No 282/2008) sets out a specific quality assurance system for recycled plastic materials and articles that come into contact with food [48].

The Regulation applied since 1 August 2008.

Regulation (EC) No 2023/2006 is a further specification of article 3 of Regulation (EC) No 1935/2004. PlasticsEurope issued a guide [49] to support individual companies in the supply chain to establish their company specific manufacturing processes and procedures according to good manufacturing practice and to comply with Regulation (EU) No 10/2011 (next section).

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[45] Good manufacturing practice: those aspects of quality assurance that ensure materials and articles conform to quality standards, do not endanger human health or cause an unacceptable change in the composition of the food.

[46] A large part of the text in this paragraph comes from the summary published by the EU, see footnote 37

[47] Quality assurance system: organised and documented arrangements that ensure materials and articles meet the quality required.

[48] Now repealed by Regulation (EU) 2022/1616, see section 1.5.7.5.

[49] GUIDELINES FOR GOOD MANUFACTURING PRACTICE FOR PLASTIC MATERIALS AND ARTICLES INTENDED FOR FOOD CONTACT APPLICATIONS, PlasticsEurope, June 2011

1.5.7.4 Regulation (EU) No 10/2011 (FCM Plastics Regulation)

Regulation (EU) No 10/2011 sets out the requirements for the manufacture and marketing of plastic materials and articles intended to come into contact with food. The Regulation is a specific measure within the meaning of Article 5 of Regulation (EC) No 1935/2004 and supplements the general rules laid down in that regulation.

Plastic materials and articles that come into contact with food may transfer toxic substances to them and may be a risk to human health. The regulation introduces migration limits [50] for substances used in such materials and articles and lays down conditions for their use to ensure food safety.

The plastic materials and articles and parts thereof may be composed:

- exclusively of plastics;
- of several layers of plastics; or
- of plastics combined with other materials [51].
- the regulation does not apply to ion exchange resins, rubber or silicones.

Key points [52]:

- The regulation lists the substances that may be intentionally used in the manufacture of plastic materials and articles. The list includes:
  - monomers;
  - additives (excluding colorants);
  - polymer production aids (excluding solvents); and
  - macromolecules obtained from microbial fermentation.
- New substances are added to the list if the European Food Safety Authority issues a favourable opinion following an application and approval procedure.
- To be placed on the EU market, the plastic materials and articles in question must comply with:
  - the requirements for use, labelling and traceability set out in Regulation (EC) No 1935/2004;
  - the good manufacturing practice defined in Regulation (EC) No 2023/2006;
  - requirements regarding composition and the declaration on compliance (see descriptions for Chapters II, III and IV below).
- The Regulation's annexes set out the conditions of use for authorised substances and migration limits. All plastic materials and articles must comply with specific migration limits and overall migration limits.
- The composition of each plastic layer of a material or article must comply with the Regulation. However, a layer which is not in direct contact with food may:
  - not comply with the restrictions and specifications of the Regulation (except for vinyl chloride monomer);

[50] Migration limits: the maximum amount of substances that materials and articles may transfer to food. They are expressed in milligrams of substance per kilogram of food (mg/kg).

[51] Including when in layers, or printed, or used as a coating, or covered by a coating.

[52] A large part of the text in this paragraph comes from the summary published by the EU, see footnote 39

– be manufactured with substances not included on the list of authorised substances (these substances, however, must not be mutagenic [53], carcinogenic [54] or toxic to reproduction, or be in nanoform [55]).

- The manufacturer must draw up a written declaration (Annex IV). This must identify the materials, articles and products from the intermediate stages of their manufacture, as well as the substances themselves. It must be renewed when substantial changes in the composition or production occur.

The Regulation applied since 4 February 2011 and has been amended 17 times between April 2011 and August 2023. A series of EU guidance documents for the regulation was published:

- General guidance [56],
- Guidance on migration testing [57],
- Guidance on migration modelling [58],
- Guidance on information in the supply chain [59]

PlasticsEurope also issued guides on the topic [49].

Chapter II of Regulation 10/2011 gives compositional requirements. Annex I lists 1083 substances (last update August 2023) that may be intentionally used in the manufacture of plastic layers in plastic materials and articles. Chapter II further specifies that substances not on the list may be used under certain conditions. The list is frequently updated and includes:

– monomers or other starting substances
– additives excluding colorants
– polymer production aids excluding solvents
– macromolecules obtained from microbial fermentation

Plastic materials and articles shall not transfer their constituents to foods in quantities exceeding the specific migration limits listed in Annex I for each substance (SML, expressed in mg of substance per kg of food). If Annex I does not provide a value, 0.01 mg/kg applies.

In addition to the SMLs, there is an overall migration limit (for migration of all constituents together to food simulants), of 10 milligrams of total constituents per dm2 of food contact

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[53] Mutagenic: a physical or chemical agent that changes the genetic material of an organism and thus increases the frequency of mutations above the natural background level.

[54] Carcinogenic: an agent directly involved in causing cancer.

[55] Nanoform: natural, incidental or manufactured substance containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nanometre-100 nanometre (i.e. one billionth of a metre).

[56] EURL-FCM - Technical guidelines, Food contact materials technical guidance documents, https://joint-research-centre.ec.europa.eu/eurl-food-contact-materials/eurl-fcm-technical-guidelines_en

[57] Training workshop "Safety of food contact materials: Technical Guidelines for Testing Migration under Regulation (EU) No 10/2011", JRC Science an Policy Reports 2015, JRC93653, EUR 27055 EN , ISBN 978-92-79-45030-3 (PDF), ISSN 1831-9424 (online), doi:10.2788/377927, Luxembourg: Publications Office of the European Union, 2015

[58] Brandsch R, Dequatre C, Mercea P, Milana M, Stoermer A, Trier X, Vitrac O, Schaefer A and Simoneau C. Practical guidelines on the application of migration modelling for the estimation of specific migration. EUR 27529. Luxembourg (Luxembourg): Publications Office of the European Union; 2015. JRC98028

[59] Union Guidance on Regulation (EU) No 10/2011 on plastic materials and articles intended to come into contact with food as regards information in the supply chain, version 1.1 of 12.01.2016, European Commission, Health and Consumers Directorate General, Brussels, 28.11.2013. https://food.ec.europa.eu/system/files/2016-10/cs_fcm_plastic-guidance_201110_reg_en.pdf

surface. This limit becomes 60 milligrams per kg of food simulant in the case of food for infants or young children.

In addition to the list in Annex I, Annex II lists mainly metals (including some rare earths) with their SML limit, the indications if salts from these elements are allowed or not, and with remarks on additional usage restrictions. Plastic materials and articles shall not release the substances of Annex II in quantities exceeding the specific migration limits expressed in mg/kg food or simulant [60].

Chapter III gives provisions for certain materials and articles. Of particular interest for the current study is article 13 on plastic multi-layer materials and articles. Summarized:

- the composition of each plastic layer has to comply with the regulation,
- however, if the layer is not in direct contact with food and is separated from the food by a functional barrier [61], the layer does not need to comply with migration limits [62] and may use substances not listed in Annex I, except e.g. mutagenic, carcinogenic, toxic to reproduction, and nanoform substances,
- the final plastic multi-layer material or article shall comply with the specific migration limits and the overall migration limit.

Article 14 on plastic layers in multi-layer multi-materials or articles has similar provisions.

Chapter IV gives requirements for the declaration of compliance and documentation. At the marketing stages other than at the retail stage, a written declaration in accordance with Regulation (EC) No 1935/2004 shall be available for plastic materials and articles, products from intermediate stages of their manufacturing as well as for the substances intended for the manufacturing of those materials and articles.

Appropriate documentation to demonstrate that the materials comply with the requirements shall be made available. That documentation shall contain the conditions and results of testing, calculations, including modelling, other analysis, and evidence on the safety or reasoning demonstrating compliance. Rules for experimental demonstration of compliance are set out in Chapter V.

The declaration of conformity inter alia must supply:

- the identity of the materials, the articles, products from intermediate stages of manufacture or the substances intended for the manufacturing of those materials and articles;
- adequate information relative to the substances used or products of degradation thereof for which restrictions and/or specifications are set out in Annex I and II to the Regulation to allow the downstream business operators to ensure compliance with the Regulation.

  At intermediate stages, this information shall include the identification and amount of substances in the intermediate material,

  - that are subject to restrictions in Annex II, or

[60] The listed substances shall only be used in accordance with the compositional requirements set out in Chapter II. If Chapter II does not provide a basis for the authorised use of such a substance, that substance may only be present as an impurity subject to the restrictions specified.

[61] 'functional barrier' means a barrier consisting of one or more layers of any type of material which ensures that the final material or article complies with Article 3 of Regulation (EC) No 1935/2004 and with the provisions of this Regulation;

[62] Except for vinyl chloride monomer

  - for which genotoxicity has not been ruled out, and which originate from an intentional use during a manufacturing stage of that intermediate material and which could be present in an amount that foreseeably gives rise to a migration from the final material exceeding 0,00015 mg/kg food or food simulant.

- adequate information relative to the substances which are subject to a restriction in food, obtained by experimental data or theoretical calculation about the level of their specific migration and, where appropriate, purity criteria in accordance with Directives 2008/60/EC, 95/45/EC and 2008/84/EC to enable the user of these materials or articles to comply with the relevant EU provisions or, in their absence, with national provisions applicable to food.

1.5.7.5 Regulation (EU) 2022/1616 (Recycled Plastics Regulation)

Regulation (EU) 2022/1616 is a specific measure within the meaning of Article 5 of Regulation (EC) No 1935/2004. It lays down the rules for [63]:

- the sale of plastic materials and articles manufactured with a suitable recycling technology from waste [64] plastic that are intended to be or can be reasonably expected to come into contact with food,
- the development and operation of recycling technologies, processes and installations to produce that recycled plastic,
- the use of plastic materials and articles in contact with food which have been, or are intended to be, recycled.

Key points:

- Suitable recycling technologies:
  - must ensure recycled plastic materials:
    - are microbiologically safe,
    - do not release their constituents into food in amounts that could endanger human health or change, to unacceptable levels, the composition of the food or its colour, aroma, taste and texture (organoleptic characteristics),
    - have labelling, advertising and presentation that does not mislead the public;
  - are:
    - categorised according to factors such as type, collection and origin of the input material and the intended use of the recycled plastic,
    - listed in Annex I to the regulation and may also be individually authorised by the European Commission.
- To be placed on the market, recycled plastic materials and articles must:
  - be manufactured by one of the following:

[63] A large part of the text in this paragraph comes from the summary published by the EU, see footnote 41

[64] Waste. Any substance or object which the holder discards or intends/is required to discard.
Interpretation is that this includes both pre-consumer and post-consumer waste. In Annex I to the regulation, the recycling technology 1 for PET is only for post-consumer waste, containing maximum 5% of materials that were used in contact with non-food materials. Recycling technology 2 is for recycling from product loops which are in a closed and controlled chain. Collection from consumers is excluded. However, table 3 specifies that the closed loop may involve e.g. manufacturing, distribution and catering services, which participate in a recycling scheme.

    - a suitable technology listed in Annex I [65],
    - a novel technology (one awaiting authorisation as suitable) in accordance with the procedure set out in Chapter IV [66];
  - contain the necessary documentation, instructions and labelling.
- Waste management operators must ensure the collected plastic waste:
  - originates only from municipal waste or from specific food retail or other food businesses, collected with a certified collection system, subject to possible exceptions;
  - contains only plastic materials and articles meeting the requirements of Regulation (EU) No 10/2011 on plastics that come into contact with food;
  - is collected separately; or
  - is collected with a recycling scheme managed by a single entity in which the participants subject to the rules of that scheme ensure that the plastic is not contaminated.
- Rules for recycled plastic require food business operators:
  - to comply, when using them, with the instructions accompanying the products;
  - to provide relevant information to consumers coming into contact with food packed in such materials.
- Rules on the development and use of recycling technologies state that:
  - several operators may develop novel technologies independently or together, but must inform their national authority and the Commission and provide detailed information of their work, including scientific evidence and studies on which it is based;
  - recycling installations using novel technology must:
    - comply with certain administrative requirements and provide and update information summarising the complete process and main manufacturing stages, with supporting documentation,
    - monitor average contamination levels by sampling plastic input and output batches, publishing a detailed 6-monthly report on their website;
  - the Commission (when it considers sufficient data are available):
    - must request that the European Food Safety Authority (EFSA) assess a novel technology,
    - must decide, on the basis of that assessment, whether to approve it,
    - may decide, either on its own initiative or when asked by a European Union (EU) Member State, to apply further conditions on the use of a technology or deem it to be unsuitable.
- Procedure for the authorisation of an individual recycling process
  - Authorisation is only needed if the suitable technology which it uses so requires.

[65] Annex I contains only two recycling technologies, one for post-consumer PET, and one for closed-loop recycling from waste not collected from consumers.

[66] This is used by the consortium with Electrolux, for the production of fridge inner liners using recycled polystyrene, see section 4.2.1.

  - The developer of the decontamination process is required to submit an application, with suitable documentation, to the relevant national authority, which then informs EFSA.
  - EFSA is to assess the process and determine whether the process can apply the suitable recycling technology so that the plastic materials are safe, and issues a scientific opinion concerning the recycling process.
  - The Commission, taking account of that opinion, is to decide whether to grant or refuse the necessary authorisation.
  - EFSA is to provide scientific guidance describing the evaluation criteria it will use for each suitable recycling technology requiring authorisation of individual recycling processes.
  - Business operators to which an authorisation on their process is granted become authorisation holders. They are to comply with general obligations, including to provide recyclers with the necessary information, notify changes to the process and its ownership to the Commission and honour their civil and criminal liabilities.
  - The Commission can modify, suspend or revoke authorisations if certain criteria are met.
- The legislation establishes an EU register for novel technologies, recyclers, recycling processes, recycling schemes and decontamination installations. It contains details of [67]:
  - the decontamination installation and recycling facility where the recycled plastic was manufactured
  - the authorised recycling process used
  - the name of the recycling scheme and identity of the operator
  - the name of any novel technology used.
- Recyclers must:
  - comply with administrative requirements, such as informing the Commission and their national authority 30 days before starting production of recycled plastic
  - draw up a compliance monitoring summary sheet for each decontamination installation under their control, using the template contained in Annex II to the regulation, and have it agreed by the competent authority in their territory

[67] Commission Regulation (EU) 2022/1616 on recycled plastic materials and articles establishes through Article 24 a Union register of novel technologies, recyclers, recycling processes, recycling schemes, and decontamination installations, as well as a list of recycling facilities. The main purpose of this register is to provide information to the users of recycled plastic to allow them to verify compliance of plastic materials they have received, as well as for competent authorities to facilitate their work on official control.

The register is kept by the Commission and can be accessed using the Food and Feed Information Portal Database | FIP.

The register provides registration numbers of the following entities:
- RON, recycling operator number;
- RFN, recycling facility number;
- RIN, recycling installation number;
- (RAN), recycling authorisation number;
- (RSN), recycling scheme number;
- (NTN), novel technology number;

At present (December 2024) the register is limited to recycling installations, facilities and companies. It will soon be updated by adding authorised processes (authorisation process is on-going), recycling schemes, and novel technologies. Also, the functionality of the register will gradually be improved.

  - provide a declaration of compliance according to the description and template set out in Part A of Annex III.
- Official controls of recycling installations include:
  - audits of operators, assessment of good manufacturing practices and examination of controls and compliance monitoring the procedures in place
  - the power of national authorities to declare a batch of recycled plastic non-compliant for the following reasons:
    - it was placed on the market without appropriate documentation or labelling,
    - the recycler cannot prove it was produced in accordance with the regulation,
    - it was manufactured at a recycling installation that does not meet the regulation's requirements;
  - the power of national authorities to require that an operator remedy the deficiencies, and even to forbid the sale of the product.

The regulation does not apply to the use of waste to manufacture substances (monomers and other starting substances, additives excluding colourants, polymer production aids excluding solvents, and macromolecules from microbial fermentation) covered by Article 5 of Regulation (EU) No 10/2011 [68].

The regulation contains some transitional arrangements and repeals Regulation (EC) No 282/2008 [69].

Regulation (EU) 2022/1616 has applied since 10 October 2022.

Main take-aways

All materials used on the inside of refrigerators and freezers (inner liners, door liners, drawers, shelves, accessories) are subject to food contact material (FCM) regulations, which are detailed and severe, and require extensive documentation and testing.

The only recycled plastic that is currently allowed in direct contact with food is recycled PET produced with a registered process (but PET is hardly used in fridges). Until now, all other recycled plastics need a virgin plastic layer as functional barrier on top to meet the requirements of the FCM regulations (however, see section 4.2.2).

See also section 4.2.1 on the use of recycled HIPS for the inner liner.

[68] This seems to exclude chemical recycling of waste where the output of the recycling process are substances that still have to enter a polymerization process, in the same way as virgin monomers would be used.

[69] Regulation (EC) No 282/2008 amended Regulation (EC) No 2023/2006, and added requirements for recycled plastic materials, provisions for the authorisation of recycling processes for plastics, a community register for recycling processes, labelling, declarations of compliance, etc. It was a (now repealed) precursor for Regulation 2022/1616.

1.5.8 Packaging regulations

The current study does not regard packaging materials for refrigerators and freezers, but the recent packaging and packaging waste regulation (PPWR) [16] [70] addresses recycled content in plastics, also in food-contact applications, so it can be interesting as a reference.

PPWR article 7 specifies the minimum recycled content in plastic packaging:

1. By 1 January 2030 […], any plastic part of packaging placed on the market shall contain the following minimum percentage of recycled content recovered from post-consumer plastic waste, per packaging type and format […], calculated as an average per manufacturing plant and year:

(a) 30 % for contact-sensitive packaging made from polyethylene terephthalate (PET) as the major component, except single-use plastic beverage bottles

(b) 10 % for contact-sensitive [71] packaging made from plastic materials other than PET, except single-use plastic beverage bottles

(c) 30 % for single-use plastic beverage bottles

(d) 35 % for plastic packaging other than those referred to in points (a), (b) and (c) of this paragraph.

2. By 1 January 2040, […]:

(a) 50 % for contact-sensitive packaging made from PET as the major component, except single-use plastic beverage bottles

(b) 25 % for contact-sensitive packaging made from plastic materials other than PET, except single-use plastic beverage bottles

(c) 65 % for single-use plastic beverage bottles

(d) 65 % for plastic packaging other than those referred to in points (a), (b) and (c) of this paragraph.

For food-contact plastics other than PET, potentially of interest for all inner parts of refrigerators-freezers, the PPWR requires 10% recycled content in 2030 and 25% in 2040 [72]. For non-food-contact plastics other than PET, the limits are 35% in 2030 and 65% in 2040, so considerably higher. These limits refer to recycled content recovered from post-consumer plastic and are calculated as an average per manufacturing plant and per year. The limits do

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[70] REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC, Brussels, 4 December 2024, PE-CONS 73/24

[71] Contact-sensitive packaging refers to plastic packaging of products covered by Regulation (EC) No 1831/2003 of the European Parliament and of the Council of 22 September 2003 on additives for use in animal nutrition (OJ L 268, 18.10.2003, p. 29), Regulation(EC) No 1935/2004 of the European Parliament and of the Council of 27 October 2004 on materials and articles intended to come into contact with food (OJ L 338 13.11.2004, p. 4), Regulation (EC) No 767/2009 of the European Parliament and of the Council of 13 July 2009 on the placing on the market and use of feed, amending European Parliament and Council Regulation (EC) No 1831/2003 and repealing Council Directive 79/373/EEC, Commission Directive 80/511/EEC, Council Directives 82/471/EEC, 83/228/EEC, 93/74/EEC, 93/113/EC and 96/25/EC and Commission Decision 2004/217/EC (OJ L 229, 1.9.2009, p. 1), Regulation (EC) No 1223/2009 of the European Parliament and of the Council of 30 November 2009 on cosmetic products (OJ L 342, 22.12.2009, p. 59), Regulation (EU) 2017/745, Regulation (EU) 2017/746, Regulation (EU) 2019/4 of the European Parliament and of the Council of 11 December 2018 on the manufacture, placing on the market and use of medicated feed, amending Regulation (EC) No 183/2005 of the European Parliament and of the Council and repealing Council Directive 90/167/EEC (OJ L 4, 7.1.2019, p. 1), Regulation (EU) 2019/6, Directive 2001/83/EC and Directive 2008/68/EC.

[72] PPWR art.7.5(a) specifies that the limits do not apply to plastic packaging that is intended to come into contact with food where the quantity of recycled content poses a threat to human health and results in non-compliance of packaged products with Regulation (EC) No 1935/2004. This is not well understood because the relatively low limits (b) seem to be specific also for food-contact applications.

(b) any plastic part representing less than 5 % of the total weight of the whole packaging unit.

not apply to plastic parts representing less than 5 % of the total weight of the whole packaging unit (art.7.5(b)) [73].

PPWR art.7.3 further specifies that the recycled content shall be recovered from post-consumer plastic waste that has been collected in the Union and recycled in an installation located within the Union according to the Union rules or collected and recycled in third countries under equivalent rules [74].

Compliance with the requirements shall be demonstrated by manufacturers or importers in the technical information (art.7.6). However, many details are still to be defined:

- 31 December 2026: Commission shall adopt implementing acts establishing the methodology for the calculation and verification of the percentage of recycled content, as well as the format for the technical documentation (art.7.8).
- 31 December 2026: Commission shall adopt delegated acts to supplement the Regulation with sustainability criteria for plastic recycling technologies (art.7.9).
- 31 December 2026: Commission shall adopt delegated acts establishing the methodology for assessing, verifying and certifying, including through third-party audit, the equivalence of the rules applied in cases where the recycled content recovered from post-consumer plastic waste is recycled or collected in a third country (art.7.10).
- 1 January 2028: Commission shall assess the need for derogations from the minimum percentages of recycled content laid down in paragraph 1, points (b) and (d), or the revision of the list of exceptions for specific plastic packaging (art.7.12).
- Where the lack of availability or excessive prices of specific recycled plastics makes compliance with the minimum percentages of recycled content excessively difficult, the Commission shall be empowered to adopt a delegated act to amend those paragraphs by adjusting the minimum percentages accordingly (art.7.13).

As regards labelling and marking:

- The Commission commits to assess the feasibility of Union-wide labelling that facilitates the correct separation of packaging waste at source (recital (5)).
- Labelling of packaging in an easily understandable way to inform consumers about the recyclability of packaging and where packaging waste should be discarded to facilitate recycling (recital (7)).
- The labelling of recycled content in packaging should not be mandatory, as that information is not critical to ensure the proper end-of-life treatment of packaging. However, manufacturers will be required to meet recycled content targets and they might wish to display that information on their packaging to inform consumers of recycled content in the packaging. To ensure that such information is communicated

[73] According to the available Bills-of-Materials, PET is hardly being used in fridges.

[74] PPWR art.7.3: For the purposes of this Article, recycled content shall be recovered from post-consumer plastic waste that:

(a) has been collected within the Union pursuant to this Regulation or the national rules transposing Directives 2008/98/EC and (EU) 2019/904, as relevant, or that has been collected in a third country in accordance with standards for separate collection to promote high-quality recycling equivalent to those referred to in this Regulation and Directives 2008/98/EC and (EU) 2019/904, as relevant; and

(b) where applicable, has been recycled in an installation located within the Union to which Directive 2010/75/EU of the European Parliament and of the Council applies, or that has been recycled in an installation located in a third country to which rules concerning the prevention and reduction of emissions into air, water and land associated to the recycling operations apply, and those rules are equivalent to those concerning emissions limits and environmental performance levels established in accordance with Directive 2010/75/EU that are applicable to an installation located in the Union carrying out the same activity; that condition shall apply only in the case where those limits and levels would be applicable to an installation located in the Union and carrying out the same activity as an analogous installation located in the third country.

in a harmonised manner across the Union, a label to indicate the recycled content should be harmonised (recital (67)).

- The previous point applies similarly to labelling for biobased plastic content (recital (68))

For products that have a digital product passport (section 1.5.4), the recycled content information and its demonstration shall be provided in that DPP.

Main take-aways

The PPWR requires minimum 10% post-consumer recycled contents for food-contact plastics others than PET in 2030, increasing to 25% in 2040. For non-food-contact plastics this is respectively 35% and 65%.

The recycled contents shall be recovered from post-consumer plastic waste that has been collected in the Union and recycled in an installation located within the Union according to the Union rules, or collected and recycled in third countries under equivalent rules.

Compliance with the recycled content requirements shall be demonstrated by manufacturers or importers in the technical information, but many details on this are still to be defined.

2. MEErP Task 2, Markets

2.1. Market for refrigerating appliances

2.1.1 Data sources

The main market data sources used for (household) refrigerators and freezers (RF) are:

- The Ecodesign Impact Accounting (EIA): collects data for all products regulated by Ecodesign and Energy Labelling regulations. Annex A collects the EIA2024 data for RF appliances [75], for sales, stock, volumes, efficiencies, electricity consumption, GHG emissions, prices, costs, business revenues and jobs.

  EIA data are based on EU28 data from the 2019 Impact Assessment [5], the 2016 review study [4] and the underlying Excel file, converted to EU27 by applying Brexit factors (see the EIA annual report). The data until 2015-2018 [76] can be considered 'historical', while data for later years are projections made at the time of the last study.

  EIA data are not detailed per type of RF appliance: a single base case with average characteristics is used for all RF models.

[75] For RFs, the EIA2024 data are the same as the EIA2023 data, which are available on CIRCABC: ecodesign - Library

[76] The 2016 review study used data available in 2015. The 2019 impact assessment used these data but may have updated some of the data up to 2018.

- The European Product Registry for Energy Labelling (EPREL) [77] [3], in the category 'Household, hotel and wine refrigerators' contains all product data that must be supplied according to Energy Labelling regulation 2019/2016 [2]. Annex B collects the EPREL data for RF appliances.

  The study team elaborated data extracted from EPREL in December 2024, as supplied by the Commission in Excel files. The data provide insight in the subdivision of the currently marketed models over the various RF types (combis, refrigerators, freezers, wine storage, minibars), their energy classes, average unit electricity consumption, average cooled volumes, etc.

  EPREL is for models, not for sold quantities. Hence, all data derived from EPREL are model-averages, but they are assumed to be indicative for 2024 sales-averages.

- In principle, EIA data already reflect the 2019 impact assessment (IA) [78] [5] and the 2016 review study [79] [4], but the EIA reports only on average characteristics of all RF appliances together, while the original sources present some data subdivided in the RF categories introduced in section 1.2 (refrigerators, wine storage appliances, fridge-freezer combis, upright freezers, chest freezers).

- APPLiA [80] [6] (formerly CECED) is a Brussels-based trade association that provides a single, consensual voice for the home appliance industry in Europe. The annual statistics reports provide useful information for this study, on e.g. sales, stock, efficiency and energy savings, material content, end-of-life destinations, etc.

  The APPLiA information is often aggregated (e.g. for all WEEE, or all large household appliances together), but some data are specific for fridges and freezers.

  The APPLiA data are often for the entire EU, including e.g. the United Kingdom, Russia, Ukraine, Turkey, Norway, and several non-EU27 Balkan states [81].

2.1.2 Sales

The EIA reports total EU27 sales slightly below 17 million units in 2023. The trend is continuously increasing.

The EIA does not provide details per type of refrigerating appliance. Based on information in the 2016 review study [4], the 2019 IA [5] and the 2024 EPREL database, the EIA total sales have been subdivided in the six RF categories introduced in section 1.2.

In the 2024 EPREL database (Annex B) the distribution over the models is:

- 8.1% wine storage appliances [82]

[77] https://eprel.ec.europa.eu/screen/product/refrigeratingappliances2019

[78] SWD(2019) 341 final, Brussels 1.10.2019

[79] Preparatory/review study for Commission Regulation (EC) No. 643/2009, FINAL REPORT, 4 March 2016

[80] https://www.applia-europe.eu/

[81] In its 2025-04-04 answers, APPLiA has supplied 2015-2024 sales data for EU27+Norway, see later footnotes.

[82] In its 2025-04-04 answers APPLiA commented: APPLiA's database includes 3.2 % wine storage. The large difference with the EPREL database could be due to appliances having a wine storage compartment and one or more other compartments. These are not wine storage appliances but may have been entered in the EPREL database as such. In APPLiA's database, the number of products with a wine storage compartment and other compartments (mostly 4-star) is 4.0 %, which would give a total of 7.2 %.

- 6.9% minibars (total net volume < 60 litres) [83]
- 13.2% refrigerators (large majority fresh-food) [84] [85]
- 10.8% chest freezers (large majority 4-star) [86] [87]
- 7.5% upright freezers (large majority 4-star) [88] [89]
- 53.4% refrigerator-freezer combis (large majority fresh-food + 4-star freezer) [90].

This corresponds well with the 1999 and 2015 distributions reported in [4] and [5] (Table 5). If the EPREL model distributions are indicative for sales distributions, the sales share of wine storage appliances is increasing in recent years, while the share of freezers is decreasing [91].

For comparison, the APPLiA 2022-2023 statistics report [15] gives total 24.7 mln RF appliances sold in 2023 (3.8 mln freezers and 20.9 mln fridges). This is 45% higher than the 17 mln from the EIA, but EIA figures are for EU27, while APPLiA data are for the entire EU, including also United Kingdom, Albania, Bosnia, Serbia, Montenegro, Ukraine, Russia, Turkey, Norway [92].

APPLiA data confirm the decreasing sales share of freezers, from 20% in 2020 to 15% in 2023. For comparison: EPREL data give an 18.3% model share for freezers.

The sales of Figure 6 have been used in this study (values in Annex A, Table 47). They use the EIA 2024 total sales, and the shares per type of Table 5[93].

Table 5: Sales (million units) and sales shares per RF type in 1999 and 2015 (for EU28 from [4][5]) and 2024 (for EU27; shares from EPREL).

	1999		2015		2024	
COLD 0 minibars	0.7	4%	1.0	5%	1.2	6.9%
COLD 1 refrigerators	2.8	15%	2.6	13%	2.2	13.2%
COLD 2 wine storage	0.2	1%	0.3	2%	1.4	8.1%
COLD 7 combis	9.7	53%	11.6	59%	9.0	53.4%

[83] In its 2025-04-04 answers APPLiA commented: APPLiA's database reports 0.7 % as minibars. The APPLiA's database includes the info if a product is low noise, but no products are included as low noise. Therefore, the APPLIiA minibars percentage is not a reliable estimate. Moreover, low-noise products are not typically produced by most APPLiA's members.

[84] Not including wine storage appliances and minibars

[85] In its 2025-04-04 answers APPLiA commented: APPLiA's database has 13.4% fresh food only products. If products are included which have other compartment types but excluding products with a 4-star compartment > 30 litres, then this number increases to 21 %.

[86] Lid opening on top; External height lower than 1000 mm in EPREL

[87] In its 2025-04-04 answers APPLiA commented: APPLiA's database contains only 2.6% of chest freezers. This large difference with the EPREL analysis can partly be attributed to the assumption that all freezers below 1000 mm are chest freezers. A large number of products lower than 1000 mm are actually upright freezers (in APPLiA's database, this is 3.5%)

[88] Door opening on front; External height 1000 mm or higher in EPREL

[89] In its 2025-04-04 answers APPLiA commented: APPLiA's database contains 13.7 % of upright freezers.

[90] In its 2025-04-04 answers APPLiA commented: APPLiA's database contains 54.4% of combi appliances refrigerators-freezers (only counting freezer volumes above 30 litres). Furthermore, the APPLiA database contains 4.2 % of products not in any of the previous categories. E.g. combination appliances without a freezer.

[91] The 1999 and 2015 data did not separately consider minibars. The minibar shares for those years have been estimated, and subtracted from the original shares for refrigerators.

[92] On 2025-04-04, APPLiA has supplied sales data for EU27+Norway. The total in 2023 is 15.7 million units of which 2.3 mln freezers and 13.4 mln refrigerators (see Figure 7). This is close to the 17 mln of the EIA, but APPLiA data show decreasing sales since 2021, while studies underlying the EIA assumed a continuous increase. APPLiA data will be further considered in the follow-up study.

[93] Compared to the EIA 2024, sales totals before year 2000 have been reduced, to avoid that stocks per household are higher in early years than in 2024.

COLD 8 upright freezers	2.4	13%	1.4	7%	1.3	7.5%
COLD 9 chest freezers	2.5	14%	2.6	13%	1.8	10.8%
Total RF sales	**18.3**		**19.5**		**16.9**	
	EU28		EU28		EU27	

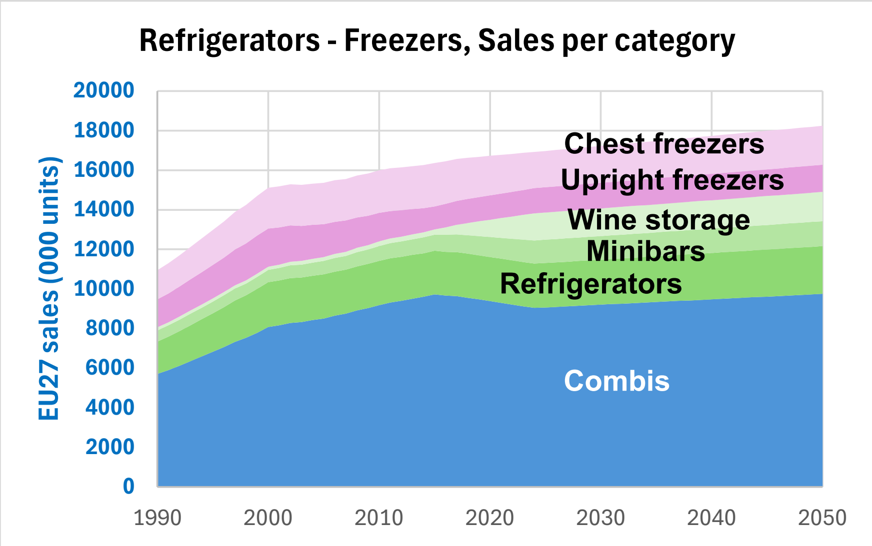

Figure 6: EU27 total sales (in thousands of units) of refrigerating appliances, per type (source: VHK elaboration of EIA2024 and EPREL data, Annex A)

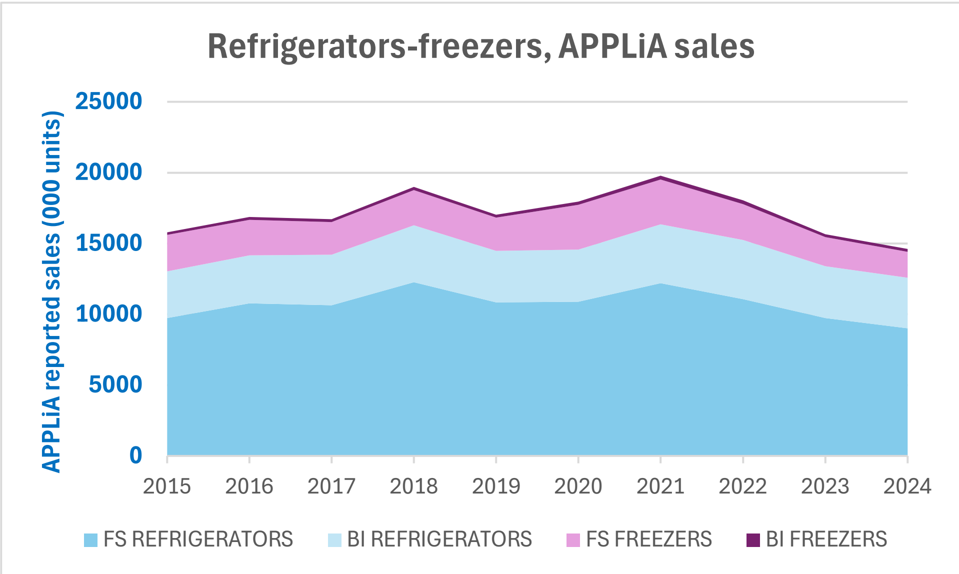

Figure 7: APPLiA reported sales in EU27+Norway (in thousands of units) of refrigerating appliances, per type (source: APPLiA answers of 2025-04-04) FS=free standing, BI = built-in

For details on the distribution of RF models over the energy label classes, the quantities of free-standing and built-in models, average refrigerated and frozen volumes, average annual electricity consumption and EEI, see the analysis of October 2024 EPREL data in Annex B.

2.1.3 Stock

The stock per RF type has been determined from the sales using a Weibull lifetime distribution with shape factor 2.28 [94], scale factor 17.7 [95] and delay factor 0.0 (the same for all RF types). Using these factors, the mean lifetime is 15.7 years and the median lifetime 15.0 years (the EIA and underlying studies used 16 years) [96] [97]. Details at the end of Annex A.

Figure 8 shows the Weibull lifetime distribution, i.e. the probability that a product has the x-axis lifetime (blue dashed curve, lefthand axis) and the share of products surviving until x-axis years after entry into service (solid orange curve, righthand axis).

Figure 9 shows the total EU27 stock of RF appliances, subdivided per type. In 2024, 262 million refrigerating appliances are in use in the EU27. Assuming that 92% of RF appliances [98] (227 mln) is used in households (199 mln in 2024), the average EU27 household had 1.1 RF appliances in 2024 [99].

For comparison, the APPLiA 2022-2023 statistics report [15] gives total 337 mln RF appliances in use in 2023 (82 mln freezers and 255 mln fridges). This is 29% higher than the 262 mln derived here for EU27, but APPLiA data are for the entire EU, including also United Kingdom, Albania, Bosnia, Serbia, Montenegro, Ukraine, Russia, Turkey, Norway.

The stocks of Figure 9 have been used in this study (values in Annex A, Table 48).

[94] Source: C.P. Balde, R. Kuehr, K. Blumenthal, S. Fondeur Gill, M. Kern, P. Micheli, E. Magpantay, J. Huisman (2015), E-waste statistics: Guidelines on classifications, reporting and indicators. United Nations University, IAS - SCYCLE, Bonn, Germany, 2015. Annex 2: Lifespan profiles of various EEE in the Netherlands, France and Belgium. Details on the Weibull distribution are in Annex III, and

Forti V., Baldé C.P., Kuehr R. (2018). E-waste Statistics: Guidelines on Classifications, Reporting and Indicators, second edition. United Nations University, ViE – SCYCLE, Bonn, Germany (newer version of the former).

UNU-key 0108 for Fridges (shape 2.2 in NL, BE, FR, 2.36 in IT) has been used.

[95] The scale factor has been determined in the EIA2023, such that the stock calculated with the Weibull lifetime distribution approximates the stock from the 2016 review study [4] and the 2019 impact assessment [5].

[96] Recycler CoolRec indicated an average lifetime of fridges of 16+ years, a bit higher for free-standing fridges and a bit lower for built-in. There is a trend towards more built-in. Average lifetime of freezers is 20 years in NL and 30 years in Belgium.

[97] In its 2025-04-04 answers, APPLiA commented: APPLiA believes it is a bit too high for fridge-freezers. A recent Quechoisir article refers to 12 years and 8 months. In addition, the European Environmental Agency (using Euroconsumers data) refers to 13 years and 5 months. We can do a further investigation if needed.
The technology is the same, and therefore, there is no reason to have a different lifetime. However, appliances in the basement are, in general, used less so their lifetime might be a bit longer.
https://www.quechoisir.org/
https://www.eea.europa.eu/en/circularity/sectoral-modules/product-lifespans/evolution-in-average-lifespans-of-household-appliances

[98] 75% for wine storage, 0% for minibars, 92% for all other types.

[99] In its 2025-04-04 answers, APPLiA commented that the 92% is probably too low. APPLiA has lower shares for minibars and wine storage appliances.

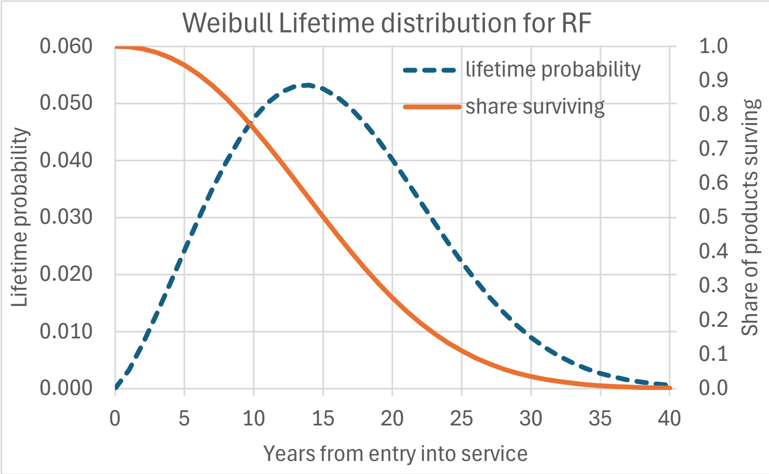

Figure 8: Probability that a product has the x-axis lifetime (blue dashed curve) and share of products surviving until x-axis years after entry into service. Weibull lifetime distribution with shape 2.28 and scale 17.7. Mean lifetime 15.7 years (source: VHK elaboration of EIA2024 data, Annex A)

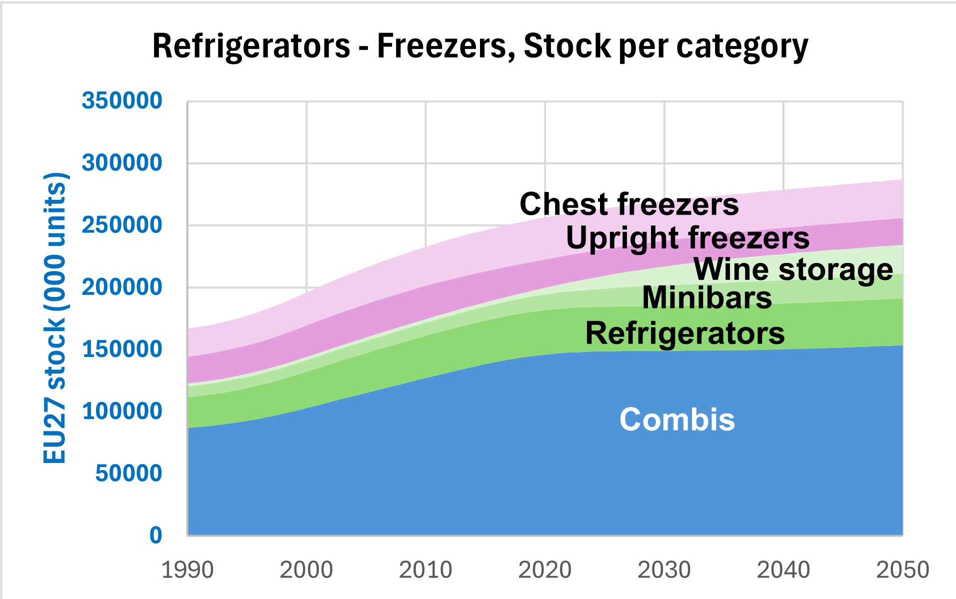

Figure 9: EU27 total stock (in thousands of units) of refrigerating appliances, per type (source: VHK elaboration of EIA2024 data, Annex A)

2.1.4 Prices and costs

The EIA provides an average purchase price for all fridge-freezers together, shown as the blue curve in Figure 10 (see also Table 45 in Annex A). In 2023, it is € 522 per unit (in 2020 euros, excl. VAT). The peak in the price around 2025 is due to a reduction in unit annual electricity consumption in kWh/a (an increase in efficiency), induced by the minimum efficiency requirements of CR 2019/2019 tier 2 of 1 March 2024. The EIA determines average product prices by interpolating between 3 price-efficiency anchor points (see above Figure 10) for the base case (BC), the least-life-cycle cost (LLCC), and the best-available technology (BAT) products. After a price increase due to measures taken, the EIA applies a 1% annual decrease to account for learning effects and economy of scale, which explains why after few years the price goes down again [100].

The graph also shows EIA's total acquisition costs and energy costs for the EU27 sales and stock. In 2023, the total user expense for RF appliances was 24.1 bn euros, of which € 10.4 bn acquisition costs and € 13.7 bn energy costs.

BC price €	BC kWh/a	LLCC price €	LLCC kWh/a	BAT price €	BAT kWh/a
508	213	624	119	881	81

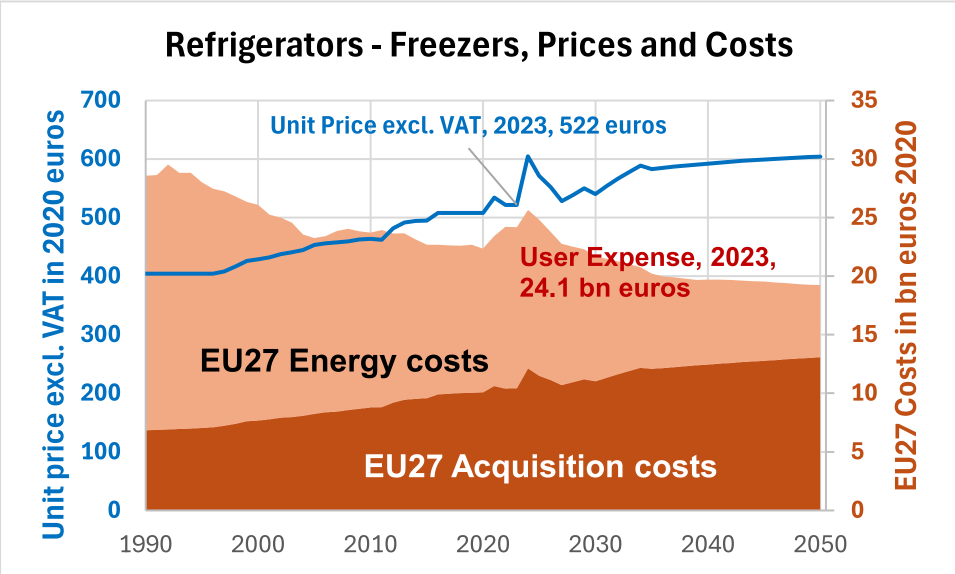

Figure 10: Price-efficiency anchor points (top), Unit prices (in 2020 euros excl. VAT, blue curve), EU27 total acquisition costs for products sold in year (in bn euros 2020 incl. VAT) and EU27 total energy costs for products in use (in stock) in the year (in bn euros, based on electricity rates from the 2022 RePowerEU 3a_v2 scenario) for RF Appliances in the EIA2024.

The 2016 review study [4] and the 2019 impact assessment [5] provide price-efficiency anchor points like those presented above for the EIA but distinguish between the RF types [101]. The original data were in 2010 euros and included VAT for the residential sector (20% VAT for 92% of the buyers). The study team removed VAT and converted the prices to 2020 euros.

Base case prices are declared to be valid for the year 2015. As the sales-weighted average LLCC efficiency of 149 kWh/a is close to that of the EIA around 2023 (144 kWh/a), the LLCC prices could also be indicative for 2023 (but they remain projections made around 2015).

Noteworthy are the high prices for wine storage appliances. If sales have recently increased as indicated earlier, prices might have come down by now [102].

[100] This needs a critical review in the follow-up study: Why does the price go down so fast? The increase seems to be 80 euros, so at 5-6 euros decrease per year, it would take at least 15 years to get back to the start price. Might be due to working with two different sets of efficiency-price pairs in the EIA?

[101] Minibars were not (separately) considered in those studies.

[102] This is a point to verify in the follow-up study

Table 6: Price-efficiency anchor points per RF type and sales-weighted average, for the 2015 base case (BC), the least-life-cycle-cost (LLCC) and the best-available-technology product, (source: [5] table 30, elaborated by the study team).

BC data for year 2015	BC	BC	LLCC	LLCC	BAT	BAT	sales
2020 euros, excl. VAT	price €	kWh/a	price €	kWh/a	price €	kWh/a	share (%)
COLD 1 refrigerators	475	119	566	79	886	55	18.6%
COLD 2 wine storage	1291	177	1371	131	2504	52	1.5%
COLD 7 combis	535	258	625	169	869	112	59.3%
COLD 8 upright freezers	422	232	522	162	662	127	7.2%
COLD 9 chest freezers	342	236	421	150	520	121	13.4%
unit sales weighted average	**501**	**226**	**591**	**149**	**835**	**103**	**100.0%**

2.1.5 End-of-Life (EoL)

2.1.5.1 Introduction

At end-of-life, refrigerators and freezers (RF) become part of the waste from electrical and electronic equipment (WEEE). From 2019, the WEEE directive (section 1.5.6) requires a minimum annual collection rate of 65 % of the average weight of EEE placed on the market in the three preceding years (in the Member State concerned), or alternatively 85 % of WEEE generated (on the territory of that Member State). To be noted that:

- The WEEE requirement generically refers to ‘collection’ and not specifically to ‘separate collection’. This is relevant because some statistics distinguish between ‘separate collection’ and ‘complementary collection’. In addition, at least for plastics, the recycling rate is larger for separately collected WEEE.
- There are two alternative references for the collection rate: ‘average EEE placed on the market in the three preceding years’ and ‘WEEE generated in a year’. In the available statistical data, both are being used (and easily confused).

During the transitional period until August 2018, refrigerators and freezers were part of the WEEE category ‘large household appliances’ [103]. After that period, RF products are part of WEEE category 1, ‘temperature exchange equipment’ [104]. In the statistical data, it is not always clear in which category RF products have been counted, raising some doubts.

The available statistical data on end-of-life processing refer to all WEEE together, to all home appliances together, or at best to the categories ‘large household appliances’ or ‘temperature exchange equipment’. There is little or no EoL processing information specific for refrigerators and freezers.

The information presented below is a study team elaboration of data from APPLiA statistical reports [105] and Eurostat data [106]. It is relevant e.g. for the determination of values for the factor

[103] WEEE directive, Annex I and II

[104] WEEE directive, Annex III and IV.

[105] The Home Appliance Industry in Europe 2022-2023, APPLiA statistical report, and https://www.statreport2021applia-europe.eu

[106] Eurostat online datasets env_waselee and env_waseleeos, accessed January 2025.

R2 (recycling output rate) of the EcoReportTool (see section 5.4), and for estimating the maximum recycled plastic content that can be realistically required for fridges (section 6.2).

2.1.5.2 Collection and recovery for all WEEE

Considering all types of WEEE together, APPLiA and Eurostat data for collected, recovered and recycled WEEE mass are the same (Figure 11, bottom curves). However, the mass of EEE placed on the market differs (Figure 11, top curves) and consequently, the collection rates also differ. Eurostat data show a collection rate of approximately 40% over the period 2009-2019 (Figure 12), decreasing in recent years due to the strong increase in the amount of EEE placed on the market (Figure 11). APPLiA data show an increase from around 30% in 2012 to 45% in 2020 (Figure 12), with differences between the two curves depending on the reference used (EEE placed on market or WEEE generated). The interpretation is that these data refer only to separately collected WEEE [107].

Recovery rates (around 90%) and recycling rates (80-85%) are the same for APPLiA and Eurostat (Figure 13).

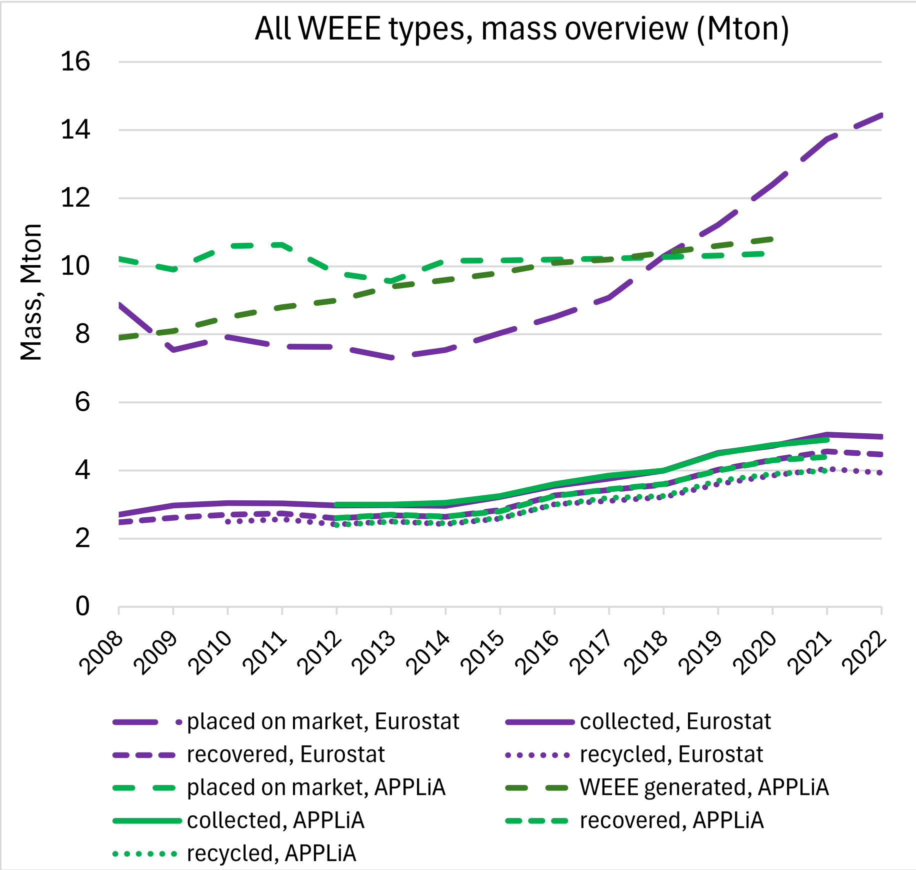

Figure 11: Mass of EEE (in Mton) placed on the market in the period 2008 – 2022, and mass of WEEE generated, collected, recovered and recycled (Source: VHK elaboration of APPLiA and Eurostat data).

[107] For comparison: the WEEE directive requires a minimum collection rate of 65% for all WEEE together (computed as collected WEEE vs. EEE placed on the market (3-years average)), or 85% if the generated WEEE is used as reference.

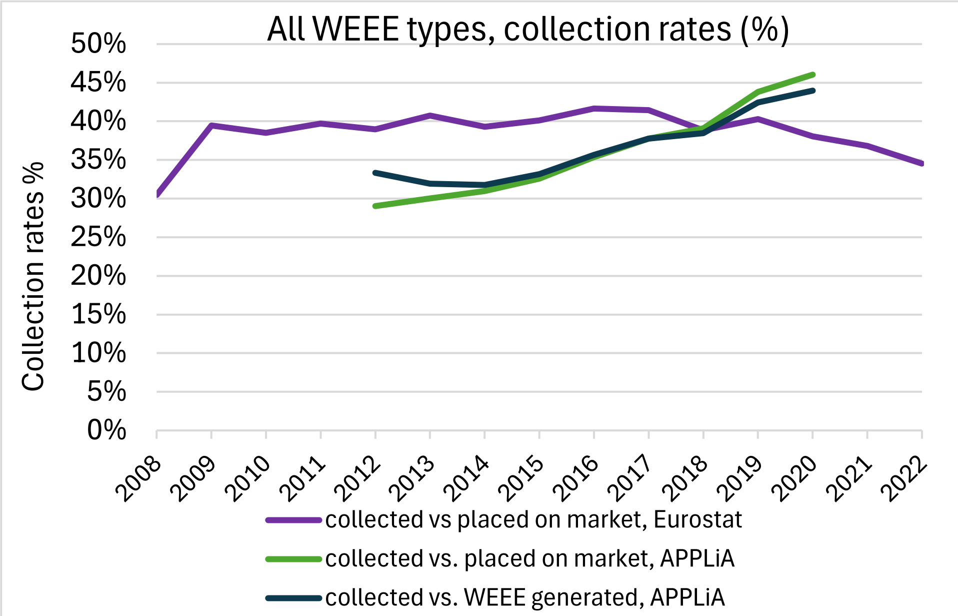

Figure 12: Collection rates for all WEEE together. The interpretation is that these data refer only to separately collected WEEE (Source: VHK elaboration of APPLiA and Eurostat data).

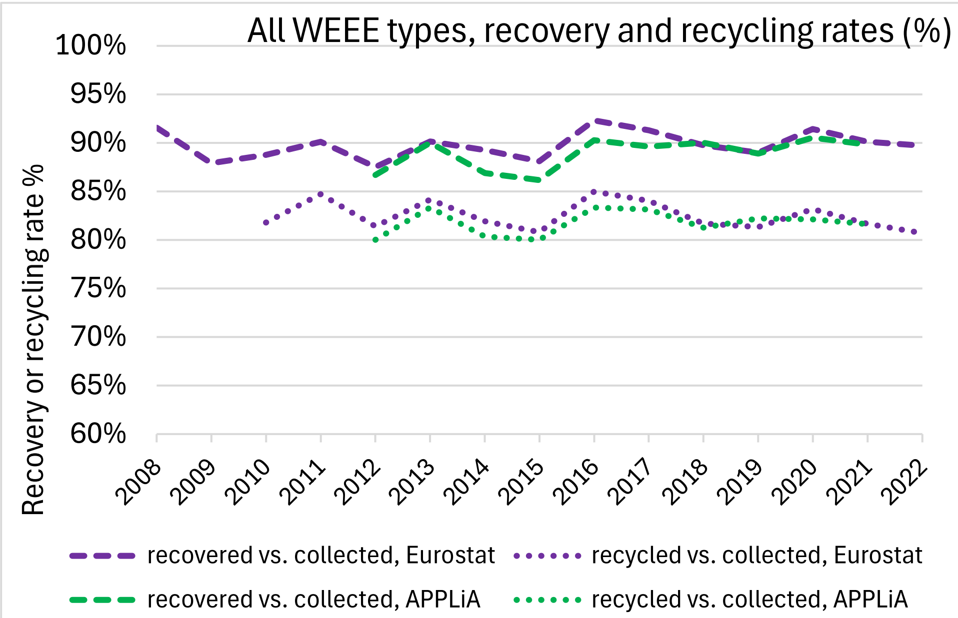

Figure 13: Recovery and recycling rates for all WEEE together (Source: VHK elaboration of APPLiA and Eurostat data).

2.1.5.3 Collection for all home appliances

The green stacked areas in Figure 14 indicate the separately collected mass of WEEE from home appliances (other WEEE is not included here) [108]. This is only WEEE collected through dedicated schemes, e.g. by organizations or companies working for the home appliance

[108] APPLiA data from https://www.statreport2021applia-europe.eu/slide/weee-flows-in-the-sector , with further elaboration by VHK.

manufacturers in the context of extended producer responsibility (EPR). The grey stacked areas indicate the complementary mass, collected outside the EPR schemes. For reference, the blue solid curve in the graph gives the WEEE generated from home appliances, and the red curve the mass of home appliances placed on the market.

Figure 15 shows the corresponding separate and total collection rates, compared to home appliances placed on the market (red curves [109]) and compared to WEEE generated from home appliances (blue curves [110]). The collection rates increased between 2012 and 2017, but they are more stable over the period 2017-2020. In 2020, of the 5.4 Mton WEEE generated from home appliances, 74% was collected, of which 54% separately. Using as reference the average mass of home appliances placed on the market (6.4 Mton), the collection rates are lower: 62% collected, of which 46% separately.

As shown in Table 7, collection rates are lower for small home appliances, which more often end up in the waste bin.

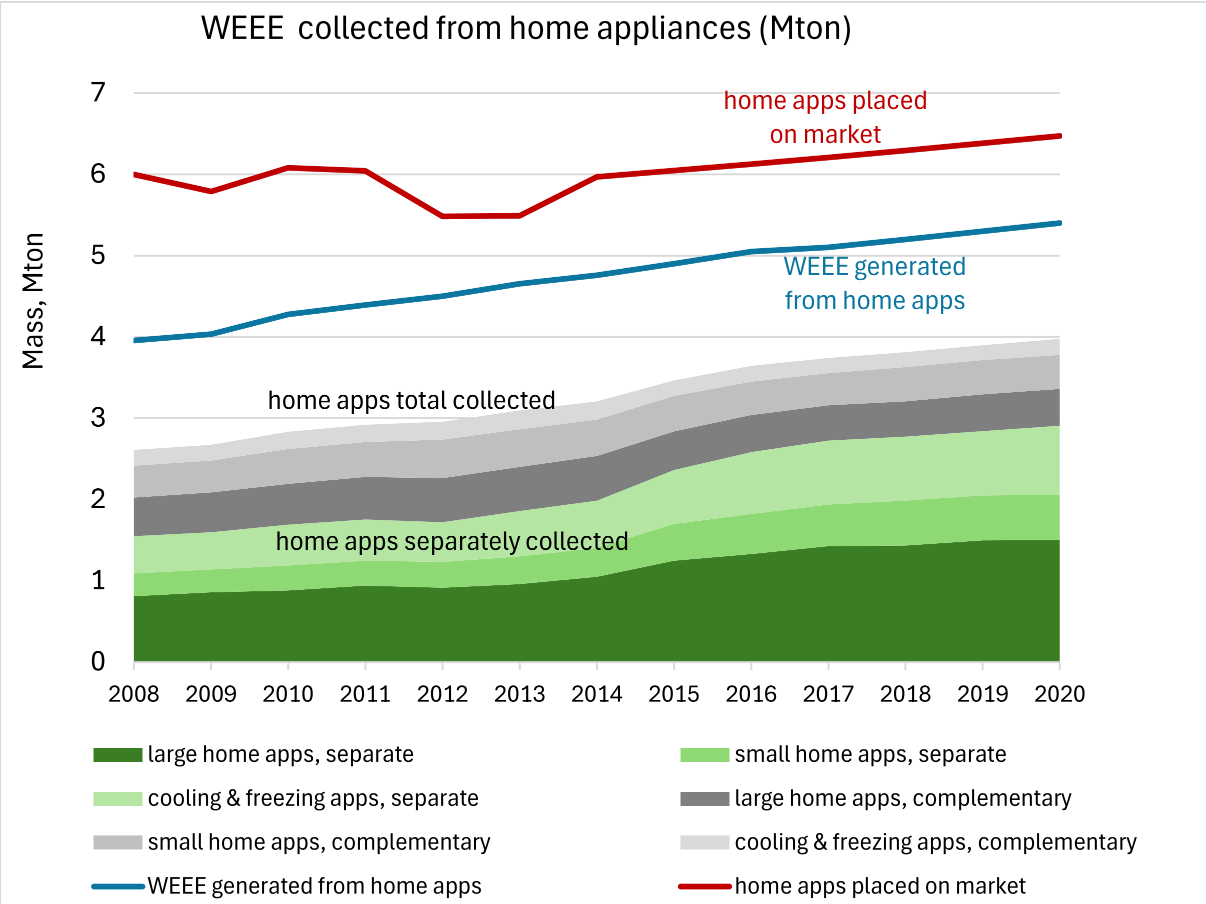

Figure 14: Mass of WEEE separately (green) or complementary (grey) collected from home appliances (in Mton) in the period 2008 – 2020, according to APPLiA data, subdivided in large home appliances, small home appliances, and cooling & freezing products. The mass of WEEE generated from home appliances (blue curve) and the mass of home appliances placed on the market (red curve) are indicated for reference. (Source: VHK elaboration of APPLiA data).

[109] Average of preceding three years

[110] In the year of the collection

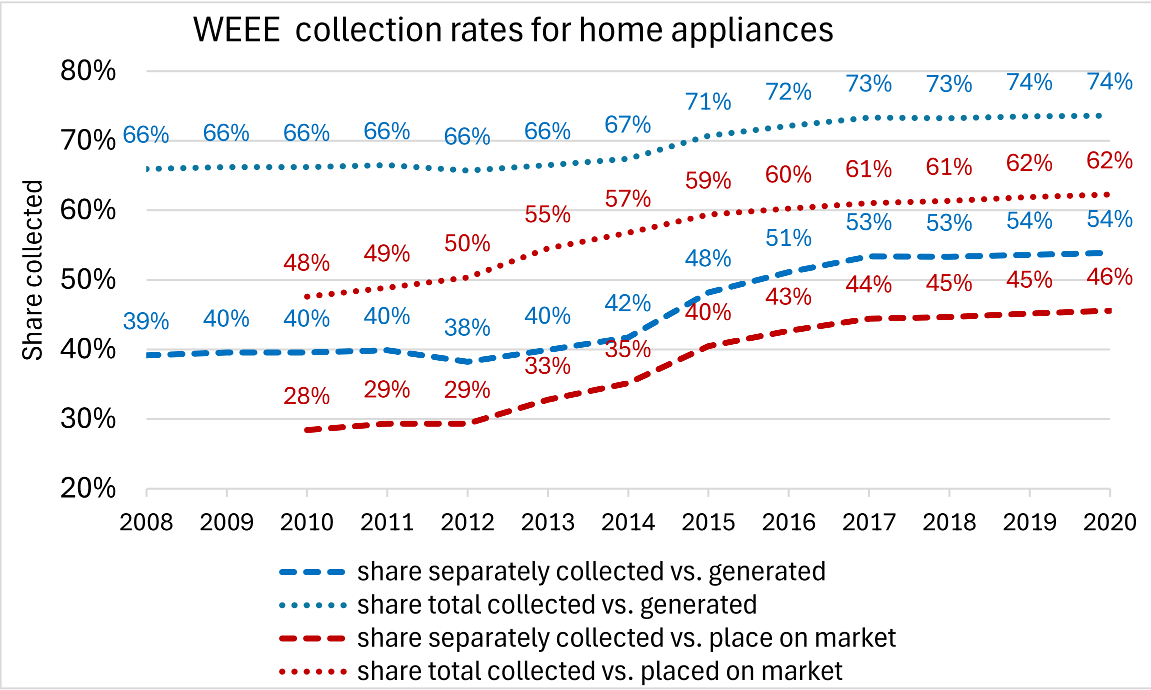

Figure 15: Separate and total collection rates for WEEE from home appliances, vs. WEEE generated (blue curves) and vs. home appliances placed on the market (red curves) (Source: VHK elaboration of APPLiA data).

Table 7: WEEE from home appliances in year 2020, generated, separate collection, complementary collection, waste bin and gap (unknown) (source: APPLiA, elaboration by VHK)

Year 2020	Large home appliances		Small home appliances		Cooling & freezing equipment		All home appliances	
	Mton	%	Mton		Mton	%	Mton	%
WEEE generated	**2.5**		**1.50**		**1.40**		**5.40**	
Collected, separately	1.50	60%	0.56	37%	0.85	61%	2.91	54%
Collected, complementary	0.45	18%	0.42	28%	0.20	14%	1.07	20%
Waste bin	0.05	2%	0.26	17%	0.01	1%	0.32	6%
Gap, unknown	0.50	20%	0.27	18%	0.34	24%	1.11	20%

2.1.5.4 Collection for large home appliances

Specifically for large home appliances, Figure 16 shows the EoL destinations, split in separate collection, complementary collection, waste bin and unknown (gap) [111]. In addition to the separate, dedicated, large-scale collection (e.g. EPR schemes), there is a complementary collection e.g. from home appliances ending up in metal scrap, or collected directly by recycling industries or by local small-scale collectors. The stacked green areas together (from APPLiA data) are the total collected WEEE mass from large home appliances. The top of the stack (including also the red and grey areas) is the WEEE generated from large home appliances according to APPLiA. For comparison, the purple dashed curve indicates the collected mass from Eurostat for the same category of products [112] and the purple solid curve Eurostat's large home appliances mass placed on the market.

[111] APPLiA data from https://www.statreport2021applia-europe.eu/slide/weee-flows-in-the-sector , with further elaboration by VHK.

[112] Eurostat online dataset env_waselee , with further elaboration by VHK.

Figure 17 shows the corresponding collection rates. Green curves come from APPLiA data, purple curves from Eurostat. According to APPLiA data, 78% of WEEE generated from large home appliances was collected in 2020, of which 60% through separate collection schemes (see also Table 7).

Eurostat collection rates (versus EEE placed on the market) are lower: 48% for large home appliances in 2018, and 42% for temperature exchange equipment over the period 2019-2022 [113]. Although Eurostat's collected mass is close to the sum of APPLiA's separately and complementary collected masses (Figure 16), the interpretation is that Eurostat's mass refers to separately collected only. The difference in collection rates seems to be mainly due to the reference used (high mass placed on the market for Eurostat compared to much lower mass of WEEE generated for APPLiA).

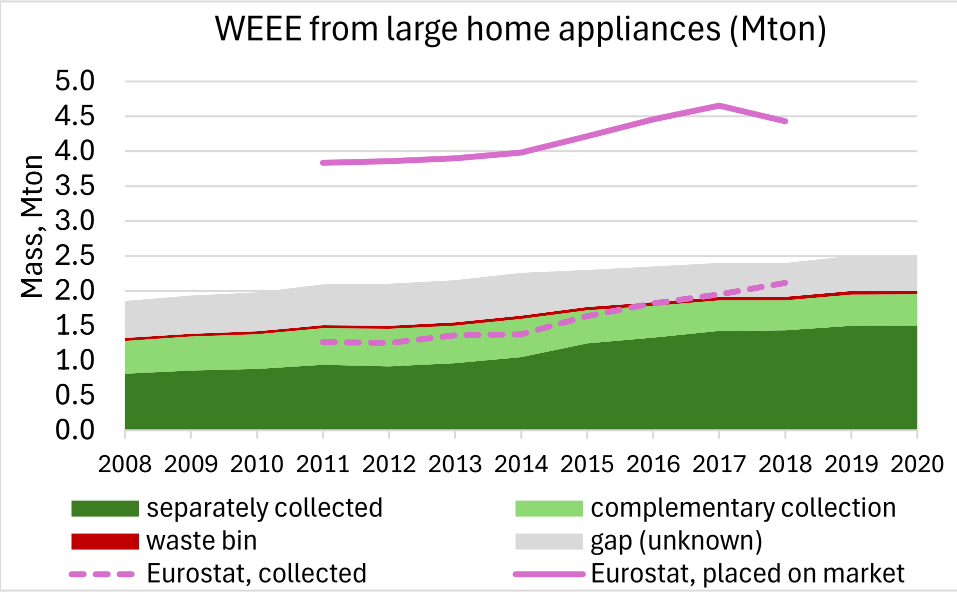

Figure 16: Destinations for the WEEE from large home appliances: separate collection, complementary collection, waste bin, and unknown (gap). The stacked areas are from APPLiA data. The dashed purple curve is the total collection from Eurostat, and the solid purple curve the EEE placed on the market from Eurostat. (Source: VHK elaboration of APPLiA and Eurostat data).

[113] Temperature exchange equipment includes, apart from refrigerators and freezers, also air conditioners and heat pumps, for which sales have recently strongly increased while units reaching EoL are comparatively low. This drives down Eurostat's overall collection rate for this category (which refers to mass placed on the market). For refrigerators and freezers alone, the collection rate could be higher.

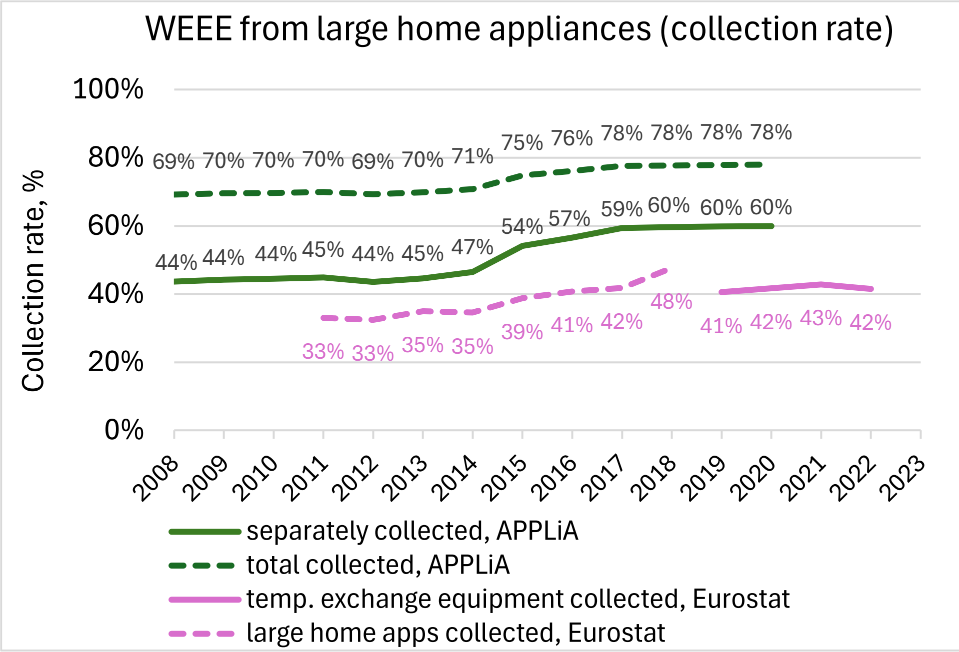

Figure 17: Collection rates for WEEE from large home appliances, for separate collection (from APPLiA), separate + complementary collection (from APPLiA), collection for large home appliances (from Eurostat, until 2018) and collection of temperature exchange equipment (from Eurostat, from 2019) (Source: VHK elaboration of APPLiA and Eurostat data).

2.1.5.5 Collection and recovery per type of material

Table 8 shows WEEE data per material type for all home appliances together in year 2018, derived from APPLiA data [114]. The totals are consistent with other presented data, and the overall 73% collection rate (vs. WEEE generated) and 93% recovery rate (vs. collected) seem reasonable. However, the subdivision over the material types presents inconsistencies: for steel, copper and concrete the amount recovered is higher than the amount collected [115]. Hence, caution is required when using the data in this table.

Nevertheless, the recovery rates for metals are generally high, while those for plastics (34% vs. generated) and glass (29% vs. generated) are significantly lower.

[114] https://www.statreport2021applia-europe.eu/slide/materials-recovered-from-weee-collected-by-the-industry
https://www.statreport2021applia-europe.eu/slide/materials-recovered
https://www.statreport2021applia-europe.eu/slide/circularity-of-the-sector
The Home Appliance Industry in Europe 2022-2023, APPLiA, p.32 Materials recovered from waste

[115] One of the reasons can be that for generated and collected the breakdown over the material types assumes that the composition is the same as for placed on the market, which is not necessarily true. In addition, the presence or not of stainless steel in the figures for steel might not be consistent.

Table 8: WEEE collection and recovery from all home appliances in year 2018, per material type, placed on market, generated, separate collection, complementary collection, material recovery, energy recovery (source: APPLiA, elaboration by VHK)

All home appliances, Year 2018, Masses in Mton	Placed on market	WEEE generated	total collected	Collected vs generated	Recovered from separate collection	Recovered from complementary collection	Total recovered	Recovered vs. placed on market	Recovered vs generated	Recovered vs. collected
Aluminium	0.17	0.14	0.10		0.064	0.03	0.094	55%	67%	91%
Concrete	0.39	0.32	0.24		0.290		0.290	74%	90%	123%
Copper	0.15	0.12	0.09		0.064	0.03	0.094	63%	76%	103%
Glass	0.23	0.19	0.14		0.055		0.055	24%	29%	39%
Plastics	2.04	1.69	1.24		0.388	0.19	0.578	28%	34%	47%
Steel	2.75	2.27	1.67		1.691	0.56	2.251	82%	99%	135%
Other	0.56	0.46	0.34		0.061	0.12	0.181	32%	39%	53%
Sum materials	**6.29**	**5.20**	**3.81**	**73%**	**2.61**	**0.94**	**3.54**	**56%**	**68%**	**93%**
Energy recovery					0.12	0.035	0.155	2%	3%	4%
Sum recovery					**2.73**	**0.98**	**3.70**	**59%**	**71%**	**97%**

2.1.5.6 Collection and recycling of plastics from home appliances

Table 9 shows further details on plastic WEEE from all home appliances, probably for year 2018, based on APPLiA data [116].

Of the 2 Mton home appliances placed on the market, 49% is separately collected, but only 18% becomes plastic recyclate: 8.7% PP, 5.3% PE, 3.4% (HI)PS and 0.5% ABS. The rest still goes to incineration (25%) or landfill (6%).

Note that only PP, PE, (HI)PS and ABS are mentioned as plastics being recycled.

9% of the plastic ends up in the waste bin (mainly from small home appliances) and most of this is incinerated.

Overall, 18% is recycled, 32% is incinerated, 8% goes to landfill, and for 42% the destination is unknown. For refrigerators and freezers (part of large home appliances or of cooling & freezing) the separate collection rate is higher, consequently the recycling share will be higher, and the share of (HI)PS in the recyclates will be higher [117].

For comparison, PlasticsEurope [118] for post-consumer plastics from EEE in 2018 reports that 18% was recycled, 52% was incinerated and 20% went to landfill. In 2022 this becomes 20% recycled, 50% incinerated and 30% landfill. In the 20% recycled, approximately 13% was post-

[116] The Home Appliance Industry in Europe 2022-2023, APPLiA, p.27 Plastic flows from home appliances
The Home Appliance Industry in Europe 2022-2023, APPLiA, p.28 Routes of recycled plastics from WEEE
https://www.statreport2021applia-europe.eu/slide/plastic-generated-vs-collected

[117] Following the 4th SH meeting of 1 July 2025, a manufacturer association commented that the actual amount (and proportion) of recycled plastic reused in a closed-loop manner for household appliances is likely even smaller than 18%. In Japan, under the Home Appliance Recycling Act, manufacturers are required to collect and recycle large household appliances, such as refrigerators, washing machines, air conditioners, and television that they have placed on the market. These manufacturers make efforts to reuse high-quality polypropylene (PP), such as that derived from vegetable compartment/vegetable drawer, by manually dismantling collected products at recycling plant (factory)s they operate themselves.

[118] https://plasticseurope.org/wp-content/uploads/2024/11/PE_TheFacts_24_digital-1pager.pdf
https://plasticseurope.org/knowledge-hub/the-circular-economy-for-plastics-a-european-analysis-2024/

consumer mechanically recycled, 6% pre-consumer mechanically recycled, 1% bio-based and 0.1-0.2% chemically recycled. Hence, chemical recycling is still a small fraction.

The same sources state that in 2022 EEE products consumed 3.1 Mt of plastics, of which 3.2% (0.1 Mt) came from post-consumer recycled plastic.

PlasticsEurope further reports that from the 16.4 Mton post-consumer separately collected plastics 49.4% was recycled in 2022, while from the 15.9 Mton mixed waste collection only 3.8% was recycled (but this is not specific for EEE, including e.g. also packaging and construction waste).

Table 9: WEEE plastics collection, recovery and recycling from all home appliances (source: APPLiA, elaboration by VHK)

All home appliances, Year 2018 (?), Masses in Mton	Plastic WEEE placed on market (or generated?) [119]	Collection [120] [121]	Collection share	EoL destination	EoL destination share	Type of recyclate	Type of recyclates, sherae
Small home apps.	1.04	0.39	38%				
Large home apps.	0.55	0.32	58%				
Cooling & Freezing	0.46	0.28	61%				
All home apps.	**2.06**	**0.99**	49%				
Separate collection		1.01	49%				
Incineration / co-processing				0.51	25%		
Landfill				0.13	6%		
Plastic recyclates				0.37	18%		
Polypropylene (PP)						0.18	8.7%
Polyethylene (PE)						0.11	5.3%
(High impact) polystyrene (HI)PS						0.07	3.4%
Acrylonitrile butadiene styrene (ABS)						0.01	0.5%
Waste bin		0.19	9%				
Incineration / co-processing				0.15	7%		
Landfill				0.04	2%		
Complementary collection		0.27	13%				
Unknown destination				0.27	13%		
undocumented		0.59	29%				
Unknown destination				0.59	29%		

2.1.5.7 Units reaching end-of-life

The stacked areas in Figure 18 show the number of refrigerating appliances reaching end-of-life, computed from the sales (section 2.1.2) and the lifetime distributions (section 2.1.3). For reference, the total sales are also indicated (blue curve).

[119] In APPLiA statistics it is presented as WEEE generated, but comparing with Table 8, it is more likely that it refers to the amount placed on the market.

[120] The amounts on the first four rows are for separate collection. The difference between 0.99 and 1.01 is due to rounding.

[121] The total collection is 1.01 Mton (separate) + 0.27 Mton (complementary) =1.28 Mton. This is close to the 1.24 Mton total plastics collected in Table 8

In year 2000, EoL quantities were 29% lower than the sales quantities, but the gap decreased to 20% in 2010, 11% in 2020 and expected 8% around 2025.

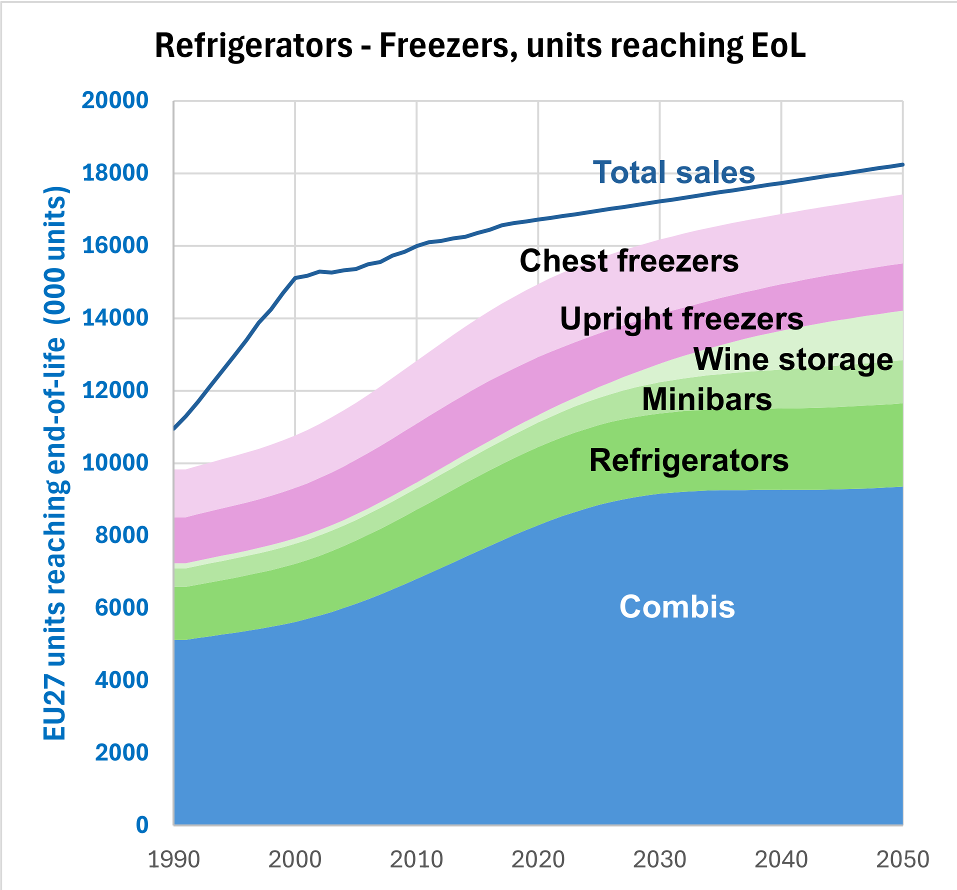

Figure 18: EU27 total refrigerating appliances reaching end-of-life (in thousands), per type (source: VHK elaboration of EIA2024 and EPREL data)

2.1.5.8 Hoarding trends in Europe

The growing accumulation of unused electrical and electronic equipment (EEE) in households is an emerging challenge with significant environmental and economic consequences. A data collection initiative led by the WEEE Forum across several European countries and Lebanon, highlights the scale of the issue. In 2022, this study surveyed 8,775 households to examine the extent of hoarding EEE and WEEE. Addressing this issue could drastically improve reuse and recycling, and contribute to a more sustainable economy (text from [122]).

The findings reveal that the average EU household owns 74 electrical items, representing approximately 90 million tons (Mt) of equipment across Europe. Out of these, 61 items are actively in use, while four items per household are hoarded but broken. This amounts to 3 Mt of appliances that could be repaired or handed over to WEEE collection schemes. In addition to this, nine working items, for a total of 7 Mt, are not being used, yet they have the potential to reduce the need for new electrical goods and minimize future WEEE generation if they were brought back into circulation.

[122] Hoarding of Electrical and Electronic Equipment (EEE) and Waste Electrical and Electronic Equipment (WEEE): A Hidden Challenge, Nov. 21, 2024, FutuRaM, https://futuram.eu/hoarding-of-weee/

Small electronic devices, such as laptops and kitchen equipment, are the most commonly hoarded items. Although small, these devices represent a large portion of hoarded WEEE by quantity. In contrast, larger items like washing machines and refrigerators, while less frequently hoarded, make up a significant portion of the total mass of WEEE when discarded.

Interestingly, the motivation for keeping unused EEE varies. The main reason cited by 46% of survey respondents was the belief that the item might be useful again in the future. Other common reasons included plans to sell or give away the item (15%), sentimental attachment (13%), and the perception that the item may increase in value (9%). A small portion of respondents (7%) admitted that they simply did not know how to dispose of these items properly.

2.2. Market for recycled materials

This chapter collects information that was gathered during the mini-preparatory study on the recycling market, and more specifically on the recycling of fridges. It is fragmented and can be further completed in the review study on fridge regulations that started in December 2024. For further information see also the general, horizontal part of the study report on recycled content and CRMs.

2.2.1 General information

Fridge recycling.

Fridge recycling started in Germany in 1987. CoolRec, a large EU fridge recycler visited by the study team, now recycles 42 ktons of fridges per year: 80 fridges per hour in a 24/7 shift.

The fridge recycling market is very fragmented with many small players. Installations processing 2500 tons of fridges per year are from 1995 or before and not efficient. Minimum requirement for efficiency in a well-operated and maintained process is 12000 tons per year.

End-of-waste declaration.

At a certain moment products officially become waste, and there are rules on how waste can be stored, transported, processed, etc. There have been problems with transport of recycled materials because officially they still had the status of waste. At a certain moment, there must be an ‘end-of-waste’ declaration to change the status of the recycled material, but it is currently (January 2025) not clear who can or has to issue such a declaration.

Organizations.

Various recycling market organizations are active in Europe (list is not exhaustive):

EuRIC (https://euric.org/) is the leading voice of the European recycling industries and strives to realise its vision by:

- Advocating for conditions that enable recycling and waste management sectors to be competitive, grow and re-invest.
- Connecting the European recycling industries and other circular economy stakeholders.
- Acting as a trusted partner between the European recycling value chain and policymakers.
- Advancing the socio-economic, climate and environmental benefits of recycling.

- Providing specific and cross-sectoral expertise on a broad range of materials including Metals (ferrous and non-ferrous), Plastics, Paper, Textiles, Tyres, End-of-life vehicles (ELVs), E-waste including batteries, Construction & Demolition waste [123]

FEAD (European Waste Management Association) (https://fead.be/) is a Brussels based association promoting the circular economy by representing Europe's private resource and waste management industry. Its vision for 2030 is:

- Shifting Europe's overall material use towards recycled materials through industrial excellence in waste management.
- To supply the European economy with secondary raw materials and energy, while managing waste in a safe and environmentally responsible way.
- To support the European Union's ambition to double its Circular Material Use Rate (CMUR) in this decade.

FEAD aims to:

Boost recycling
- Introduce mandatory recycled content requirements, to build on proposals for PET bottles, to create strong European markets for recycled materials
- Improve the recyclability of products through eco-design and reduce of substances of concern, and where needed, to contribute to efficient EPR schemes
- Ensure the implementation of existing recycling targets at national level
- Use eco-labelling to empower consumer decision making
- Leverage public sector buying power through obligatory green public procurement
- Accelerate programs designed to strengthen regulatory enforcement to help all EU Member States reach their recycling targets

Foster resource efficiency
- Recycle as much as possible, yet recognize that not all waste can be recycled either technically or economically at this moment in time
- Recover energy and construction materials from non-recyclable and non-compostable waste in waste-to-energy facilities

Encourage private sector investment in the circular economy
- Enforce Single Market rules on state aid
- Open up household waste markets to competition and give private entities a level playing field
- Abolish the principle of unanimity in the process of negotiations related to VAT harmonization in the European Union

PRE, Plastic Recyclers Europe (https://www.plasticsrecyclers.eu/) is the voice of the European plastics recyclers, representing 850 recycling facilities, 13.2 Mtons installed capacity, €9.1 billion turnover and 30 thousand employees. PRE stands for:

[123] EuRIC has branches for:
- Ferrous metals recycling (EFR, European Ferrous Recovery & Recycling Branch, including end-of-life vehicles recycling)
- Non-ferrous metals recycling (EuroMetrec, European Non-Ferrous Recovery & Recycling Branch, including E-waste recycling)
- Plastics (EPRB, European Plastics Recycling Branch)
- Paper (ERPA, European Recovered Paper Branch)
- Tyres (EuRIC MTR, Mechanical Tyre Recycling Branch)
- Textiles (EuRIC Textiles, Textiles Re-use & Recycling Branch)
- Construction and Demolition (ECDB, EuRIC Construction and Demolition Branch)

- Advancing circularity of plastics through increased quality plastics recycling & use of recycled materials in high-end products
- Improving recyclability of plastic products
- Harmonizing of the recycling standards & practices across Europe
- Genuine transition towards the circular economy

ERP, European recycling platform (https://erp-recycling.org/ **)**: Created by producers for producers, the ERP informs consumers about, and services both private companies and public authorities with optimal solutions for recycling waste from electronic and electrical equipment (EEE), batteries, packaging and, most recently, textiles. ERP makes it easy for its members (companies that place new products on the market) to meet compliance and reporting requirements at the best possible price and with the least possible admin.

CPA, Circular Plastics Alliance

(https://single-market-economy.ec.europa.eu/industry/industrial-alliances/circular-plastics-alliance_en)

The Circular Plastics Alliance aims to boost the EU market for recycled plastics. The alliance covers the full plastics value chains and includes over 330 organisations representing industry, academia and public authorities. New stakeholders can join the alliance by signing its declaration. The signatories "take action to boost the EU market for recycled plastics up to 10 million tonnes by 2025". The Circular Plastics Alliance is an initiative under the European Strategy for Plastics (2018), in particular under Annex III related to voluntary pledges by industry.

The deliverables of the CPA include:

- Design for recycling work plan [124]: 26 products targeted, but most are in agriculture, packaging and construction, for use of recycled LDPE, HDPE, PP, EPS, PET, PS and PVC. Under Electrical and Electronic Equipment, small household appliances, large household appliances and <u>cooling and freezing appliances are targeted for use of recycled ABS, PS and PP</u>.
- CPA Roadmap to 10 Mt – Untapped Potential Report [125]. Achieving the European Commission's 2018 target of 10 million tonnes of recycled plastics used in the EU by 2025 requires producing an additional 3.4 million tonnes of recycled plastics in Europe by 2025 (compared to 2020). Therefore, sorting capacities should increase by at least 4.2 million tonnes by 2025 and recycling capacities by at least 3.8 million tonnes. This corresponds to estimated investment needs between € 7.6 billion and € 9.1 billion.
- A European monitoring system. The CPA established a monitoring system to track progress towards 10 million tonnes of recycled plastics produced and used in Europe by 2025. This is the first-ever EU-wide monitoring system on recycled plastics. As per the CPA declaration, this system is transparent and trusted, with auditing and traceability of both the system and data. The CPA has approved two platforms for collecting data in compliance with the CPA monitoring rules and methodology
    - MORE, managed by EuPC, collecting data only on the use of recycled plastics

[124] Circular Plastics Alliance, DESIGN FOR RECYCLING WORK PLAN, Updated final draft – Version Sept. 2021, https://ec.europa.eu/docsroom/documents/47334

[125] Circular Plastics Alliance – Roadmap to 10 Mt recycled content by 2025, September 2021, https://ec.europa.eu/docsroom/documents/46956

- RecoTrace managed by PolyREC, collecting data on both the production and use of recycled plastics

I4R platform (https://i4r-platform.eu/): provides treatment and recycling facilities and preparation for re-use operators with access to WEEE recycling information in line with the requirements of Directive 2012/19/EU.

Article 15 of the Directive 2012/19/EU (WEEE Directive) requires producers to provide information free of charge about preparation for re-use and treatment for each type of EEE placed on the market. This provision with slightly different wording already existed at the time of the first WEEE Directive (old Art. 11). Since 2005, manufacturers have been collecting the information according to a harmonized reporting format for each product and uploaded it on their website.

To better respond to recyclers' needs, APPLiA and DIGITALEUROPE have created this single central online platform – the Information for Recyclers Platform (I4R) – where recyclers can access recycling information at product category level. The WEEE Forum, an international association of producer responsibility organisations and a centre of competence, will host and maintain the platform. To meet the requirements of Directive 2012/19/EU, the recycling information will be linked to the presence and location of materials and components in electronic waste that require separate treatment.

The European Power Tool Association (EPTA) has recently joined the I4R platform and contributed with a new product category on Power tools and four new product fiches.

A grand total of 47 product fiches in six product categories are currently at the user's disposal.

Research projects.

Various research projects on recycling have been performed or are ongoing in Europe (list is not exhaustive):

PRecycling (https://www.precycling-project.eu/) aims to produce high-quality recyclates from plastics waste streams by developing an easy-to-use methodology for sorting, sampling, tracing, recycling techniques, and analysis procedures of both plastic waste streams (PWS) and recyclates, and to assess the environmental and financial viability of them in selected waste management processes for plastics waste and secondary raw materials, in order to change the current paradigm of low cost non-environmentally friendly actions such as landfilling [126].

PRecycling aims at achieving specific technological/strategic goals:

- Development and demonstration of standard, robust and easy-to-use sampling and analysis procedures to ensure consistent recyclate quality and safe products.
- Development of methodologies to determine the degree of degradation of recycled materials and to foresee their end-of-life.
- Development of methods for traceability of recyclates to allow the identification of the origin of recycled materials via digital information management, throughout marking technologies and blockchain approaches.
- Development of methods for detection and separation of legacy additives in the plastics waste streams to ensure safe recycling of plastics containing such additives.

[126] This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101058670.

Plast2bcleaned (https://plast2bcleaned.eu/): In 2021, 10 million tons of Waste Electrical and Electronic Equipment (WEEE) were generated in Europe containing 25 wt. % of plastics. Due to the growing number of electronics sold and decreasing product life spans, this waste stream is predicted to continue to grow in the following years. WEEE plastics often contain undesired additives that hamper recycling in Europe. WEEE plastics containing brominated flame retardants (BFR) as additives are currently incinerated or landfilled. Hence for WEEE plastics, a closed-loop solution is needed. PLAST2bCLEANED's aim was to develop a human and environmentally safe recycling process for WEEE plastics in a technically feasible and economically viable manner. Three material loops were intended to be closed: (1) polymer; (2), bromine fraction; and (3) antimony trioxide fraction [127].

Circular Foam project (https://circular-foam.eu/): The project "CIRCULAR FOAM - Systemic expansion of territorial CIRCULAR Ecosystems for end-of-life FOAM" will develop and demonstrate all technological steps required to achieve circularity of plastics in post-consumer applications, using the example of rigid PU foams used as insulation in refrigerators and construction [128]. Project duration: 1st October 2021 - 30th September 2025 (48 months). Further information in section 4.2.3.

INCREACE project (https://increace-project.eu/):

INCREACE aims at increasing the uptake of recycled plastics in various products through innovative and interdisciplinary solutions. This goes along the plastics recycling value chain embedded in a systemic framework with a focus on Electrical and Electronic Equipment (EEE). By using (in principle) recycled plastics from Electrical and Electronic Waste (WEEE), the INCREACE project will tackle areas where the use of recycled plastics is marginal today.

INCREACE is a project funded by the European Health and Digital Executive Agency (HADEA) of the European Commission under the Horzion Cluster 4 program.

The project partners will develop new data-driven sorting solutions to prevent potentially hazardous substances entering the recycled plastics system and combine complementary recycling technologies (mechanical, chemical and solvent based) to increase the overall recycling yield. Traceability is essential; therefore, the project will rely on an innovative blockchain approach. The overall concept will be applied to and validated by specific business cases. INCREACE will also analyze implications of systematic changes in the plastic industry from different perspectives.

The business cases include food contact applications and high-tech plastic components in EEE.

In INCREACE, PHILIPS and PEZY collaborated to develop a tool for designers to calculate the recyclability rate of a product and point you to design improvements. It enables designers to develop recyclable designs only using product data available to the designers (for electronic small household devices). We call the tool RAT (recyclability assessment tool). COMING SOON (in March 2025).

[127] https://plast2bcleaned.eu/wp-content/uploads/2024/07/Project-Sumary_Plast2_V4_compressed.pdf

[128] This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101036854

PRIMUS (https://www.primus-project.eu): researching new polymer recycling technologies that allow to produce new technically and safety compliant recycled materials that can be used for manufacturing high value products. Further information in section 4.2.2.

ABSolEU project (https://absoleu.univ-cotedazur.eu/): The ABSolEU project is an initiative funded under the EU's Horizon Europe Program. It is simultaneously a multilateral collaboration that aims to pave the way to circularity for the ubiquitous plastic ABS, found in durable products from toys and other consumer goods to automotive components, and therefore revolutionize the current state of the art of ABS recycling in Europe and beyond.

FutuRaM project (https://futuram.eu/about/): FutuRaM will develop the Secondary Raw Materials knowledge base on the availability and recoverability of secondary raw materials (2RMs) within the European Union (EU), with a special focus on critical raw materials (CRMs). The project research will enable fact-based decision making for the recovery and use of 2RMs within and outside the EU, and disseminate the data generated via an accessible knowledge base developed in the project. The project runs from June 2022 to May 2026.

2.2.2 Market for recycled metals

Steel

Based on EURIC's metal recycling fact sheet [129]:

- European steel scrap recycling collects and re-processes more than the demand for steel scrap in the EU. In 2018, the domestic supply of the EU-28 exceeded 112 million tonnes. This is consistently apparent year after year, showing that there is no scrap shortage in the EU.
- The largest importer of steel scrap from the EU-28 is Turkey, whose imports represent more than 50% of EU-28 steel scrap exports (11.09 million tonnes in 2018). The Turkish steel industry relies vastly on the EAF steel production route using steel scrap as main infeed [130].
- In 2018, European scrap recyclers exported more than 21,400 thousand tonnes and imported 2,850 thousand tonnes.
- The proportion of steel scrap used in relation to crude steel production in the EU is 56%. Steel scrap use (consumption) for steelmaking was 93.8 million tonnes in the EU in 2018.
- Over 90% of EoL stainless steel is currently collected and recycled into new products.
- 16% of steel in the EU is used for domestic appliances.

For comparison, the average refrigerating appliance contains 40.2 kg of ferrous metals [131]. Multiplying this by the 14.6 million appliances reaching end-of-life in 2018 (section 2.1.5.7), gives 587 thousand tonnes of generated ferrous waste from fridges. Assuming a 78%

[129] https://circulareconomy.europa.eu/platform/sites/default/files/euric_metal_recycling_factsheet.pdf The publication is from 2020, but reported data are older.

[130] An electric arc furnace (EAF) can handle 60-70% of metal scrap. Such furnaces are mainly found in Turkey and India. Blast furnaces in the EU can handle only up to 10% of metal scrap.

[131] Ecodesign Impact Accounting 2024, see also section 5.2.1

collection rate of EoL fridges (section 2.1.5.4) this means 458 thousand tons of ferrous scrap. Ferrous scrap from fridges is 0.5% of the total 93.8 million tonnes used in the EU in 2018.

According to the world steel organisation, in 2021, around 70% of the total metallic input to steel production globally was derived from iron ore, with scrap making up the other 30% [132].

For stainless steel, in 2019 globally, 95% was recycled at end-of-life, of which 70% was used to make new stainless steel, and 25% to make new carbon or special steel. Of the inputs into stainless steel production, 37% was stainless steel scrap and 11% carbon steel scrap (total 48% scrap in input) [133].

Aluminium

Based on EURIC's metal recycling fact sheet [129]:

- 4.9 million tonnes of aluminium were recycled in the EU in 2017.
- In the coming decades, demand for aluminium is expected to increase by a further 50% by 2050, reaching over 9 million tonnes of scrap demand in the EU.
- Secondary aluminium production represents globally twice the production of primary aluminium. As a result, aluminium scrap from recycling is a valued commodity, traded worldwide, and the major source of total aluminium production.
- Of the total amount of aluminium scrap generated in the EU at EoL (i.e., 4,338 thousand tonnes of aluminium), about 2,986 thousand tonnes of aluminium were collected and recycled, resulting in an EoL recycling rate of 69%.
- 6% of aluminium in the EU is used for consumer durables.

For comparison, the average refrigerating appliance contains 1.6 kg of aluminium [131]. Multiplying this by the 14.6 million appliances reaching end-of-life in 2018 (section 2.1.5.7), gives 23.6 thousand tonnes of generated aluminium waste from fridges. Assuming a 78% collection rate of EoL fridges (section 2.1.5.4) this means 18.4 thousand tons of aluminium scrap. Aluminium scrap from fridges is 0.4% of the total 4.9 million tonnes used in the EU in 2018.

Copper

Based on EURIC's metal recycling fact sheet [129]:

- 44% of EU copper demand comes from recycled sources.
- 70% of copper in EoL products is recycled.
- 90% of copper in civil infrastructure is recycled.
- The modest natural deposits of copper within the EU (48,000 thousand tonnes) drive a strong reliance on recycling, otherwise imports of primary and secondary forms to meet the domestic demand would increase.

[132] https://worldsteel.org/wp-content/uploads/Fact-sheet-on-scrap_2021.pdf

[133] https://worldstainless.org/pdf-viewer/viewer.html?file=https%3A%2F%2Fworldstainless.org%2Fwp-content%2Fuploads%2F2025%2F03%2FThe_Global_Life_Cycle_of_Stainless_Steels.pdf

- Despite the amount of secondary copper sent to domestic processing is supplemented by imports of copper waste and scrap, in absolute terms, the EU-28 is a net-exporter of secondary copper forms.
- The EU exported 986,000 tonnes of copper scrap with a value of €1.91 billion to third countries in 2016.
- Of the total amount of copper scrap generated at EoL (i.e., 2,625 thousand tonnes of copper), about 1,603 thousand tonnes of copper (61%) were collected and recycled within the EU.
- 25% of copper in the EU is used for 'other equipment' (different from transport, construction, industrial and infrastructure)

For comparison, the average refrigerating appliance contains 2.2 kg of copper [131]. Multiplying this by the 14.6 million appliances reaching end-of-life in 2018 (section 2.1.5.7), gives 32.1 thousand tonnes of generated copper waste from fridges. Assuming a 78% collection rate of EoL fridges (section 2.1.5.4) this means 25 thousand tons of copper scrap. Copper scrap from fridges is 1.6% of the total 1.6 million tonnes collected and recycled in the EU.

In a meeting with the study team, a specialist EU copper recycler [134] explained that copper is a scarcity market, where demand is higher than supply. The main issue would be to increase end-of-life collection rates and adequately regulate exports of copper scrap and recycled copper, so that the supply of recycled material can be increased. Setting minimum recycled content requirements for copper in e.g. fridges or electric motors was anyway judged positively by the recycler. The main questions would be at which percentage of recycled content, how this percentage would exactly be defined, and if the recycled copper would be available in sufficient quantities. See further information in section 6.2.2.

No focus on recycled metal content

During the stakeholder meeting following phase 1 of the present study, there seemed to be agreement that setting minimum recycled content requirements on metals is not useful. The recycling chain for metals is well established. Due to the fixed availability of waste metal supply (as it depends on the volume of old cars and appliances, etc., that are scrapped), introducing minimum ecodesign requirements for recycled metals in home appliances might lead to a shift of supply of metals with recycled content between sectors that use steel, such as e.g. the construction industry. Hence, such requirements do not assist the recycling industry, resolve waste stream problems, or reduce environmental impacts. Consequently, setting minimum recycled content requirements on metals used in fridges has not been a study focus. For further information see also the general, horizontal part of the study report on recycled content and CRMs.

In its comments after the September 2024 stakeholder meeting, APPLiA emphasised that metals used in refrigerating appliances such as copper, aluminium and ferrous materials already contain a significant amount of recycled material. In general, metals demonstrate good recycling rates. The reason for this is that there is a market for recycled metals, and these can readily be used to produce new metal raw material. However, appliance manufacturers do not have control over the amount of recycled metals in the supply of metal they receive. Overall, metals are not disposed of in landfill or incinerated and become a lost resource. Metals are recovered and reused [135].

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[134] https://www.montanwerke-brixlegg.com/

[135] APPLiA input to priority products under ED study on ReCo and CRM, 2024-09-13, Refrigerators, Q2: For which components/materials is recycled content being used; how much? (Plastics, copper, aluminium, ferrous metals, electronics)

2.2.3 Market for recycled plastics

In 2023, 54 Mt of plastics were produced in Europe, of which 79.4% was fossil-based, 1.4% bio-based or bio-attributed, and 19.2% from recycling. The latter included 13.2% mechanically recycled post-consumer, 5.8% mechanically recycled pre-consumer, and 0.2% chemically recycled [136]. The EU plastics production decreased from 62.3 Mt in 2018 to 54 Mt in 2023. Post-consumer mechanically recycled plastic increased from 4.9 Mton in 2018 to 7.1 Mt in 2023, with a peak of 7.7 Mton in 2022. Pre-consumer mechanically recycled plastic decreased from 3.8 Mton in 2018 to 3.1 Mton in 2023.

In 2022 [137]:

- 58.8 Mt plastic produced in Europe
- 54.1 Mt plastic converted to products and parts (-4.7 Mt import/export balance)
- 53.3 Mt plastic products and parts consumption by users (-0.8 Mt imp/exp balance)
- 32.3 Mt plastic waste collected and sorted in 2022 (60% of consumed). Approximately half from separate waste collection (with high recycling rate) and half from mixed waste collection (with low recycling rate) (Table 10).

  Collection increased from 24.4 Mt in 2018 to 32.3 Mt in 2022. Recycling and energy recovery shares increased since 2018 while the landfilling share decreased.

Table 10: Plastic collection and recycling shares

	Total collection 2018	Total collection 2022	Separate collection 2022	Mixed collection 2022
Collection	24.4 Mt	32.3 Mt	16.4 Mt	15.9 Mt
Recycling	14.0%	27.0%	49.4%	3.8%
Energy recovery	30.3%	49.5%	39.6%	59.7%
Landfill	55.7%	23.5%	11.0%	36.5%

- Of the 53.3 Mt consumed plastics, 4.0 Mt (7.5%) was contained in electrical and electronic equipment, of which:
  - 3.1 Mt was converted into products and parts in Europe
  - 0.9 Mt is import/export balance
  - 2.0 Mt was collected and sorted post-consumer, of which
    - 20% to recycling
    - 50% to energy recovery
    - 30% to landfill
  - 0.1 Mt was the input of post-consumer recycled plastics into EEE products. This is 3.2% of the total 3.1 Mt plastics conversion for EEE, and 1.5% of the total PCR plastics used in the EU (6.8 Mt).
  - 0.1 Mt was the input of pre-consumer recycled plastics into EEE products.

[136] Source: https://plasticseurope.org/wp-content/uploads/2024/11/PE_TheFacts_24_digital-1pager.pdf

[137] Source : https://plasticseurope.org/knowledge-hub/the-circular-economy-for-plastics-a-european-analysis-2024/

- Of the 54.1 Mt converted plastics in 2022, 43.7 Mt was fossil-based, of which [138]:
  - 8.6 Mt was PP (15.9%)
  - 3.6 Mt was PUR (6.7%)
  - 1.3 Mt was PS (2.4%)
  - 0.8 Mt was ABS (or SAN) (1.5%)

- In 2023, the total installed recycling capacity in the EU27+3 was 13.2 Mt [139]. This gradually increased from 6.6 Mt in 2018. Of the 2023 capacity, 13% is for PP, 9% for PVC and 2% for PS and EPS.

Currently, PS (GPPS and HIPS), PP and ABS seem to be the only types of plastics recycled from fridges (see also section 4.2).

For additional information, see also JRC's modelling of plastic flows [140]

For further details on collection and recycling rates for home appliances, see section 2.1.5.

For price information on virgin plastics compared to those for recycled plastics, see the general, horizontal part of the study report on recycled content and CRMs.

In comments following phase 1 of the study [141], APPLiA observed that:

- compared to metals, for recycled plastics it is much more difficult to obtain a stable supply of sufficient quality and quantity.
- The use of recycled plastics is very limited in practice due to Food Contact Material requirements and further restricted through the stringent legal requirements contained in RoHS & REACH. Due to food contact regulations the only available recycled plastic as food contact grade is r-PET from food containers. This legal requirement precludes the possibility of introducing other types of recycled plastics without food contact material properties (barrier). Therefore, there is a small set of plastic polymers that can be integrated into a product and additional testing is often needed for post-consumer recycled material.
- The ability of the manufacturers to use recycled plastic material and its competitive advantage is further affected by its price fluctuations, where recycled plastics compete with the price of virgin plastic, which tends to follow the price of oil.
- Post-industrial content should also be taken into account, as plastics cannot be infinitely recycled as well as plastics with legacy substances, which cannot be recycled and are currently incinerated instead.

[138] Only plastic types most relevant for refrigerating appliances are shown here. Unfortunately, the source does not report recycled plastics by type

[139] Plastics-Recycling-Industry-Figures_2023.pdf, Publications - Plastics Recyclers Europe

[140] Amadei, A. and Ardente, F., Modelling plastic flows in the European Union value chain, EUR 31242 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-57510-8, doi:10.2760/66163, JRC130613. JRC Publications Repository - Modelling plastic flows in the European Union value chain

[141] APPLiA input to priority products under ED study on ReCo and CRM, 2024-09-13, Refrigerators, Q2: For which components/materials is recycled content being used; how much? (Plastics, copper, aluminium, ferrous metals, electronics)

Plastic recyclers are having difficult times. This is due to cheap virgin plastic (there is an overproduction in Korea and Japan that comes to EU) and due to a drop in demand (automotive, appliances).

Setting Ecodesign requirements on recycled content is necessary but will not resolve these problems (also because of a time-delay in the impacts). More protective measures need to be urgently taken.

2.2.4 Market for recycled glass

Glass consumption per application

The consumption of glass in the European Union varied from 36.3 to 39.3 Mton over the period 2019-2022 [142] [143]. Of this [144]:

- 60% is container glass (or hollow glass, e.g. bottles and jars, packaging)
- 30% is flat glass (e.g. for windows, PV panels) [145]
- 10% is domestic glass (e.g. tableware, drinking glasses), speciality glass (including also products like handmade glass jewellery or optical glasses [146]), or used for glass fibres (reinforcement, insulation, data transmission).

According to Glass for Europe [147] [148]:

- 10 million tons of flat glass are produced every year in the EU,
- The largest flat glass market is the building industry, which accounts for 80% of the output.
- About 15% is processed into glazing for the automotive and transport industry.
- The 5% remaining is shared between glass for many different applications such as solar applications, appliances (for example fridges or ovens), electronics, furniture, etc..
- Less than 1% is used in products intended for food contact. This limited number of articles includes cutting boards, decorative serving plates, tables, counter tops and fridge shelves.

For comparison, the average refrigerator-freezer contains 5.8 kg of glass, in shelves and doors (see also section 5.2.1). Multiplying this by 16.9 million units sold in the EU27 in 2023, the annual flat glass consumption by new sold fridges is around 98 kton. This is around 1% of the

[142] https://www.statista.com/statistics/1402078/consumption-of-glass-in-the-european-union/#:~:text=The%20apparent%20consumption%20of%20glass,million%20metric%20tons%20in%202022.

[143] Glass Alliance Europe states that 40 million tons of glass are produced annually in Europe. https://glassallianceeurope.eu/the-world-of-glass/

[144] https://single-market-economy.ec.europa.eu/sectors/raw-materials/related-industries/non-metallic-products-and-industries/glass_en

[145] In its 2025-04-04 answers, APPLiA stated that glass used in fridges is as prescribed in EN 572-1. Commodity glass, which consists of silicon dioxide, calcium oxide, sodium oxide and magnesium oxide. CEN, EN 572-1:2012+A1:2016(Main), Glass in building - Basic soda-lime silicate glass products - Part 1: Definitions and general physical and mechanical properties

[146] https://climate.ec.europa.eu/system/files/2016-11/bm_study-glass_en.pdf

[147] https://glassforeurope.com/the-sector/key-data/

[148] https://glassforeurope.com/food-contact-materials/

10 Mton flat glass annually produced in the EU, and 0.25% of the total glass consumption in the EU (near 40 Mton).

Glass packaging recycling

For glass packaging (container glass), the recycling rate in the EU27 in 2022 was 76%. The rate increased from 60% in 2005 to 75% in 2014 and remained almost constant in later years [149]. Other sources state a glass packaging recycling rate around 80% in the period 2021-2023 [150]. For further information on glass packaging recycling routes and destinations per member state, see [151].

Flat Glass recycling

As regards flat glass from construction and demolition waste, Glass for Europe [152] [153] [154] [155] states:

- The average share of cullet [156] used to produce flat glass in Europe increased from 20 to 26% between 2010 and 2018.
- Despite its recyclability and the potential, it is estimated that today only 5% of end-of-life flat glass is effectively recycled into new flat glass products. This is due to the lack of obligations to properly dismantle and sort windows or glazing from buildings before or after renovation/demolition. Instead, end-of-life glass is often crushed together with other building materials and used for pavement aggregates or put into landfills.
- It is estimated that 1.5 million tonnes of post-consumer construction and demolition waste glass (from old windows, facades, internal partitions, etc). is generated annually in the EU. The Renovate Wave and the new Energy Performance of Buildings Directive (EPBD) are meant to further increase this number by accelerating the rate of renovations.
- Only the use of recycled flat glass of the highest quality (clean and non-contaminated flat glass) is possible for new flat glass production. This is essential to preserve the integrity of the manufacturing equipment and to ensure the quality, safety and performance requirements of the final products. For example, the use of soda-lime silicate glass coming from bottle banks is extremely complex and would entail huge costs for the flat glass industry. It is therefore important that flat glass cullet is not downcycled and is used in closed loop or else the resource and its benefits in terms of CO2 emission reduction are lost for the flat glass industry.
- It is essential that the end-of-life glazing is dismantled, sorted and sent to a recycling route for this waste to be transformed into a valuable resource. Should all end-of-life glazing be recycled into flat glass in Europe, the percentage of cullet used to produce new flat glass products could be increased to roughly 40%, compared to today's 26% average.

[149] https://www.statista.com/statistics/1258851/glass-recycling-rate-in-europe/

[150] https://feve.org/eu-glass-value-chain-80-collection-rate/ European Container Glass Federation.

[151] https://closetheglassloop.eu/wp-content/uploads/2023/05/Packaging-Glass-Recycling-in-Europe-Performance-Report-2023.pdf

[152] https://glassforeurope.com/recycling-of-end-of-life-building-glass-2/

[153] https://glassforeurope.com/recycling-2/

[154] https://glassforeurope.com/wp-content/uploads/2025/01/Position-Circular-Economy-Act-January-2025.pdf

[155] https://glassforeurope.com/sustainability-in-the-flat-glass-sector/

[156] Cullet is broken or waste glass used for recycling

As regards quality issues, a 2016 study [157] remarks that:

- Even if cullet is available, the glass industry is reliant on its suppliers to meet basic quality specifications to be able to make saleable glass. Unfortunately, the collection and reprocessing infrastructure is not always able to do this. This is a particular problem when post-consumer glass is collected mixed with other recyclates (paper, plastic, metals, glass ceramics, ceramics) or when glass of different colours are collected mixed together. Material and colour separation at the source is therefore crucial.
- The quality requirements of the product must not be undermined. The specific quality requirements of several products limit the ability of the industry to use even high-quality post-consumer cullet. In some special cases, the technique for producing the glass is even such that no solid raw materials can be used. The possibilities of post-consumer cullet recycling in flaconnage, tableware, flat glass and special glass production are very limited for evident quality reasons. For these sub-sectors, only internal cullet is recycled or, in the case of flat glass, perfectly treated post-consumer cullet.

Glass Magazine [158] further clarifies that:

- Within the flat glass industry, there are three origins of cullet: internal cullet (offcuts in the plant itself); pre-consumer cullet (offcuts in the downstream fabrication process); and end-of-life post-consumer cullet (glass from an old car windshield or an old window that has been dismantled). The vast majority of cullet used in flat glass is internal, coming from offcuts in the plant itself. In Europe, 75 to 80 percent of cullet is internal; 20 to 25 percent is pre-consumer; just 0 to 5 percent comes from end-of-life cullet [159].
- In Europe, on average, float plants are running with approximately 26 percent of recycled cullet [160]. This is an average. There are float plants in Europe running with 40 or 50 percent of cullet in a batch. Though that also means there are others that are much lower.
- Almost all types of fabricated glass can be recycled, even coated, laminated or insulating glass. However, if additional processing is necessary, this may affect economics, and in some cases it may limit the markets. Ceramic band, found mainly in automotive applications, can be present at a limited percentage in cullet and will burn off in the float oven. Insulation units must be disassembled prior to re-use. The spacers must be removed prior to recycling. However, the sealants (silicone/ polyisobutylene/ polysulfide) will burn off in a float oven so long as it meets certain threshold limits. Coated glasses can be used, but some coatings may affect the final color of the glass. For laminated glass, the glass cullet itself can be re-used, but the PVB [161] itself can be more difficult to recycle as after crushing laminated glass, 4 percent

[157] https://climate.ec.europa.eu/system/files/2016-11/bm_study-glass_en.pdf

[158] https://www.glassmagazine.com/article/flat-glass-recycling

[159] Most of the consulted sources consider only pre-consumer and post-consumer cullet for glass recycling rates or recycled glass content. Internal cullet is not considered. However, this may not be done consistently in all sources. The often-cited 26% recycled cullet seems to exclude internal cullet, but in majority it is pre-consumer cullet.

[160] AGC Glass Europe states an average cullet ratio of 30% in their raw materials, and the aim to increase this to 50% by 2030. https://www.agc-glass.eu/en/sustainability/decarbonisation/recycling?language=de

[161] PVB Laminated Glass has a thin layer of polyvinyl butyral (PVB) film at its heart. The PVB film is made from a thermoplastic material that is sandwiched between two layers of glass. When the glass and PVB film are laminated together, they form a strong and durable bond that helps to ensure the integrity of the glass over time. This bond is created by heating the glass and PVB film to a high temperature, which softens the PVB, allowing it to flow and spread evenly over the surface of the glass. The heated glass and PVB film are then placed under pressure, which helps to ensure that the bond is as strong as possible. One of the key benefits of PVB Laminated Glass is its increased safety, holding the glass together in the event of breakage.

of the glass fragments remain on the PVB. Introducing glass fragments to a PVB extruder would damage the equipment.

- Metal contaminants in the cullet should be avoided. Aluminum can create infusible particles on the glass ribbon, making it unfit for sale and non-recyclable in flat glass furnaces. Stainless steel contains nickel that can create ‘spontaneous’ glass breakage in tempered glass; tungsten can lead to deposits that make the glass not sellable. And lead can lead to deposits that can attack the glass.
- Borosilicate glass and ceramic glasses, such as those used for fire-rated architectural applications, appliances or fireplace products can have recycling problems. Other “doubtful products” include digitally printed glass, smart glass and electronic mirrors.

AGC Glass Europe [162] (and other Glass organizations) aim at flat-to-flat closed loop recycling, avoiding other forms of recycling (to other glass sectors) or downcycling. This requires an increased quantity of cullet returning to the flat glass industry. Today the clean cullet that can be used in float glass furnaces represents only 8.5 per cent of all the glazing waste collected because we need to ensure that the cullet is not contaminated, that means not mixed with other contaminant materials.

Glass recycling from fridges

In APPLiA statistics (section 2.1.5.5, Table 8), the recovery rate of glass from home appliances is relatively low: 29% of the generated glass waste, or 39% of the collected waste. However, both fridge manufacturers [163] [164] and fridge recyclers [165] suggest that the recycling rate for glass is near 100% (of collected waste), and that glass recycling is not an issue to be considered in this study.

On average, glass represents a significant 8-10% of the refrigerator mass, and considering the situation sketched above for flat glass recycling, there seem to be some relevant issues:

- The input of post-consumer cullet into new flat glass production is below 5%. The 39% (or higher) recovery rate probably refers to other second-life uses for the glass.
- The glass shelves in fridges often have a plastic or metal front, which can represent quality problems during recycling back into flat glass.
- The glass doors (used in some fridges) are thermally insulating, using spacers between the glass sheets. In addition, these doors often have plastic or metal frames. The removal of spacers and frames before ‘culleting’ is paramount for recycling into new flat glass products.
- Vacuum Insulation Panels containing glass fiber do not seem advantageous from a recycling point of view: glass fiber is currently not being recycled but landfilled.

[162] https://www.agc-glass.eu/en/sustainability/decarbonisation/recycling?language=de

[163] Personal communication of Electrolux to the study team

[164] Circular Foam, Prototype of improved refrigerators, D2.3, 14/12/2023, Corrado Cecchini, Electrolux. Figure 4, fridge baseline recyclability index, 98% recycling rate for glass, 0% for glass fibre (all landfilled)

[165] Personal communication of CoolRec to the study team

Miscellaneous

Not all types of glass products can be recycled. Items such as mirrors, drinking glasses and lightbulbs cannot be recycled and need to be disposed of carefully [166].

Drinking glasses, flower vases, mirrors etc. have a different melting point and chemical composition than bottles and jars. If these materials are mixed with glass from bottles and jars it can contaminate glass recycling or weaken recycled glass which hurts recycling programs [167].

Reference organisations:

CPIV, the Standing Committee of the European Glass Industries.

FEVE, the European Container Glass Federation

GLASS FOR EUROPE, the European Flat Glass Federation

APFE, the European Continuous Filament Glass Fibres Association

ESGA, the European Special Glass Association

EDG, the European Domestic Glass Association

FERVER (European Glass Recyclers' Federation)

2.2.5 Market for recycled electronics

See the general, horizontal part of the study report on recycled contents and CRMs.

2.2.6 Market for recycled CRMs

See also the general, horizontal part of the study report on recycled contents and CRMs.

In comments following the 4th stakeholder meeting of 1 July 2025, a global leader in non-ferrous metals recycling, clarified that [168]:

- starting from industrial waste and end-of-life materials containing CRMs embedded in complex matrices, including WEEE (Waste Electrical and Electronic Equipment), ELVs (End-of-Life Vehicles), and batteries, more than 20 types of metals are produced in output. This includes critical and/or strategic raw materials: Co, Li, Ni, Cu, Ir, Te, Sb, Bi, Pt, Pd, Rh, Ge, Ta. Other recovered elements - Au, Ag, Re, Se, As, Sn, W, Pb, Ru - are not classified as critical or strategic but are recycled due to their intrinsic value or as by-products.
- The recycling operations use advanced technologies to extract these metals from complex waste streams and are typically integrated with refining processes that also handle primary materials. These primary materials are not mined ores or concentrates, but rather residues and by-products from primary metal production. These still contain valuable traces of CRMs that would otherwise be lost. This integration enables

[166] https://www.bbc.co.uk/bitesize/articles/zc46m39#zgvvydm

[167] https://ucrra.org/lets-be-clear-not-all-glass-belongs-in-the-recycling-bin/#:~:text=Drinking%20glasses%2C%20flower%20vases%2C%20mirrors,glass%20which%20hurts%20recycling%20programs.

[168] Umicore feedback on the Ecodesign preparatory study, July 2025.

benefitting from economies of scale, resulting in higher metal recovery yields, lower energy consumption, reduced emissions, and minimal residual waste.

- At a broader level, non-ferrous metals recycling in the EU is highly interconnected. Many companies operate in collaborative networks where material flows are integrated - waste from one company becomes feedstock for another. Toll treatment is a common practice, where intermediate materials are processed by third parties and returned to the principal in refined form. Chains of custody are always based on mass balance. Requiring physical traceability - for example, for due diligence or recycled content claims- would disrupt optimal material flows, leading to higher environmental impacts and reduced competitiveness.
- In a complex mixture of several CRMs and precious metals, the recycling costs will be allocated mainly to the precious metals. The only costs that are allocated to the CRMs are the costs for refining of the intermediates containing those CRMs. If there are no precious metals in the waste stream, and all costs must be borne by the CRMs, it could be not economically viable. Therefore, it is a political decision which CRMs must be recycled. E.g. in the batteries regulation, the regulator has decided that Li, Co, Ni and Cu must be recycled, independently from their economical value. This is important for recyclers: given the price volatility of many CRMs, if recycling would only happen if the prices were high, the recycling industry will not emerge. And an emerging recycling industry for CRMs is needed because scale leverage effects will lower the recycling costs.

3. MEErP Task 3, Product usage

Product usage aspects are less relevant for the current study on recycled contents and CRMs.

See the 2016 review study report [169].

The new review study on fridge regulations that started in December 2024 will provide updates on product usage as far as necessary.

[169] Preparatory/review study, Commission Regulation (EC) No. 643/2009 with regard to ecodesign requirements for household refrigeration appliances and Commission Delegated Regulation (EU) No.1060/2010 with regard to energy labelling of household refrigeration appliances, FINAL REPORT, VHK and ARMINES in collaboration with Viegand & Maagøe and Wuppertal Institute, contract co-ordination VITO, 4 March 2016

4. MEErP Task 4, Technologies

4.1. Household refrigerator technologies

4.1.1 Vapor compression, absorption and solid-state

Vapour Compression cycle:

The vapor compression cycle is the fundamental refrigeration process used in most household refrigerators. It consists of four main stages:

1. **Compression**: The refrigerant gas is compressed by the compressor, increasing its temperature and pressure.
2. **Condensation**: The high-pressure gas moves to the condenser coils, where it releases heat to the surroundings and condenses into a high-pressure liquid.
3. **Expansion**: The liquid refrigerant passes through an expansion valve, where it rapidly expands and cools, reducing its pressure.
4. **Evaporation**: The low-pressure liquid absorbs heat from inside the refrigerator through the evaporator coils, cooling the interior while turning back into a gas to restart the cycle.

Absorption Refrigeration using Ammonia

The absorption cycle uses heat as the driving force. Due to the absence of a compressor, the noise emission is lower than for the vapor compression, and consequently absorption technology is used for low-noise applications such as minibars in hotel rooms and wine storage appliances. Low-noise appliances are around 3% of the refrigeration appliances registered in the EPREL database. The technology uses five main stages:

1. **Evaporation**: A liquid refrigerant, usually ammonia, absorbs heat from the refrigerator interior and evaporates, producing a cooling effect.
2. **Absorption**: The ammonia gas is absorbed into a water or hydrogen mixture in an absorber unit, forming an ammonia-water solution.
3. **Heat Addition (Desorption)**: Heat is applied (typically from a gas flame, electric heating element, or solar energy) to the solution, causing the ammonia to separate from the water and turn into a high-pressure gas.
4. **Condensation**: The high-pressure ammonia gas moves to the condenser, where it releases heat and condenses into a liquid.
5. **Expansion & Recirculation**: The liquid ammonia flows through an expansion valve into the evaporator, restarting the cycle.

Solid state refrigeration

Solid-state refrigerators use thermoelectric, magnetocaloric, and electrocaloric or elastocaloric technologies instead of traditional vapor-compression systems. They have no moving parts. Thermoelectric models use the Peltier effect and are common in small coolers and the magnetocaloric cooling, which relies on magnetic fields has been tested for larger applications.

Solid state fridges currently have a lower efficiency and higher cost compared to other refrigeration technologies. However, they are smaller and quieter in comparison. Further research on the technology is required for them to become more mainstream.

4.1.2 Components of refrigerator / freezers

4.1.2.1 Main structure

The main structure (body) of a refrigerator or freezer (RF) carries all other components and transfers the weight of the fridge and of the contained foodstuffs to the floor. In addition, it encloses, together with the door(s), the cooled space. Hence it has a structural and thermal insulation function.

For the reference refrigerator-freezer combi (section 5.3), 43% of the mass is in the body. In addition to steel reinforcement beams near the bottom of the RF, a large part of the body is a sandwich structure, typically made of steel sheet on the outside, a plastic (HIPS) inner liner, and rigid polyurethane (PUR) foam between them (with or without additional vacuum insulation panels, VIPs, see section 0). These materials adhere to each other, which is essential for the structural strength and rigidity and for the thermal insulation.

For stand-alone fridges, the external steel sheet is typically coated with powder or baked enamel to prevent rusting, and for aesthetic reasons. The more expensive models may use stainless steel. Built-in fridges, in which the outer surfaces are not visible, typically use hot-dip galvanized steel sheets.

Due to Ecodesign energy efficiency requirements, the amount of PUR has been increasing in the last decades, while top-of-the-range models increasingly use VIPs.

At end-of-life, considering the non-dismantlability, the entire body is shredded, with subsequent separation processes recovering the steel, HIPS and PUR. For further remarks on recycling, see sections 4.2 and 6.3.4.

4.1.2.2 Door(s)

The function of the door(s) is to close the cooled space and to provide access to foodstuffs stored inside it. Most RFs have the door(s) at the front, but e.g. chest freezers have a lid on top. RFs can have one or more doors, e.g. a door for the freezer on top and for the refrigerator at the bottom, or vice-versa. Side-by-side models with two doors next to each other also exist.

For the reference refrigerator-freezer combi (section 5.3), 12% of the mass is in the doors. The door has a thermal insulation function, and it typically has the same sandwich structure as the body (steel-PUR foam-HIPS).

However, RFs with (partially) transparent (glass) doors are increasingly found, especially in wine storage appliances, but not only. They allow looking inside the fridge without opening the doors, which has an aesthetic function, but can also limit the number of door openings (and thus save some energy). As the doors have a thermal insulation function, double or triple glazing is used. RFs with transparent doors have separate, lower energy efficiency requirements in Ecodesign regulation 2019/2019.

Doors increasingly include user-interface displays, which have an informative function and a control function (user settings).

The doors are attached to the body by means of (metallic) hinges, which are among the components for which Ecodesign regulation 2019/2019 requires spare parts availability. The same applies to the door handles (mostly metal or ABS) and gaskets. This implies that those components are accessible and removable.

The door gaskets are strips that line the edges of the doors, and ensure an airtight seal when the doors are closed, preventing warm air entering and cold air escaping the RF. The gaskets are typically made from synthetic rubber, neoprene, EPDM, soft PVC, silicone or similar materials. To ensure that the doors remain properly closed, magnetic strips are often integrated in the seals.

The gaskets are attached to the doors with either a push-in or a screw-in method. The push-in gaskets are pressed into a groove or channel on the refrigerator door and stay in place due to their shape and elasticity. Screw-in designs mostly include a mounting plate which is screwed to the door, sandwiching the gasket in between. Older models may have used riveted or glued gasket attachments, but considering the replaceability requirement in regulation 2019/2019, modern fridges should no longer use this.

At end-of-life, recyclers will typically remove glass doors from the body, for separate processing, but otherwise the doors remain attached to the body and are shredded together with it. For further remarks on recycling, see sections 4.2 and 6.3.4.

4.1.2.3 Internal components

For the reference refrigerator-freezer (section 5.3), 20% of the mass are internal shelves, drawers, baskets and accessories such as egg tray, ice cube tray, butter box or bottle holder. These are typically mobile components that can be taken out of the fridge by users (e.g. for cleaning) and that are thus easily removable also for recyclers.

The components can be in glass, plastic (PP, GPPS, PC, some ABS) or steel (e.g. porcelain/epoxy coated steel wire shelves), or a mix of these. Coated steel wire shelves and glass shelves can have a pressed-on or glued-on plastic or metal border facing the user. These borders may integrate an end-of-stroke function for drawers positioned under them. The bottle shelf can use a mix of steel and plastic. A plastic drawer might use a handle in a different type of plastic.

Glass will typically be removed by the collector or recycler before shredding. For plastic and steel components, the recycler can choose whether to separate them or shred them with the rest of the fridge. For further remarks on recycling, see sections 4.2 and 6.3.4.

4.1.2.4 Hermetic compressor

The compressor is the heart of a refrigerator or freezer. It is typically located behind or beneath the refrigerator, and easily accessible from the outside. Its main functions are circulating and compressing the refrigerant in the vapour compression cycle (section 4.1.1).

Except for low-noise absorption-type fridges, which do not have a compressor, all household RF appliances use a hermetic compressor. This is a sealed unit that includes the compressor and its motor [170]. Large capacity two-door appliances still have two compressors, but fewer two-compressor-appliances exist today compared to the past [171].

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[170] For images and exploded views, see e.g. https://www.secop.com/products/hermetic-compressors-basics#c2738 and https://www.secop.com/fileadmin/user_upload/technical-literature/catalogs/ac_voltage_compressors_12-2024_desk490d202.pdf

[171] In its 2025-04-04 answers, APPLiA stated that the share of household fridge/freezers using more than one compressor is very small, and thus negligible.

Due to the increase in energy efficiency requirements, variable speed drive high-efficiency compressors are increasingly being used. The associated motors have permanent magnets, typically of the ferrite-type. Electrolux reported that for their RF models, globally, approximately 50% uses a single-speed and 50% a variable-speed compressor. In the EU, due to the more advanced energy efficiency requirements, the share of variable speed drives is likely higher. See additional remarks in section 4.1.4.

APPLiA stated that the typical compressor motor power is 0.05-0.08 W per litre, depending on the appliance type and energy efficiency level [172].

For the reference refrigerator-freezer (section 5.3), 11% of the mass is in the hermetic compressor. Most of this is steel, cast iron, copper (mainly for the motor winding wire) and (mineral) lubrication oil, with low quantities for aluminium and plastics.

At end-of-life, fridge recyclers remove refrigerant and lubrication oil and then cut-away the hermetic compressor (and the starting capacitor) from the rest of the fridge before shredding, sending it to specialized recyclers. For further remarks on recycling, see sections 4.2 and 6.3.4.

4.1.2.5 Cooling circuit

Except for the compressor and controls, the cooling circuit includes the condenser, the evaporator, and the expansion valve.

For the reference refrigerator-freezer (section 5.3), 10% of the mass (6.2 kg) is in the cooling system (excluding the compressor), of which 5.8 kg for metals. Ferrous metals are 3.9 kg, of which 3.6 kg cast iron for the wire-on-tube condenser. Aluminium is 1.2 kg (most in the evaporator) and copper 0.7 kg (in a heat exchanger and several smaller parts). Plastics are 0.3 kg. The refrigerant, typically R600a iso-butane, weighs 0.048 kg. Other RF models may use different masses and materials. Electrolux reported a general trend to replace copper with aluminium, for cost reasons.

Some parts of the cooling system are external, e.g. the WOT condenser on the back or bottom of the fridge. Other parts, like the evaporator, are inside the structure, (partly) embedded in the fridge body.

At end-of-life, fridge recyclers remove the refrigerant from the cooling circuit. The rest of the cooling circuit is typically shredded together with the rest of the fridge. For further remarks on recycling, see sections 4.2 and 6.3.4.

4.1.2.6 Airflow components

For the reference refrigerator-freezer (section 5.3), 2% of the mass (1.1 kg) is in internal air flow components. This includes e.g. fans, housings, air flow ducts and outlet covers. The entire mass is listed on the BoM as plastic, most GPPS.

The number of fans per fridge varies. A manufacturer estimated that 40% of the fridges have two fans, 40% one fan, and 20% no fan [173]. Some have two fans internally and one to assist cooling externally. Fan motors are 1-4 W and can be single speed or variable speed. The latter use a permanent magnet with ferrite or rubber compound magnets with ferrite powders.

[172] In APPLiA's 2025-04-04 answers.

[173] In its 2025-04-04 answers, APPLiA stated: Appliances with one fan are increasing in number. Those with two fans are the no frost and high efficient refrigerators. 60% of appliances have at least one fan.

Internal air flow components are integrated in the main structure. Considering the low masses and the low value of the components, recyclers typically shred them with the rest of the fridge. For further remarks on recycling, see sections 4.2 and 6.3.4.

4.1.2.7 Electric and Electronic components

RF products can contain the following types of electric and electronic components:

1. Hermetic compressor:
    a. See sections 4.1.2.4 and 4.1.4.
    b. Capacitor for motor starting. Single phase induction motors used in fridges need capacitors for starting (and some use them also for running). The capacitors are usually electrolytic, and the older ones can contain polychlorinated biphenyls (PCBs). See also section 6.3.4.7.
2. Cables and wiring
    a. The power cable connects the fridge to grid electricity. Conductor wires are made of copper or aluminium, surrounded by an insulation layer in PVC or XLPE (cross-linked polyethylene). The plugs and prongs are made of brass (Cu-Zn alloy), nickel or silver plated. Power cables are external and typically removed by recyclers before shredding and further processed by specialized recyclers.
    b. Internal electric wiring has lower voltage and currents but essentially uses the same materials as the external cable. The wiring is (partially) embedded in the body walls, and therefore not removed by recyclers before shredding.
3. Power management:
    a. Overload protector: Prevents damage to the compressor during power surges or overheating. It is a small plastic component connected to the relay switch.
    b. Relay switch: Ensures proper electrical flow to the compressor. It consists of silver- or gold-plated copper contacts. The coils are made of copper. The casing is in Bakelite or ABS plastic. The switches are connected to the compressor and can be dismantled easily.
    c. Power supply unit: Converts 220 V grid electricity to the voltages required for various electronic components. It is located behind the rear access panel inside the fridge near the temperature control panel. It consists of a circuit board which has copper, a microcontroller made of silicon, capacitors made of ceramic, resistors made with metal film. Printed circuit boards are among the components for which regulation 2019/2019 requires spare parts availability. See also sections 4.1.3, 5.6.5, 6.3.4.7 on printed circuit boards.
4. Air circulation:
    a. Evaporator fan motor: Circulates cool air from the evaporator coils throughout the compartments. It is usually located in the freezer compartment near the evaporator coil. It has motor windings made of copper or aluminium wire, shaft of steel, and the blades made of ABS or PC plastic. The bearings of the motor are made of either bronze or ceramic. Removal of the fans is relatively simple for standalone models, but for built-in fridges it can be more difficult because they are integrated in kitchen furniture.
    b. Condenser fan motor: Helps dissipate heat from the condenser coils. It is located at the bottom rear of the appliance behind a protective cover or panel.

5. Safety and diagnostics:
    a. Thermal fuse: Protects the appliance from overheating. It consists of temperature-sensitive components that melt or break the circuit when overheating occurs. The fuse element is made of tin, lead, bismuth or silver alloy. The metal leads are made of copper or nickel-plated wires and the housing is made with ABS plastics or metal.
    b. Diagnostic module: Logs errors and communicates faults through display panels or error codes.
6. User interface and control
    a. Touch panels or keypads: Allow users to set temperatures, activate special modes, and control other settings. They are located on the fridge doors near the top section. The modern units have a touchscreen surface. They contain microchips and touch controllers made with silicon; the electrical contacts contain gold. Printed circuit boards are among the components for which regulation 2019/2019 requires spare parts availability. See also sections 4.1.4, 5.6.5, 6.3.4.7 on printed circuit boards.
    b. Control boards

       Many refrigerators have a control panel made of a plastic housing with electronic components. It collects sensory input from numerous sensors in the freezer/food section, the run time of the compressor, the number of times the doors have been open, the fans, etc. It also allows the user to adjust the temperature settings, energy saving features, etc.

       Electronic control panels have an ABS or polycarbonate plastic casing, silicon microcontrollers, and silver or gold electrical contacts. They use thermistors and a microcontroller to monitor and adjust the temperature. The PCB processes the sensor data and sends signals to the compressor, fans, and the defrost system.
    c. Display module: Shows temperature, settings, and error codes.
    d. Thermostat knob or dial: Provides manual temperature control. It is located inside the fridge and consists of an external knob/dial made of ABS or polycarbonate. The internal shaft is made of aluminium or steel and the thermostat body contains brass (copper-zinc alloy) or stainless steel.
    e. The thermostat is located inside the refrigerator, usually mounted on an interior wall. It controls the cooling process by monitoring the temperature and turning the compressor on and off, or by modifying the speed. There are two types of thermostats. Mechanical thermostats which use a capillary tube and a bimetallic strip to detect temperature changes and electronic thermostats which use sensors (Negative Temperature Coefficient thermistors) and a microcontroller to detect and regulate the temperature. The mechanical thermostats are manually adjustable and are found in older and budget units whereas the newer smart refrigerators and high-end units use the electronic thermostat.

       The capillary tubes are made with copper or stainless steel, and the bimetallic strips are made of nickel and Iron alloy or copper and aluminium alloy. CRMs like nickel, manganese or cobalt based NTC materials are used to make thermistors.

       The thermostat knob or dial provides for manual temperature control. It consists of an external knob/dial made of ABS or polycarbonate. The internal shaft is made of aluminium or steel, and the thermostat body contains brass (copper-zinc alloy) or stainless steel.

   f. Temperature sensors.

7. Light sources.

   Modern fridges used LED light sources. These can be plug-in or screw-in LED lamps, or LEDs mounted on a small electronic board. A single fridge can have more than one light source. Light sources are among the components for which regulation 2019/2019 requires spare parts availability.

8. Ice and water systems:

   These systems include valves, pumps, dispensers, ice makers, and the controls to provide clean cold water and ice. They require electrical and plumbing integration.

   a. Water dispenser control board: Manages water flow, filtration, and dispensing.
   b. Ice Maker module: Controls ice production.
   c. Solenoid valve: Manages the water flow to water dispenser and ice maker.

9. Additional features:

   a. UV sterilisation lamp: Maintains hygiene by killing bacteria in specific compartments. The UV light tube is made up of quartz glass (SiO_2), the electrodes, filaments, ballast, wiring and connectors are made of tungsten, nickel or copper alloys [174].
   b. Humidity sensors: Monitor and adjust moisture levels in crisper drawers. The sensing element is made of polymer film and ceramic which absorbs moisture and changes the resistance based on humidity.
   c. Wi-Fi module: Enables smart control and connectivity to apps for remote monitoring.
   d. IoT sensors: Communicate fridge status, inventory levels, and alerts to smart home systems.

For the reference refrigerator-freezer (section 5.3), 2% of the mass (1.1 kg) is in electrical and electronic components. However, 0.8 kg of this is listed on the BoM as various types of plastic (largest masses for PP and HIPS). The ‘real’ electronics is only 0.5% of the total fridge mass (0.302 kg), of which 0.177 kg for electronics boards (controller board, UI-board), 0.110 kg for cables and wiring, and 0.015 kg for LEDs and their boards. The electronic components have a small mass share but a much higher share in environmental impacts (section 5.6.5).

4.1.3 CRMs in refrigerator / freezers

CRMs are those listed in Annex I and II of the Critical Raw Materials Act [175], see also Table 4 and the phase 1 report of the current study [176].

[174] This description seems outdated. Modern fridges are expected to use LED technology.

[175] REGULATION (EU) 2024/1252 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202401252

[176] Ecodesign preparatory study for product specific measures on scarce, environmentally relevant and critical raw materials and on recycled content, Interim Study Report, Phase 1: Prioritization of materials and product, e.g. Table 21, https://www.ecodesignmaterials.eu/documents

Refrigerators – freezers have been selected for phase 2 of the current study mainly for the potential to use recycled plastics. Compared to other product groups, they did not score high (15th place) on the CRM ranking derived in phase 1. Consequently, CRMs in fridges were not a study focus.

Table 11 shows the CRM quantities used in household refrigerators – freezers (RF), as preliminarily derived in phase 1 of the current study, see following notes.

- The table uses a decimal point, and a comma as thousands separator. Values with decimal point are in blue font.
- The phase 1 analysis also includes some materials that were studied in CRM context but that did not end up on the final list of Critical or Strategic Raw Materials. These data are in grey.
- Column (0): mass in the average RF, in grams per unit
- Column (1): mass in RFs sold in EU27 in 2020 (16.7 mln), in metric tons (thousands of kilos)
- Column (2): supply risk factor, used as weighting factor in column (4)
- Colum (3): primary material production in tons, used as weighting factor in column (4)
- Column (4): CRM weighted score: EU27 sales mass (1) multiplied by supply risk factor (2) and divided by primary production (3).
- Column (5): ranking of CRM materials used in refrigerator-freezers based on the weighted CRM score.
- Column Metal alloy: CRM mass derives from metal masses on the Bill-of-Materials (major alloying elements)
- Column Display: CRM mass derives from breakdown of display / screen mass (none for RFs)
- Column PCB / Elec: CRM mass derives from breakdown of Electronics mass on the Bill-of-Materials, using literature breakdown for low-grade PCBs.
- Column Glass: CRM mass derives from breakdown of Glass mass on the Bill-of-Materials.
- Column Critical RM: materials listed in Annex II of the CRM Act as Critical
- Column Strategic RM: materials listed in Annex I of the CRM Act as Strategic.

Table 11: CRMs in refrigerator-freezers, see notes below table. Source: current study, phase 1 report

material	(0) Mass per unit RF (g)	(1) Mass in RF sold in 2020 (ton)	(2) Supply Risk Factor (SR)	(3) Primary production (ton)	(4) CRM weighted score, (1)*(2) / (3)	(5) Rank among CRMs in RFs	Metal Alloy	Display	PCB / Elec	Glass	Critical RM	Strategic RM
Silicon metal (Si)	155	2,588	1.4	3,000,000	1.2E-3	1	x				x	x
Palladium (Pd)	0.007	0.11	1.5	220	7.5E-4	2			x		x	x
Aluminum (Al)	1,636	27,366	1.2	63,000,000	5.2E-4	3	x		x		x	x
Coking coal	22,954	384,070	1.0	1,000,000,000	3.8E-4	4	x		x		x	
Copper (Cu)	2,298	38,453	0.1	21,000,000	1.8E-4	5	x		x		x	x
Iron (Fe)	29,810	498,793	0.5	1,500,000,000	1.7E-4	6	x		x			
Tin (Sn)	3.0	50	0.9	290,000	1.5E-4	7			x			
Bismuth (Bi)	0.044	0.7	1.9	9,100	1.5E-4	8			x		x	x
Nickel (Ni)	48	810	0.5	2,700,000	1.5E-4	9	x		x		x	x
Silica sand	4,279	71,603	0.3	240,000,000	9.0E-5	10				x		
Chromium (Cr)	109	1,822	0.7	16,000,000	8.0E-5	11	x		x			
Antimony (Sb)	0.329	5.5	1.8	130,000	7.6E-5	12			x		x	
Manganese (Mn)	77	1,294	1.2	21,000,000	7.4E-5	13	x				x	x
Zinc (Zn)	193	3,233	0.2	13,000,000	5.0E-5	14	x		x			
Gold (Au)	0.017	0.29	0.4	3,300	3.5E-5	15			x			
Silver (Ag)	0.016	0.28	0.8	28,000	7.9E-6	16			x			
Cobalt (Co)	0.007	0.11	2.8	130,000	2.4E-6	17			x		x	x
Strontium (Sr)	0.009	0.15	2.6	160,000	2.4E-6	18			x		x	
Beryllium	0.0003	0.01	1.8	6,000	1.7E-6	19			x		x	
Lead (Pb)	0.658	11	0.1	5,000,000	2.2E-7	20			x			

Baryte	0.023	0.4	1.3	8,800,000	5.7E-8	21				x			x	

The study team identified the following components in fridges that potentially contain scarce, environmentally relevant and critical raw materials:

- Motors, Compressors, Fans, VSDs (Copper, Aluminium, Ferrite permanent magnets)
- Capacitors (Tantalum)
- LED light sources (Gallium, Indium, rare earths (e.g. Yttrium, Europium) used as phosphors in some white LEDs).
- Batteries (Lithium-ion) [177]
- Magnets (door gasket, mostly ferrite)
- Displays (LED matrix, OLED, Indium-Tin-Oxide)
- Thermostats and temperature/humidity sensors (Cu, Al, Ni, Mn, Co)
- Control electronics boards and components (Cu, Au, Pd, Pt, Ag, Si, Ga, As, In)
- Power supplies (Cu, Al, rare earths)
- Electric connectors, switches and wiring/cabling (Cu)
- Parts in Aluminum or aluminium alloy (Al itself, alloying elements)
- Parts in Copper or copper alloy (Cu itself, alloying elements)
- Parts in steel (alloying elements, coatings; use of coking coal)
- Plastic parts (fillers, additives, pigments, flame retardants)
- Coatings (large variety of possibilities [178])

RF manufacturers indicated that variable speed compressors with permanent ferrite magnet motors are increasingly being used in fridges.

The small fan motors (1-4 W), for internal air circulation and/or assisting external heat dissipation, also use permanent ferrite magnet motors, or rubber compound magnets with ferrite powders.

For cooling generators, and for electric motors with permanent magnets, article 28 of the CRM Act (see section 1.5.5) already requires a labelling indicating whether those products incorporate one or more permanent magnets, and if so, whether those permanent magnets belong to any of the following types:

(i) neodymium-iron-boron
(ii) samarium-cobalt
(iii) aluminium-nickel-cobalt
(iv) ferrite

In future, there will also be a data carrier providing access to information on the weight, location and chemical composition of all individual permanent magnets included in the product, and on the presence and type of magnet coatings, glues and any additives used, and to information enabling access and safe removal of all permanent magnets incorporated in the product, at least including the sequence of all removal steps, tools or technologies required for the access and removal of the permanent magnet [179].

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[177] In comments following the 4th SH meeting, a stakeholder noted that Lithium batteries mostly appear (in smaller cases) within commercial refrigerators for the reason of tracking if the cold chain is uninterrupted. A clear labelling of those devices is very important for recyclers.

[178] https://www.plastmagazine.it/masterbatch-coloranti-classificazione-e-applicazioni/

[179] In comments following the 4th SH meeting, a stakeholder noted that the CRM Act will very likely be modified by a technical specification prepared by CEN, where only ferrite above 200 grams and 25 for NdFeB, SmCo, and AlNiCo will need labelling.

4.1.4 Trends in design

Recyclers have noted that the Ecodesign energy efficiency requirements set in the past have led to the use of more PUR foam, which is currently not recyclable. In future it is expected that more vacuum insulation panels will be integrated into the fridge walls, further complicating recycling processes (see next section).

In addition, the requirements induced manufacturers to changes in the compressors and their controls. In a conventional refrigerator, the compressor operates at maximum capacity in response to thermal load, or it is turned off when the desired temperature has been achieved. However, the energy consumption requirements of a refrigerator vary widely based on various factors. Refrigerators with advanced adaptive compressors use electronic controls and variable speed compressors (with permanent magnet motors) which operate smoothly and, on average at a lower level over time, to maintain the ideal temperature. More precise sensors throughout these refrigerators tell the compressor exactly where to direct any additional cooling, and how much cooling is needed, allowing the refrigerator to maintain different temperatures in different compartments. Again, this is a significant improvement over traditional refrigerator models that are simply designed to maintain set temperatures in the fresh food and freezer compartments, which can be wasteful. The added energy savings from this technology are impressive. Refrigerators employing these systems cut energy use by at least 30% [180] [181] [182].

Other trends (to be expanded in the review study):

- Shift in condenser location, from behind to below
- More and more complex user interface displays,
- More (partly) transparent doors
- Addition of water dispensing, ice cubes dispensing
- LED (and maybe OLED) lighting
- Increase in average refrigerated / frozen volumes?
- More plastic, less metal?
- More glass?
- Less copper, more aluminium?
- Smart appliances

[180] https://www.energystar.gov/products/ask-the-experts/technology-breakthrough-energy-efficient-refrigerators#:~:text=Today's%20models%20have%20better%20insulation,reduce%20energy%20use%20in%20refrigerators.

[181] https://www.energystar.gov/partner-resources/products_partner_resources/brand-owner/eta-consumers/advanced-compressors

[182] https://en.wikipedia.org/wiki/Refrigerator

4.1.5 Vacuum Insulation Panels (VIPs)

Vacuum Insulation Panels (VIPs) are high performance insulation materials used in refrigerators and freezers to improve energy efficiency.

VIPs consist of a rigid, highly porous core material made of fumed silica [183], glass fibre [184], perlite [185] or aerogel [186] providing structural support [187] and an air-tight membrane which is an aluminium film, metallised plastic or multi-layer material which encloses the core and prevents air and moisture from entering. Chemicals known as 'getters' can be added to the core material to collect gases that leaked through the membrane or that outgassed from the membrane materials [188]. Desiccants can be added to absorb moisture. Opacifiers can be added to scatter and absorb infrared radiation. The air is removed from the panel to reduce heat transfer through conduction and eliminate convection. Some VIPs include a valve to allow re-evacuation of the panel if the vacuum degrades.

VIPs provide significantly higher thermal insulation efficiency [189], with (initial) thermal conductivity values as low as k=0.002–0.004 W/m·K [190], compared to PU foam's k=0.020–0.025 W/m·K. Typically, VIP panels of 2 cm thickness are used in fridges, embedded in PUR for structural strength and protection. In that sense, even though the k-value is at least 4-5 times better than PUR, the U-value of such a PUR/VIP panel is 'only' 33 % better. The panels are not used all-around, but only in (some of) the walls where they have most effect, i.e. bottom, back and front (door), and only in the larger and more expensive models. It can be estimated that in those models the sides with VIP panels make up 30-40 % of the envelope surface area and can bring about a 15% reduction in the transmission heat losses (12 % in total electricity consumption) [191].

[183] Fumed silica is obtained from silica heated to high temperature and condensed from the vapour state in a powdery form. It is characterised by extremely small particle sizes of 5-50 nanometres in diameter resulting in high surface area. Panels using fumed silica have a density of 160-230 kg/m3 and an (initial) thermal conductivity of 3.5-5 mW/m.K. The core material is advertised to be recyclable. Panel specifications from va-Q-tec. https://www.va-q-tec.com/en/

[184] Fiberglass or Glass fibre is made from thin strands of glass that are woven together and reinforced with a binder or resin, or hot-pressed non-woven without organic binders (a type of felt). It is primarily composed of silica (SiO_2). Fiberglass VIPs are slightly heavier than fumed silica VIPS (210-270 kg/m3) but have lower thermal conductivity (1.5-3.0 mW/m·K). Panel specifications from Knauf. https://www.oem.knaufinsulation.com/vacuum-insulated-panels

[185] Perlite is a naturally occurring volcanic glass that expands when heated, creating a lightweight, porous material with high insulation and moisture-retention properties. Perlite can be a low cost and high durability alternative for fumed silica. Perlite has a slightly higher thermal conductivity compared to fumed silica (~7-16 mW/m·K). https://www.perlite.org/wp-content/uploads/2024/11/Perlite-Vacuum-Insulation-Panel-Cores.pdf

[186] Aerogel is an ultra-lightweight, highly porous solid made by removing the liquid from a gel and replacing it with a gas without a significant collapse of the gel structure. Aerogels can be made from a variety of chemical compounds, but silica aerogels are most widely used. Aerogels have a very low density: the record is 1.9 g/m3 (compare: air is 1.2 g/m3). Aerogels are structurally strong and have good thermal insulation properties (~13-20 mW/m·K). https://en.wikipedia.org/wiki/Aerogel

[187] The core material avoids the collapse of the panel when creating the vacuum.

[188] https://en.wikipedia.org/wiki/Vacuum_insulated_panel

[189] In materials with high porosity (75% - 99%) such as foams, powders and fibres, the overall thermal conductivity is influenced greatly (50–70%) by the thermal conductivity of the gas trapped in the pores. Due to the suppression of gas conduction, the effective thermal conductivity of an evacuated porous material can be reduced by three to four times compared to its un-evacuated state. This is the principle of vacuum insulation panels.

Mostly, the reported thermal conductivity of VIPs is based on the centre of panel value measured within 1–100 days of manufacturing and the long-term classifications, such as energy saving potential and energy labelling, are calculated using these values. However, it is important to note that thermal conductivity of VIPs increases with time. The rise in conductivity is caused by two major factors namely pressure rise (leading to gaseous conductivity rise as Eq. (3)) and moisture level rise. https://www.sciencedirect.com/science/article/abs/pii/S0140700719305249

[190] Initial values in the centre of the panel. Including border effects, the thermal conductivity can be 0.005-0.006 W/m.K. With time, when vacuum decreases and some moisture can enter the panel, the degree of thermal insulation can degrade.

[191] Preparatory/review study, Commission Regulation (EC) No. 643/2009 with regard to ecodesign requirements for household refrigeration appliances and Commission Delegated Regulation (EU) No.1060/2010 with regard to energy labelling of household

Hence, for the same wall thickness, VIPs increase thermal insulation efficiency, or for the same degree of insulation, VIPs allow for thinner walls, enabling larger storage capacity within the same external fridge dimensions.

The benefits of using VIPs in refrigerators have been well established. However, VIPs face obstacles in being the insulation of choice in refrigerators due to a variety of factors such as [192]:

i) uncertainty over an assured thermal conductivity,

ii) uncertainty over the lifetime of the VIPs [193],

iii) uncertainty over a constant supply of VIPs if their demand ramps up, and

iv) the high cost of VIPs, which can be five times per unit area higher than conventional foam insulation.

Due to the high costs of VIPs, their use is limited to high performance fridges. However, APPLiA [194] noted that, because of the increasingly stringent requirements on energy efficiency in the ecodesign and energy labelling regulations, manufacturers are increasingly using vacuum insulation panels. It is expected that the use of VIPs, either alone or in combination with PUR foam, will significantly increase by 2030, and the study on recycled content and recyclability should take this into account [195].

APPLiA further recommended that such considerations should not be limited to the end-of-life impact of VIPs but take also into account the overall performance of VIPs throughout the products' lifetime and the energy efficiency benefit they provide. The inclusion of VIPs is based on a careful assessment by manufacturers, which requires trade-offs between competing objectives such as energy efficiency and recyclability. In addition, timelines should be considered in relation to BoM changes: almost all fridges now arriving at recyclers (with a BoM of 16 years ago) are without VIPs. The fridges now produced will have a share of VIPs but reach their end-of-life 16 years from now and will then be treated in evolved recycling processes. And 16 years from now, a much larger share of manufactured fridges will use VIPs. Also, the construction of the product and its parts play a large role for a product's recyclability. The recycler's stream and how treatment technology/processes evolve will also significantly influence the recycling result.

From the recycling point of view, the sandwich structures with PUR foam already pose difficulties. When VIPs are integrated in these panels on a large scale, the complexity will further increase. The core materials, such as fumed silica, can become respirable dust during recycling, posing health risks and necessitating stringent dust control measures. Glass fibres are not recyclable. When shredded together with VIPs, the PUR foam will contain more impurities (aluminium, silica, glass fibre), which can obstruct its chemical recycling [196].

refrigeration appliances, FINAL REPORT, VHK and ARMINES in collaboration with Viegand & Maagøe and Wuppertal Institute, contract co-ordination VITO, 4 March 2016

[192] Vacuum insulation panels for refrigerators, International Journal of Refrigeration, Volume 112, April 2020, Pages 215-228 https://www.sciencedirect.com/science/article/abs/pii/S0140700719305249

[193] Other sources report that VIPs have a longer lifespan with minimal degradation over time, whereas PU foam can lose its insulating properties due to moisture absorption and aging.

[194] APPLiA input to priority products under ED study on ReCo and CRM, 2024-09-13, Refrigerators, Q1: Up-to-date information on Bill-of-Materials (BOM) for refrigerator-freezers.

[195] In its 2025-04-04 answers, APPLiA noted that: APPLiA does not have reliable data on the use of VIPs, but in the next years the number of VIPs will increase. The recycling industry should be prepared for this increase. We have a mandatory sticker that should help in the correct treatment by recyclers. The design is dictated by APPLiA's Code of Conduct. https://www.applia-europe.eu/codes-of-conduct-for-vacuum-insulation-panels-vips

[196] In comments following the 4th SH meeting, stakeholders have confirmed that currently the biggest challenges for recycling facilities are indeed vacuum-isolation panels. Those are often very fine-grained which makes their pre-separation before

4.2. Plastic recycling technologies

4.2.1 Recycling of the HIPS inner liner (case Electrolux)

4.2.1.1 Introduction

The walls of a refrigerator or freezer [197] typically have a sandwich construction, which must provide the degree of thermal insulation required to meet the minimum energy efficiency requirements (section 1.5.1) but also has a structural function [198] and an aesthetical function [199]. The inner side of the walls (the inner liner and door liner, potentially in contact with the food) is usually made of High Impact Polystyrene (HIPS). The outer side is usually made of steel sheet. The thermal insulation in the centre of the sandwich typically uses polyurethane foam (PUR). The three constituents (HIPS, PUR and steel) adhere to each other, which is essential for the functions of the sandwich structure [200] [201].

4.2.1.2 Consortium

Electrolux Italia S.p.A. developed a line of built-in refrigerators [202] with inner liners made of recycled polystyrene (B) coextruded with one layer of virgin polystyrene (A) [203]. The latter layer acts as a 'functional barrier', ensuring that migration of substances from the recycled material to the food in the refrigerator remains below the regulatory limits [204]. The refrigerators are on the market since October 2022 [205]. The inner liners are made from 70% recycled plastic, which equates to 13% of the total plastic used in the refrigerator. The plastic is sourced from a specialty supplier (CoolRec in the Netherlands [206]) that collects and refines plastic from discarded refrigerators in Europe. Electrolux won the European Plastic Recycling Award for "Automotive, Electrical or Electronic Product of the Year 2023" for its refrigerator inner liner with recycled plastic [207].

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shredding difficult or even impossible. At the moment, devices containing VIPs can only be recycled when the share of the panels is rather low. There is currently no solution to the recycling of the material. Current research and development is rather focused on the recycling of PU-foam which may lead to practical applications within the next 1-2 years. However, VIPs contaminate the PU foam and a separation of those materials is not implementable. The increasing usage of VIPs may actually lead to a decline of recycling rates - despite modern recycling facilities. Recyclers therefore advocate the use of PU-foams, and not of VIPs.

[197] Potentially including the door(s), although in some cases the doors are made in glass.

[198] It must be sufficiently rigid to maintain the shape of the product, and resist to manufacturing, assembly, distribution, installation and use. It must support trays, shelves etc. that carry the food and serves as a support for other components of the product.

[199] Except maybe for the outer sheets of built-in products.

[200] No additional adhesive is used. The PUR itself adheres to the HIPS and steel.

[201] In more recent high-performance models, vacuum insulation panels may be used, see section 0.

[202] the Electrolux 500-900 Series and AEG 5000-9000 Series

[203] The door liner is still made from virgin plastic (start 2025), for technical manufacturing reasons, that have recently been resolved. For the near future, use of recycled HIPS is planned also for the door liner.

[204] The use of the virgin material barrier is a food contact measure that Electrolux took, and this was verified with Fraunhofer. It is a certified (and also more costly) process than doing it without. Even without recycled content, Electrolux already used a multi-layer inner liner, because this produces a stronger and thinner inner liner. The virgin top layer was proposed to comply with the food contact regulation more easily. And it is also more convenient in case something changes in the recycled content composition. On the need for the barrier, see also section 4.2.2.

[205] World's first fridge with 70% recycled plastic inner liners is ours, https://www.electroluxgroup.com/en/worlds-first-fridge-with-70-recycled-plastic-inner-liners-is-ours-34846/

[206] CoolRec Plastics is one of the largest recyclers of waste from electrical and electronic equipment (WEEE) plastics in Europe, https://www.coolrec.com/en/plastics

[207] Circularity wins: Our recycled plastic fridge inner liner scoops top award, https://www.electroluxgroup.com/en/circularity-wins-our-recycled-plastic-fridge-inner-liner-scoops-top-award-35753/

As required by Regulation (EU) 2022/1616 (section 1.5.7.5), the technology for the use of rHIPS in the fridge inner liners was developed by a consortium, with the Italian Ecol Studio acting as 'novel technology developer' [208]. In addition to CoolRec and Electrolux, other partners of the consortium are MG Plastic recycling facility, and converters Roverplastic (Italy) and Jász-Plasztik (Hungary) [209] [210].

Figure 19: Indication on the inner liner of a refrigerator, declaring 70% recycled plastic content (courtesy Electrolux Group [207])

4.2.1.3 Production process

The processes involved in the production of the inner liners are:

- Input for the recycling process are post-consumer fridges, from WEEE collection by retailers and municipalities [211]. Fridges from all brands are collected mainly from the Netherlands, Belgium, northern France, and some from Germany and United Kingdom. Only the inner liners of those fridges are used [212].
- Appliances arriving at the recycling plant are unloaded and sorted. Manual removal of liquids (refrigerant, lubrication oil), compressors, capacitors, external cables, glass, wood, lamps, food waste, batteries, mercury switches [213]. A composition mass balance is performed.

[208] Developer: independent third party of the "R-Rigid PS Consortium" that acts as developer according to Art.32(2) of Regulation (EU) 2022/1616. The developer is also responsible for handling non-conformities and for the 6-monthly monitoring reports.

[209] R-HIPS for refrigerator inner liner, Elisabetta Silvestrini (Ecol Studio SpA), Corrado Cecchini (Electrolux Italia SpA), International Conference on Food Contact Compliance, Baveno (Italy), 26-28 September 2023.

[210] Monitoring programme for the project "rPS- materials and articles in which the recycled plastic is used behind a Functional Barrier", Ecol Studio 2024, https://www.ecolstudio.com/images/Report-Electrolux/REPORT-2024.pdf

[211] In CoolRec, 85% of the fridges arrives from extended producer responsibility (EPR) streams (separate collection). Other 15% comes from small local collectors or from own collection (complementary collection). Collection schemes can differ per country. E.g. in Germany municipalities can opt out of EPR schemes for specific product groups. Coolrec deals with 100% of the fridges collected in NL and 80% in BE.

[212] The inner liners do not contain flame retardants or fibre reinforcement, but flame retardants are used in other plastic parts in fridges to meet requirements from Low Voltage directive and Safety directives (that is one of the reasons that only inner liners are used for recycling).

[213] Electrolux commented that they do not use mercury switches in their products, and neither should competitors, because they have been banned under RoHS. However, in 2025 recycler CoolRec still encounters them in some discarded fridges and freezers.

- Mechanical shredding and separation of valuable materials (plastics, PU, metals) in a dedicated completely incapsulated plant [214]. This produces flakes of pre-decontaminated rHIPS with a verified high level of purity (96%). Analyses to determine the presence of contaminating substances with molecular weight < 1000 Dalton [215] in the flakes [216].
- The flakes are additionally decontaminated (level I), melted and compounded in an extruder together with 5% additives [217] (controlled temperature, pressure, speed), producing rHIPS granulates / pellets. These are stored in 'big bags' and labelled to ensure traceability. Characterization of mechanical, impact and rheological properties. Analyses to determine the presence of contaminating substances with molecular weight < 1000 Dalton in the pellets. The Certificate of Analysis (CoA) of the batch is edited.

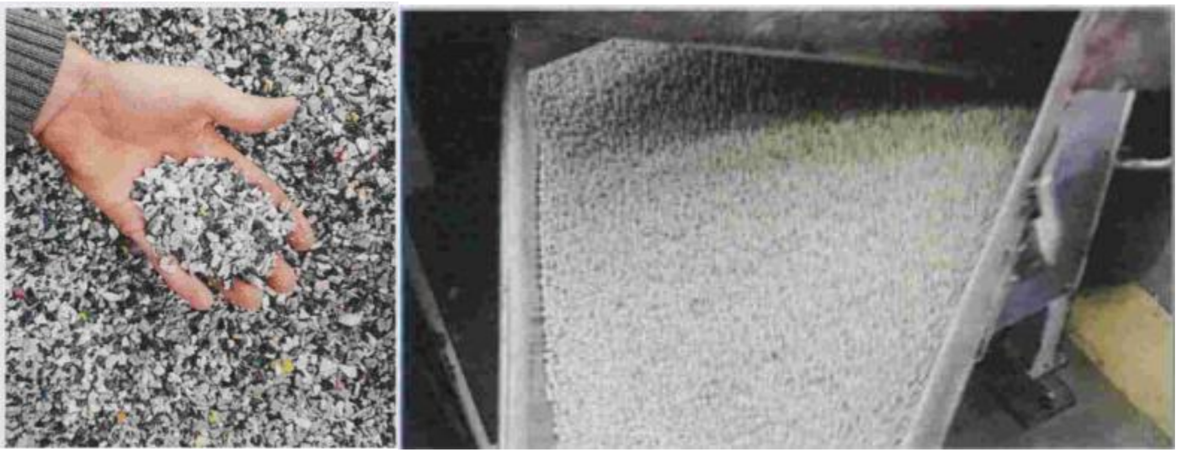

Figure 20: Flakes after shredding (left) and granulates after extrusion (right) (courtesy Electrolux Group [209])

- Transport of the rHIPS pellets to the converter and decontamination (level II). Co-extrusion step where rHIPS pellets (B layer) and virgin HIPS pellets mixed with masterbatch (light grey colorant) (A layer) are extruded together to form 2-layer (A/B) sheets. In line cutting to specific dimensions with the shear.

[214] Sorting of the shredded flakes. Different sorting processes are subsequently used to separate plastic from metals, to separate plastic types, metal types, precious and critical materials. The sorting processes include magnetic & eddy separators, density separators (float/sink in water/salt with different densities), air separators, wind shifters, electrostatic separators, optical sorting.

[215] The dalton (symbol: Da), also known as an atomic mass unit, is a unit of mass that is equal to one twelfth of the mass of a free carbon-12 atom at rest. Its value is approximately equal to 1.660 x 10^{-27} kg.

[216] Various analytical methods are used to detect the substances in input and output plastics. The analytical equipment is usually composed by:

• Headspace-GC/Ms (Gas Chromatography with Mass Spectrometry) for analysis of volatile substances:
- Sample thermostatation: 25min a 125°C.

• SPME-GC/MS and GC/MS after solvent extraction of the sample for semi volatile substances:
- SPME-GC/MS analysis: sample thermostatation: 1h at 60°C
- GC/MS analysis after solvent extraction: hexane extraction of the sample for 1h in ultrasonic bath and for 16h at room temperature.

• LC-QTOF-MS (Liquid Chromatography with Mass Spectroscopy with QTOF detector) analysis after solvent extraction of the sample for semi volatile and non volatile substances.
- Acetonitrile extraction of the sample for 1h at 60°C.

• ICP-MS analysis after acid mineralization of the sample and XRF spectrometry for heavy metals

[217] The additive is polybutadiene and virgin polystyrene. It serves as impact modifier to replace the rubber phase deteriorated during the life of the refrigerators, to reach the proper resistance to impact and to chemicals. The additive is food contact approved but is not intended as a contribution to the achievement of the food contact certification. It does not contain silver and does not impact subsequent recycling.

- Transport of the sheets to the refrigerator manufacturer, and transformation into thermoformed articles by heating them up and then stretching them to form a bubble, which adheres to the mould due to vacuum pressure. After thermoforming, the component is cooled and further refined. Sample thickness check on the functional barrier. Analyses to determine the presence of contaminating substances with molecular weight < 1000 Dalton in the final thermoformed sheets. Measurement or estimation of the migration levels. Analysis to confirm that no residual migration from the contaminants has been detected over 0.01 mg/kg food.
- Assembly of all refrigerator components and foaming of the inner liners.

4.2.1.4 Technology development

The HIPS recycling process developed by the Electrolux consortium involved a continuous improvement of the separation processes and a patient re-looping from bench-scale tests in the lab to extrusion and vacuum forming trials. The concept was identified some 20 years ago, and more intensive development work took place during the recent three years. The effectiveness of the defined solution was successfully checked on different product architectures across the world [218].

The food contact regulations applicable for domestic refrigerators are CR 1935/2004, 2023/2006, 10/2011 and 2022/1616 (details in section 1.5.7). For all recycled plastics, with the only exception of recycled PET, the food contact declaration by raw material producers is not available. This makes the standard procedure to food contact certification unapplicable, as a list of potential contaminants to be detected in the migration test is not available. A viable solution was identified in the application of a layer of virgin plastic working as a functional barrier [219], stopping the migration of undesired contaminants. A challenge test was designed to determine the minimum thickness of the layer of virgin HIPS effectively working as a barrier [220]. The challenge test protocol involved:

- The material (sheet, shredded product, pellet, flakes, etc.) is contaminated with model contaminants (doping with surrogates).
- The contaminated material is analysed to see the contamination degree obtained.
- Efficiency (%) calculated based on the measured concentration of surrogate contaminants before and after decontamination process.

[218] European FS and BI refrigerator ranges, Asian & Pacific models, North-American models.

[219] See also section 4.2.2

[220] Regulation (UE) No 10/2011 for virgin plastics introduces the definition of functional barrier:
- Migration < 0.01mg/kg of non-listed substances in Annex I
- Absence of CMR (carcinogenic, mutagenic or toxic to reproduction)

Regulation 2022/1616 in article 32 contains ‘Specific transitional provisions applicable to the manufacture of materials and articles in which the recycled plastic is used behind a functional barrier’:
1. The following additional requirements shall apply to the operation of recycling installations that already manufactured recycled plastic materials and articles in which the recycled plastic is used behind a plastic functional barrier before 10 October 2022:

(i) the decontamination installation manufacturing the recycled plastic as well as any post-processing installation adding the functional barrier is included in a list of installations submitted by a developer notifying the specific recycling technology applied by all the installations on the list in accordance with Article 10(2); and,

(ii) results from migration tests, challenge tests, and/or migration modelling, as appropriate and applicable to the notified recycling technology and to the specifics of the process that the recycling installation applies, unequivocally show that the functional barrier is capable, taking into account the contamination level of the recycled plastic, of acting as a functional barrier in accordance with Regulation (EU) No 10/2011 during the foreseeable shelf-life of the manufactured recycled plastic materials and articles, which comprises the time from their manufacture onwards, and the maximum shelf-life of the packaged food, if any

Five substances were tested, differing in polar / non-polar, volatile / non-volatile, vapor pressure and boiling point. Tests were performed separately on B layer samples (recycled material) and on A/B layer samples, to check the possible migration of substances and the effectiveness of the barrier [221].

The results of the tests indicated the use of a B layer with thickness of 2.7 mm and an A layer functional barrier with thickness 0.6 mm.

4.2.1.5 Consumer acceptation

Another aspect of the development process was consumer research, which in general indicated no concerns to accept recycled plastics. In some markets, sustainability is conceived as an added value:

- The change in aesthetics is accepted. Most consumers prefer the light grey colour of the rHIPS [222].
- No concerns regarding quality, hygiene and safety using recycled plastics in fridges.
- Communication needs to be carefully considered – clear, relevant, cut through, and greenwashing-free.
- Studies confirm that recycled plastic is worth paying more for.

4.2.1.6 Patent

Electrolux has filed a patent on 28 November 2022 under international application number PCT/EP2022/083425. It was published on 6 June 2024 under number WO 2024/114878 A1 [223], and Electrolux hopes that it will be released end 2025. The patent claims cover [224]:

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[221] Migration tests have been performed by using ethanol 10 % (A), acetic acid 3 %(B) and oil (D2) as simulant for 10 days at 20°C.

[222] What the users see is the virgin A-layer, not the rHIPS layer. Small remaining residues of PUR in the rHIPS can affect the colour of the inner liner base material (yellowish shade), which can be visible through the thin virgin layer. A coloured inner liner avoids this. The chosen grey colour was also well accepted by consumers and does (at least initially) distinguish the appliances with recycled plastic from other appliances.

[223] https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2024114878

[224] Claims:
1. A refrigerator inner liner comprising first layer of a re-cycled material adapted to face the insulation wall of a cooled refrigerator compartment, and a second layer of virgin material adapted to face the inside of a cooled refrigerator compartment.
2. The refrigerator inner liner according to claim 1, wherein the second layer placed in direct contact with the first layer.
3. The refrigerator inner liner according to claim 2, where a third, cap layer is placed onto the second layer.
4. The refrigerator inner liner according to any one of claims 1 - 3, wherein the cap layer has a thickness of 0-200 µm.
5. The refrigerator inner liner according to any one of claims 1 - 4, wherein the second layer has a thickness of 100 -- 1000 µm.
6. The refrigerator inner liner according to any one of claims 1 - 5, wherein the first layer has a thickness of 900 -- 4800 µm.
7. A refrigerator comprising a cooled compartment and a door for accessing the cooled compartment, wherein the inside walls of the cooled compartment are provided with the refrigerator inner liner according to any one of claims 1 -- 6.
8. The refrigerator according to claim 7, wherein the door is provided with the refrigerator inner liner according to any one of claims 1 -- 6.
9. A method of producing a refrigerator inner liner comprising to provide a first layer of a re-cycled material adapted to face the insulation wall of a refrigerator and a second layer of a virgin material adapted to face the inside of a cooled refrigerator compartment, wherein the second layer is placed in direct contact with the first layer.
10. The method according to claim 9 further comprising to provide a cap layer placed onto the second layer.
11. The method according to claim 9 or 10, wherein a co-extrusion process is used to place the second layer onto the first layer.
12. The method according to claim 9 or 10, wherein a co-lamination process is used to place the second layer onto the first layer.
13. The method according to claim 9 or 10, wherein a co-extrusion process is used to place the cap layer onto the second layer.
14. The method according to claim 9 or 10, wherein a co-lamination process is used to place the cap layer onto the second layer.

- the above described 2-layer A/B construction for the inner liner, with virgin and recycled material respectively, optionally with an inner third layer (for aesthetic reasons), within certain thickness ranges,
- refrigerators using such inner liners (also for the doors),
- the production process for such inner liners, by co-extrusion or co-lamination

4.2.1.7 Cost aspects

Questioned on cost aspects of the use of r-HIPS, Electrolux commented that the overall handling and creation of a new material costs more compared to virgin HIPS and does increase complexity. Pricing strategies could not be disclosed, but the appliances with the recycled inner liner are sold at a premium price that is considered interesting by some consumers, and that does not generate a loss to Electrolux.

The solution based on the barrier cap layer requires a specifically designed extrusion line, also due to a change in the cap layer thickness. The related investment is in the range of some millions of euros. In addition, certification costs of € 0.5 million were sustained to be compliant with EU regulation 2022/1616 (section 1.5.7.5).

For virgin material, a continuous material quality monitoring program is not necessary. The use of recycled plastic, especially in a food contact application, requires an ongoing quality monitoring process, with costs up to at least 100,000 €/year, including personnel and certification.

4.2.2 Recycling of HIPS, research in the PRIMUS project

The PRIMUS website (https://www.primus-project.eu) introduces the project as follows [225]:

> *29 million tons of waste plastic are generated from daily consumer activity, but only 1/3 is collected for recycling. One reason for this is that plastics are complex materials, and they are used in a wide range of different applications, and recycling these complex plastic products and components usually generates low value materials, so burning it for heat or electricity is economically viable. But not environmentally viable.*
>
> *The PRIMUS Project wants to change this by researching new polymer recycling technologies that allow us to produce new technically and safety compliant recycled materials that can be used for manufacturing high value products, so collecting and recycling plastics becomes now economically feasible, as well as good for the environment.*
>
> *Increasing the collection and recycling of waste plastics will not only help protecting the environment but will also boost a new emerging industrial economy with the creation of thousands of jobs throughout Europe.*

[225] PRIMUS is a project funded by the Horizon Europe in the following call: HORIZON-CL4-2021-RESILIENCE-01-10: Paving the way to an increased share of recycled plastics in added value products (RIA). PRIMUS is a 3-year project with a total budget of 7 M€. PRIMUS has 10 partners, and 2 affiliated entities. The partners are: VTT, Circularise, Tallin University, University of Eastern Finland, Maier, Maier technology Centre, Greendelta, Cikautxo, Cikatek, Mondragon, Plastic Recyclers Europe, CoolRec.

Of particular interest for the current study is PRIMUS' work package 3 [226], whose objective was to deliver high-performance recyclates and raw material formulation with recycled content for four PRIMUS demos:

1) DEMO1 PC/ABS for automotive interior,

2) DEMO2 TPV for electric vehicle cooling circuit,

3) DEMO3 high impact PS for food contact refrigerator liner, and

4) DEMO4 EPDM washing machine gasket.

As regards Demo 3 for the fridges, promising results were achieved from the upgrading of r-HIPS flakes from EoL refrigerators. Mechanical properties and melt flow characteristics for extrusion thermoforming were upgraded to a level comparable to the primary HIPS material. Recycled content up to 70% was demonstrated. Mechanical and rheological testing, and NIAS [227] screening tests showed that closed loop recycling of HIPS in refrigerator liners is technically feasible.

As confirmed by a personal communication to the study team, the results of the project demonstrate that recycled HIPS can also be used directly in food contact applications [228]. The virgin layer barrier as used by Electrolux (section 4.2.1) is not necessary to meet the requirements from the food contact regulations.

Main take-aways [229]

The PRIMUS project demonstrated that recycled HIPS from closed-loop end-of-life refrigerators can be used directly in food contact applications, without the use of barrier layers (if collection, processing and recycling is properly done).

4.2.3 Recycling of polyurethane

Rigid polyurethane foam (PUR) is used as core material in the sandwich structure typically forming the body and doors of a fridge or freezer (section 4.1.2). For its structural and thermal functions, it must adhere to the outer sheet (usually steel) and to the inner liner (usually HIPS), meaning that end-of-life separation of the PUR from the other materials presents difficulties. Parts of the cooling system (copper, aluminium) and electric wiring (for light sources, sensors, controls) can be embedded in the foam. After shredding and separation, some PUR remains attached to the steel and HIPS, which does not seem to present recycling problems [230]. Vice versa, the PUR may contain some HIPS, steel, copper and aluminium contaminants, which can be a problem during recycling.

PUR foam from recent fridges contains blowing agent cyclopentane. APPLiA reported that approximately 20% of the old appliances coming back as WEEE today still contain CFCs at

[226] PRIMUS project, WP3. Production of quality recyclates, DEMO 3: r-HIPS from refrigerators to refrigerators demonstrating food contact, Ref. Ares(2024)4761788 - 02/07/2024, https://www.primus-project.eu/wp-content/uploads/2024/09/D_3.3-PRIMUS-demo-cases-studies-report.pdf

[227] NIAS are Non-Intentionally Added Substances. These are chemicals that are present in a food contact material (FCM) or food-contact article (FCA) but have not been added for a technical reason during the production process. See also section 1.5.7.

[228] The food contact regulation allows the use of 100% recycled material. The PRIMUS project has shown that recycled HIPS can meet the FCM requirements directly, also without the use of a virgin barrier layer.

[229] Following the 4th SH meeting, a manufacturer organisation commented that the conclusion from the PRIMUS project is very optimistic. Currently, the certified recycled material is not available on the market. Theoretically possible but associated with considerable effort and additional costs.

[230] According to CENELEC standards, 0.5% PU foam is allowed in plastics and 0.3% in metals.

the end of life [231]. As the phase out of CFCs in fridges and freezers was introduced in 1995 and HCFCs were forbidden in 2010, the amount of cooling units containing these substances reaching EU recycling plants is constantly decreasing. The blowing agents are recovered during shredding (all types together), but traces may remain present in the shredded foam, and the presence of halogens can cause problems during recycling.

In addition, modern high-energy-efficiency fridges may contain vacuum insulation panels inside the PUR foam, which further complicates recycling, and recycling problems are expected to increase in future when VIPs start being used in large quantities [232].

PUR foam is generally being recovered from fridges, grinded and then incinerated with heat recovery, as an alternative fuel in industrial processes. On some occasions the grinded PU may be used as filler in other products or as an additive to the polyols used for PUR foam production [233]. Different PUR producers are working on chemical recycling concepts and processes which will enable to recycle the shredded PUR foam to close the loop [234]. These processes are expected to be applicable at large scale by 2030 [235].

The end-of-life problems of PU foam have been recognized since decades and there is a wide literature on its recycling. A non-exhaustive summary is provided below:

Recypol project (2001-2004) [236] [237]

The overall goal of this LIFE Project was to demonstrate a real economically and ecologically viable recycling (cycle) of all polyurethane plastics (PUR) and then to effectively implement it, by:

- Establishing a technical scale plant to demonstrate an economically and ecologically viable recycling system (full cycle, not down cycling) for all PUR.
- Providing a system to be implemented at PUR manufacturers of reasonable size to immediately use their PUR-scraps to regain polyol and refeed it into the process.
- Refining raw recyclate into ready-to-use material blends to allow other manufacturers without own recycling plants to use the technology.
- Establishing new techniques to enable recycling of soft and/or semi-hard polyurethane.

[231] APPLiA input to priority products under ED study on ReCo and CRM, 2024-09-13, Refrigerators, Q6: Where are we with research on the recycling of polyurethane? Processes, costs, feasibility, already in practice? Can polyurethane insulation be separated during dismantling?

[232] Personal communication of recycler CoolRec to the study team.

[233] Layman's report, LIFE ENV/D/000398, "Large scale polyurethane recycling", 'Recypol nach mass', RAMPF 2004. A maximum of 10% PU can be added to the polyol, otherwise viscosity becomes too high.

Whereas only a small portion of the energy used for manufacturing is retrieved in the form of heat during the energy-recovery process, in the case of material recycling, at least the recyclate is reintegrated into the original production. Nevertheless, even with the best process, the so-called regrind method by which extremely finely ground PUR powder is added to the polyol components, only about 10% of the recyclate can be added due to the increased viscosity.

[234] https://press.kraussmaffei.com/en/news/kraussmaffei-at-k-2025-pure-synergy-effects-reaction-technology-with-injection-molding-and-extrusion (...PU is frequently used for insulating applications such as refrigerators, and at the end of the appliances' life, the question of disposal arises. Until now, PU from old refrigerators has often been incinerated, for example to generate energy in cement production, but it is foreseeable that the thermal recycling of plastics will be more restricted in the near future. Krauss Maffei is in the process of industrializing a process for the continuous chemical recycling of PU through depolymerization. The project partners are BASF, Rampf (Producer of sustainable recycled polyols) and Remondis (processing and recycling of old electrical appliances)....)

[235] Stakeholder comments following the 4th stakeholder meeting of 1 July 2025.

[236] Large-Scale Polyurethane Recycling, LIFE02 ENV/D/000398, RECYPOL (2001-2004)

https://webgate.ec.europa.eu/life/publicWebsite/project/LIFE02-ENV-D-000398/large-scale-polyurethane-recycling#

[237] Layman's report, LIFE ENV/D/000398, "Large scale polyurethane recycling", 'Recypol nach mass', RAMPF 2004

The project is stated to have been successful. RAMPF Ecosystems has, in cooperation with FH Aalen and with the support of the EU LIFE-Programme, developed three new types of processes (partial glycolosis, polyolysis, acidolysis) and has also used them for the first time technically on a large scale for the recovery of raw materials, including semi-rigid and flexible PUR foams.

The new technology uses a process which recycles either post-consumer PUR or PET waste as well as industrial PUR production waste [238]. The prerequisite to use the recycling process is a high purity, as any impurities, often present in post-consumer waste, complicate the process and deteriorate the resulting polyols.

The final product is a high-quality recycling polyol (RECYPOL®), which can be used either alone or mixed with new polyol to produce PUR-foams. The recyclate can be added to the new product without a loss in quality of the final product, and without the necessity of retrofitting machines. The recycled polyol has lower costs than the primary polyol.

The project report concludes that in future, about 97 - 99% of various types of resultant PUR can be recycled through the efficient use of these methods, which is particularly significant in the field of flexible foams.

Note that the developed processes do not seem to be applicable to the rigid PU foam of the fridges (only flexible and semi-hard are being mentioned, and high-purity input material is required). In addition, it is not clear what happens to the isocyanate contained in the foam. Is this part of the filter residues and incinerated with heat recovery?

Where we are and where we are going (2024) [239]

Polyurethane waste streams show a wide range of chemical structures, molecular weights, degree of crystallinity, crosslinking density, and hard-to-soft segment ratios, among other parameters, all of which significantly affect the recycling processes and the properties of the final recycled materials and products. Therefore, it is not possible to identify an ideal, unique, feasible, reliable, and even scalable recycling technology that is suitable for all polyurethanes, but it is necessary to develop specific recycling approaches that maximize the yields, purity, and exploitability of the resulting recycled products, trying, at the same time, to minimize the environmental impact and overall energy consumption.

Several recycling methods have been designed and successfully applied: among them, the most promising ones, also considering industrial exploitation, are mechanical recycling (through regrinding and compression moulding) [240] and chemical recycling (mainly through glycolysis reactions). It is expected that these two recycling strategies will continue to be exploited in the future, as they are currently quite well-established and consolidated, even on an industrial scale. Conversely, almost all the other recycling strategies are still focused on lab-scale research investigation, despite the significant outcomes achieved up to now; it is, therefore, difficult to foresee their development and exploitation on a larger processing scale. Both regrinding and glycolysis are cost-effective and limit the impact on the environment; at

[238] PUR waste is broken down into small pieces of about 5 cm in a slicer for the production of recycling polyols. These are continuously introduced into a depressurised reaction container, in which there are already process reagents as basic substances depending on the type of residual substances, namely polyol, glycol or carboxylic acid, as well as catalysts and deaminating agents. At temperatures of about 200 degrees centigrade and with constant stirring, the PUR molecular chains are split. After the completion of the reaction process (lasting about 7 hours), the resultant liquid, which is a mixture of polyols and low-molecule urethane, is filtered. Filtration residues consist exclusively of incidental foreign matter. These can easily be removed through incineration with no after-effects and resultant energy may be reused.

[239] Recycling of polyurethanes: where we are and where we are going, Gabriele Rossignolo, Giulio Malucelli and Alessandra Lorenzetti, DOI: 10.1039/D3GC02091F (Tutorial Review) Green Chem., 2024, 26, 1132-1152, https://pubs.rsc.org/en/content/articlehtml/2024/gc/d3gc02091f

[240] It is understood that this applies only to thermoplastic, soft polyurethane, and not to the rigid foams as found in fridges.

variance, the energy recovery through pyrolysis, gasification, and two-stage combustion, despite the important reduction of the waste volumes that are landfill-confined and the high value of the recovered energy, are still limited by the quite complicated control of the emission of toxic and hazardous products.

Further, although biodegradation can be performed using mild conditions (i.e., at room temperature and without the need for hazardous chemicals), it is still limited by the quite restricted number of suitable microorganisms and enzymes (indeed, the isolation of new microorganisms able to degrade polyurethanes is usually labour-intensive and time-consuming), and also by the biodegradation time that is usually high, and therefore has not expressed its full potential yet.

A further issue that undoubtedly may slow down the progress in polyurethane recycling regards the diversified forms (i.e., foams, bulk materials, and elastomers) and structures of the manufactured polyurethanes, which makes it more difficult to identify the most appropriate recycling strategy. In this context, a selective collection of polyurethane wastes could help a lot.

The development of reliable and feasible recycling strategies for polyurethane wastes and scraps demands cost-effectiveness and environmental friendliness: at present, these are still two challenging issues, especially when they are not considered individually. Besides, at present, the recovery and recycling of polyurethane wastes have no structured market; further, the cost and emission factors of the recovery processes have not been consolidated yet.

It is expected that, in the next few years, research on the recycling of end-of-life polyurethanes will make further progress, at least starting from the lab scale, leading to a significant improvement in the recycling processes (also including low environmental impact approaches) and their reliable use, hopefully on an industrial scale.

Pilot Project „Go! Create“ [241]

How can polyurethane insulation materials from old refrigerators be returned to the material cycle on an industrial scale instead of being used to generate energy? The recycling of this post-consumer waste is the focus of a collaboration between KraussMaffei, Rampf, Remondis, and BASF.

After disposal, as prescribed by the EU in Directive 2012/19/EU on waste electrical and electronic equipment (WEEE), the rigid foam ends up as regrind, which up until now has mainly been used for energy purposes. According to PlasticsEurope, this process recovers about 30 per cent of the energy used in the production of PUR, but the carbon is not retained in the material cycle. The four partners will change that by using a new chemical recycling process known as depolymerization to obtain a recycled polyol. This polyol is to be used in the production of PUR materials in order to close the material cycle.

To date, processes for the chemical recycling of PUR have mainly focused on industrial waste, usually from production. This industrial waste is characterized by a high degree of purity, which significantly facilitates recycling. The recycling stream originating from post-consumer waste is much more complex to handle, as it is heavily contaminated with foreign substances such as other types of plastics and metals.

The goal is to develop an industrial process that delivers high-quality recycled polyols that are comparable to polyols obtained from primary fossil raw materials.

[241] Pilot Project „Go! Create“, Chemical Recycling of PUR Insulation Materials, 6th Oct 2022, https://en.kunststoffe.de/a/news/chemical-recycling-of-pur-insulation-mat-3030347

Polyurethane Recycling Through Acidolysis [242]

The article focuses on the utilization of dicarboxylic acids (DA) as depolymerization agents, achieved through a process known as acidolysis. The resulting recycled polyol finds successful applications in various PU products, including rigid and flexible foams, adhesives, and coatings. Analysing the impact of recycled polyol on the properties of new PU products reveals that it slightly affects the morphology and colour of foams, there is no significant impact on density or thermal conductivity. Notably, flexible foams exhibit increased stiffness when produced using recycled polyol. Additionally, the strength of PU adhesives and the surface hardness of PU coatings are enhanced with the incorporation of recycled polyol, albeit with a reduction in gloss. The recycled PU coatings also display a more hydrophobic surface.

The article examines existing data regarding the recycling of PU through acidolysis and the subsequent utilization of the recycled polyol (RP) in the production of new PU materials. The recycling of PU via acidolysis constitutes a complex system involving both chemical and thermal depolymerization processes. Consequently, the properties of the resulting RP are sensitive to various reaction parameters such as reaction temperature, reaction time, PU/DA ratio, as well as the type of DA and PU employed. Nevertheless, meticulous optimization of these recycling conditions ensures RP with suitable properties, thereby serving as a replacement for petroleum-based raw materials in the production of new PU materials.

The authors have examined the environmental and economic advantages of this approach, and state that the advantages are clear. However, they also signal economic and environmental challenges, which are expected to become even more severe in the near future.

Foam2Foam (2018-2021) [243]

The goal of the Foam2Foam project was to implement the circular economy concept in the polyurethane (PU) life cycle by incorporating a viable chemical recycling process to obtain new, high-quality products (green polyols) that can be used to manufacture new PU-based parts. The project was being carried out in the period 2018-2021 at national level and involved three companies (Titan Recycling, Arcesso Dynamics and AMB Electrónica de Brescia) and two technology centres (Gaiker and AIMPLAS).

Currently, PU waste is subjected to mechanical recycling, which involves reducing it to pellets or powder for subsequent use as a filler or additive in other products. This treatment results in low-value materials. Because of this, current recycling rates are very low, at around 10%, and the majority ends up in landfill. For this reason, this project aims to examine the viability of chemical recycling through glycolysis, which consists of chemical depolymerization by breaking the polymer chains with chemical agents (including a solvent, generally in the presence of a catalyst) under specific, controlled reaction conditions. This process is used to obtain new, high-quality polyols that can be used to manufacture polyurethane again. Depending on the polyol obtained, different kinds of parts (rigid, flexible or foamed) can be manufactured.

The project focused on three main waste streams: a post-consumer PU waste stream from refrigerator insulation (WEEE), a stream from the furniture industry (flexible foam from mattresses) and a post-industrial stream for plastic parts that have been rejected during the

[242] Gama, N., Godinho, B., Madureira, P. et al. Polyurethane Recycling Through Acidolysis: Current Status and Prospects for the Future. J Polym Environ 32, 4777–4793 (2024). https://doi.org/10.1007/s10924-024-03278-6 , https://link.springer.com/article/10.1007/s10924-024-03278-6

[243] https://www.recycling-magazine.com/2020/07/31/chemical-recycling-of-polyurethane-waste/ , Chemical recycling of polyurethane waste, "FOAM2FOAM: Circular Economy of Polyurethane Foams Via Chemical Recycling" is a project financed by the Ministry of Science, Innovation and Universities under the Retos Colaboración (Collaboration Challenges) programme, part of the National Programme for Research Aimed at the Challenges of Society. 2020-07-31

manufacturing process (scrap, defective parts, etc.). However, project results were found only for the post-industrial waste processing [244].

Circular Foam project (2021-2025) [245]

The project "CIRCULAR FOAM - Systemic expansion of territorial CIRCULAR Ecosystems for end-of-life FOAM" will develop and demonstrate all technological steps required to achieve circularity of plastics in post-consumer applications, using the example of rigid PU foams used as insulation in refrigerators and construction. Project duration: 1st October 2021 - 30th September 2025 (48 months)

The Circular Foam consortium is composed of all actors required to close the circular value chain (process industries, manufacturing, waste management, technology providers, incl. also research partners, logistics, social scientists and economists working with the public sector and citizens).

The resulting systematic approach will be implemented in three pilot regions (North Rhine-Westphalia/DE, Silesia/PL and Greater Amsterdam region/NL). The results will include recommendations for further replication in Europe.

The waste streams will be upcycled chemically, which means that they will be valorized to become new virgin-equivalent feedstock for the chemical industry to produce new high-performance plastics. In this way, it will become possible to replace limited fossil-based resources by the renewable waste-based ones, thus not only reducing waste, but also becoming more sustainable and making a step forward to climate neutrality.

Under Task D2.3 the project studied a prototype of improved refrigerators [246]. The recyclability of a baseline fridge and an improved modern design were compared. Six parameters were used to evaluate recyclability (material choice, material combination, joining methods, recycling process and recycling system). Material choice (PU-foam and glass fiber) is the main parameter limiting recyclability. Ferrous metals are easily separated and recycled in a mechanical process due to their magnetic properties. Glass has a pure fraction thanks to ease of manual separation. Among material combinations and joining methods, glued parts and composite panel are key obstacles for recycling, while snap fits promote recyclability. Copper and aluminium (otherwise valuable materials) risk ending up in the plastic stream when surrounded by foam.

Compared to the baseline fridge, the improved design has slightly higher recyclability (86% vs. 81%) due to the replacement of non-recyclable materials but is consequently a heavier product [247]. The absolute amount of material not recycled is roughly the same. The improvements achieved to optimize automation of assembling during production do not affect recyclability since the recycling process is not a reverse assembling, but rather a mechanical fragmentation.

For future developments the Task D2.3 report states:

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[244] https://www.mdpi.com/2073-4360/14/6/1157/review_report Synthesis of Rigid Polyurethane Foams Incorporating Polyols from Chemical Recycling of Post-Industrial Waste Polyurethane Foams, Polymers 2022, 14(6), 1157; https://doi.org/10.3390/polym14061157, by Izotz Amundarain, Rafael Miguel-Fernández, Asier Asueta, Sara García-Fernández and Sixto Arnaiz

[245] https://circular-foam.eu/ This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101036854

[246] https://circular-foam.eu/Outcomes/Deliverables/_/CIRCULAR%20FOAM_Deliverable%202.3%20revised%20.pdf

[247] The comparison seems to consider only the bill-of-materials, and the recyclability of the material types. No details are provided on differences in e.g. joining methods.

- In the next few years, it is likely that in Europe, more plastics will be recovered from the mixed scrap fractions which are mechanically treated today. New technologies will be introduced, and existing technologies will be improved.
- More manual steps are foreseen to be added to the recycling process of refrigerators and freezers, like manual removal of storage boxes in a mono stream of PS and removal of electronics to be able to capture precious metals.
- The most important area of improvement has been identified as the Recycling or Reuse of PU-foam and glass fiber in vacuum insulation panels (VIP). If both PU foam and VIP core material were recyclable, this could raise the recyclability index by ~9% and ~3% respectively.
- There are impurities in the plastic fraction and non-ferrous fraction coming out from the recycling facilities. This is partly because of the PU foam that is attached to all kinds of materials and hinders separation of those. The above is from a recycling perspective only, not considering the function or climate impact of the components.
- Another important area of improved design for the prototype is to secure the recycling of the electronics which could be done by separation before the fragmentation. A take-back system or an agreement with a service partner or a recycling company could be an option. To achieve higher recyclability for the electronic components it would be worth considering changing the plastic materials to any of the four types that are recycled today, if possible, from a functional and safety point of view.

Review study 2016, section 7.3.3 [248]

PUR offers, except for vacuum panels, the best insulation solution (U-value) compared to other materials, but it is not really a 'plastic' (thermoplastic). It is a thermoset material, processed from 2 main components. This makes it very difficult to recycle, certainly not in a 'closed loop' (recycled foam in new foam).

To illustrate this point: in the US, where the EPA is requiring a minimum (9 %) recycled content, the manufacturers try to meet the requirement not by using recycled foam, but by using polyols (one of the components) from recycled chemicals [249] [250].

End-of-life PUR can be recycled chemically (costly and potentially polluting) or mechanically (crushed and compressed to form wood-like blocks) [251]. Most end-of-life PUR comes from dismantled flexible PUR-parts of furniture (sofas), matrasses, carpet under-coverings or from hard PUR-panels (e.g. roof insulation).

In the case of refrigerating appliances, the PUR foam is stuck between the steel cabinet and the PS inner-liner and cannot be dismantled [252]. The most used solution, also to recover the foaming agent responsibly, is to shredder —in a special, closed environment— the base cabinet to fine grains, recover the steel parts through magnetic separation and incinerate (with

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[248] Preparatory/review study, Commission Regulation (EC) No. 643/2009 with regard to ecodesign requirements for household refrigeration appliances and Commission Delegated Regulation (EU) No.1060/2010 with regard to energy labelling of household refrigeration appliances, FINAL REPORT, VHK and ARMINES in collaboration with Viegand & Maagøe and Wuppertal Institute, contract co-ordination VITO, 4 March 2016

[249] http://www.foam-tech.com/about_ft/environment.htm

[250] EPA procurement guidelines for federally funded buildings (regards building insulation foam)

[251] http://www.intcorecycling.com/How-to-recycle-pur.html

[252] Please note that the sandwich construction of St-PUR-PS is vital for the mechanical strength and rigidity of the cabinet structure. A bad idea, both thermodynamically and in terms of material resources, would be to use separate panels in a self-sustained steel cabinet, which would need to be much heavier.

heat recovery) the PUR-PS particles that remain [253]. This means that also the PS will not be recycled but only used for heat recovery [254].

Given that 25 % of the product is not (easily, economically) recyclable and that the WEEE target is 80 %, the non-recyclability of PU creates a problem for manufacturers. The simplest solution would be to increase the weight of the rest, i.e. to employ extra resources to make sure that the PS-PUR fraction stays below 20 %. We are not aware that any manufacturer is willingly engaged in such a practice and designers will always try to find weight- increasing elements that also offer a functional bonus. However, the WEEE recycling target of 80% does implicitly reward e.g. the use of glass shelves (instead of the previous light steel racks) and the use of new models with stainless steel cabinets (instead of using thin pre-painted carbon steel).

Main take-aways

- PUR foam is mainly produced from a polyol component, an isocyanate component and blowing agent cyclopentane. EoL fridges arriving to recyclers may still contain legacy blowing agents with CFC.
- PUR foam from EoL fridges is contaminated with other types of plastics (e.g. HIPS), steel, aluminium, copper, blowing agents.
- PUR foam from fridges is typically incinerated with heat recovery; 30% of the energy used to produce the foam can be recovered.
- PUR foam can be finely grinded and used as filler in other products. It can be used as additive to polyols during new foam production (maximum 10% of mass).
- Several processes exist for the chemical recycling of polyurethane. These processes deliver recycled polyols that can be used in new foam production. The presence of impurities complicates chemical recycling.
- The recycling technology for isocyanate is still under development. The technologies for polyols are ahead.
- There continue to be economical and environmental challenges for the chemical recycling of PUR foam from fridges. The recovery and recycling of polyurethane wastes has no structured market. Recyclers have stated to the study team that chemical recycling of PUR foam from fridges is not economically viable yet.

4.2.4 Recycling of polypropylene (PP)

In 2018, 6600 kton of rigid PP were used in EU28+2. Of this, 37% went to packaging, 20% to automotive applications, 20% to household products, 7% to building and construction, 4% to EEE, and 11% to other applications [255].

[253] Ron Zevenhoven, TREATMENT AND DISPOSAL OF POLYURETHANE WASTES: OPTIONS FOR RECOVERY AND RECYCLING, Helsinki University of Technology Department of Mechanical Engineering Energy Engineering and Environmental Protection Publications (TKK-ENY-19), Espoo 2004

[254] This might have been true at the time of the review study, but nowadays PS is being recycled from fridges (section 4.2.1

[255] https://www.plasticsrecyclers.eu/wp-content/uploads/2022/10/hdpe-pp-market-in-europe.pdf

PP is widely used for rigid food packaging such as margarine tubs, yogurt containers, and trays (as well as flexible food packaging such as packets and wrappers). It is lower density, more lightweight and more durable than PET, yet can be similarly manufactured to be transparent (unlike HDPE), and has a wide temperature tolerance allowing it to be hot-filled and also put in the microwave, dishwasher or freezer.

Bottle caps (circa 0.7 Mt): 55% of plastics caps and closures are made from HDPE, while 45% are made from PP. HDPE is more commonly used for standard plastic caps, whereas customized and hinged caps are more commonly made from PP due to its high stress tolerance.

Other packaging, including boxes and crates (at least 0.66 Mt HDPE, 0.27 Mt PP): Since both polymers are strong and lightweight, they are used to manufacture boxes and crates, pallets, drums/kegs and bulk containers for transporting goods.

A primary use of PP is food packaging: 55% of PP rigid packaging (1 Mt) is food contact, equivalent to around 10% of total PP demand.

Recycling of PP

In 2018, the EU28+2 had the processing capacity to recycle 1.7 Mt of rigid HDPE and PP, of which 1.2 Mt was for post-consumer material [256] [257]. Combined rHDPE and rPP production in the EU28+2 in 2018 was estimated at 0.8 Mt from post-consumer material, with this figure rising to 1.2 Mt when pre-consumer recyclate is included. EU28+2 recycling capacity has increased recently and is expected to continue to grow with additional investment [255].

The 1.2 Mt capacity for post-consumer rigid polyolefins is estimated to produce in the region of 0.8 Mt of rHDPE and rPP, based on assumed utilization at 86% and an average yield assumption of 80%. Typical output yields from recyclers vary depending on the material:

- Household packaging is diverse and has high levels of moisture, organic and non-target material. Yields are between 70% and 90% depending on the quality of the input material and the standard of sorting at sorting plants for household recycling.
- Conversely, yields from bulk containers and other rigid applications, where levels of non-target material and organic contamination is lower, tend to be 90% or higher.

The largest end markets for rPP are for injection molding in the automotive industry, and in packaging and construction. In packaging applications, rPP can be used in non-food film packaging applications, and injection-molded reusable transport packaging products such as crates and boxes.

A proportion of PP and HDPE packaging is recycled into mixed polyolefin recyclate, often in compound form for use in injection-molded applications (i.e. buckets, flowerpots). Additives are used to enhance structural characteristics for specific product categories.

Plastics Recyclers Europe [255] report 67 kton of rPP used in EEE in 2018, on a total PP consumption of 285 kton for EEE. This would imply an rPP usage rate of 23%.

PP in refrigerators-freezers

For base case COLD7 (refrigerator-freezer combi, representing 53% of annual fridge sales in the EU, section 2.1.3), PP represents 10% of the plastics mass and 4% of the overall fridge

[256] Since the reprocessing steps for HDPE & PP rigid applications are the same, the same capacity can process both HDPE & PP (in batches), and the total capacity is tracked together.

[257] In 2023 this increased to 3.4 Mt for PP alone in the EU27+3. Source: Plastics Recycling Industry 2023, https://www.plasticsrecyclers.eu/publications/

mass. Polypropylene (PP) is mainly used for drawers and body reinforcements. Many other small parts, related mainly to water drain, ice-contact or humidity control.

In the APPLiA average BoM for freezers, PP is 12% of the total mass (section 5.2.2), and in the average BoM for refrigerators 6%.

PP from fridges is being recycled (with refinement up to 98% purity) but depending on the applied separation processes this might be limited to PP with density below 1.10 g/cm3.

PP is recyclable if it is unfilled or with maximum 10% chalk, talcum, or fibre glass filler.

HDPE may end up as an impurity in the PP and then also ends up in the recycled PP [258].

It seems unlikely that recycled PP is currently being used in fridges.

4.2.5 Recycling of Acrylonitrile Butadiene Styrene (ABS)

ABS plastic consists of three main components [259]:

- Acrylonitrile: An organic compound with the chemical formula C3H3N, it provides the rigidity and mechanical strength of ABS plastic.
- Butadiene: An organic compound with the chemical formula C4H6, it provides elasticity and impact resistance.
- Styrene: Having the chemical formula C8H8, this is an organic compound that provides the gloss and thermal stability of ABS plastic.

In addition, depending on the final product, manufacturers may add additives such as flame retardants, antistatic agents, colorants or anti-corrosion agents. Other additives can include:

- Processing-aid additive is added to the polymer to lower the friction between plastics and machines during production. It helps enhance the melting, processability, and handling of high molecular weight plastics without any technical effect on products. Polymer processing aids have a wide range of applications, including blown film, extrusion, and injection moulding. Thanks to processing-aid additives, thermoplastic resins can be extruded more effectively. They can add aesthetic qualities by reducing flow traces and die lines, resulting in glossy, transparent products.
- Smelly plastics (especially recycled plastics) can affect their application and competition. Therefore, eliminating bad odours is essential to enhance plastics' effectiveness and value in industrial production.

  Odour-removing additive is a saviour that works as an odour-neutralizer. It does not replace the original smell in products with fragrances or perfume. Instead, it will prevent the absorption of unwanted odours and irritating chemicals. Odour control additive is utilized widely in rubber plastic products or items made of regrind material such as home appliances, toys, or textile packaging.
- Moisture exists in everything, and polymer material is no exception. Especially in technical resins, moisture may cause fisheye and surface defects on final products. Desiccant additive is added to the formula to absorb moisture in the plastic materials,

[258] Study team visit to CoolRec facilities and CoolRec answers of 14/3/2025.

[259] https://europlas.com.vn/en-US/blog-1/recycled-abs-plastic-recycling-code-process-advantages-and-disadvantages

thereby limiting common errors in processing (bubbles, fisheyes, ...) and improving the quality of the end-product [260].

ABS is a thermoplastic polymer, which means it can be melted and reshaped multiple times without losing its properties, which depend on the constituent proportion of the monomers. [261].

The advantages of ABS plastic are its relatively low melting point and glass transition temperature, making ABS easy to melt down and use in injection moulding. Products and components made from ABS offer high impact and heat resistance as well as strong tensile strength. Other benefits include dimensional stability, chemical resistance, low production costs and ease of machinability [262]. This makes it versatile for a great number of applications.

ABS if often used for telephone handsets, rigid luggage, domestic appliance housings (food mixers, vacuum cleaners), electroplated parts, radiator grills, handles, computer housings, keyboards, displays, automotive applications, healthcare, reels, construction, 3D printing elements [263], electrical frames [264]. ABS is used in products that do not get hot, because of its low melting point. Industrially it is used where there is a need for a relatively cheap product which can withstand bumps and knocks, so it is often found in housings. Probably one of the most widely known and recognisable products made from ABS is Lego [265].

Recycling of ABS

ABS plastics are recyclable – this includes sheets, shower trays, car parts, skeletal waste and ABS pipe. Recycled ABS is becoming increasingly popular as raw ABS can be expensive to use in manufacturing. Recyclers ask to keep acrylic-capped ABS and ABS with Fire Retardant (FR) separate in the waste supply. Some recyclers can supply the recycled ABS plastic segregated according to material origin [263].

According to Europlas [259], compared with other recycled plastics such as PP, PVC, LDPE or HDPE, ABS recycled plastic is superior in low cost, suitable for industry.

Advantages:

- Equivalent physical properties: Even after being crushed and recycled many times, recycled ABS plastic retains the same physical properties as new ABS plastic

Disadvantages

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[260] Desiccant masterbatches can contain Calcium Oxide (CaO), which is a strong water absorber. In polymer processing, Calcium Oxide disperses, eliminates moisture, and prevents phenomena such as fisheye. It also solves moisture problems in extrusion (blow film, film casting, blow moulding, etc.) and injection moulding. Especially for recycled plastic, it helps remove moisture and cuts out the oxidizing effect that occurs during the recycling of the polymer.

[261] https://www.plasticexpert.co.uk/plastic-recycling/abs-plastic-recycling/#:~:text=Yes%2C%20ABS%20plastic%20(Acrylonitrile%20Butadiene,times%20without%20losing%20its%20properties.

[262] https://www.sulapac.com/blog/replacing-abs-plastic-sustainably/#:~:text=%E2%80%93%20ABS%20has%20a%20complex%20composition,cost%20to%20the%20whole%20process.

[263] https://www.vandenrecycling.com/en/what-we-do/buy-and-sell-plastic/abs/#:~:text=Is%20ABS%20recyclable%3F,expensive%20to%20use%20in%20manufacturing.

[264] Material recycling of acrylonitrile butadiene styrene (ABS) from wiring devices using mechanical recycling, Esra ÇETİN, Oytun Tuğçe TÜRKAN, Sustainable Chemistry for the Environment, Volume 6, June 2024, 100095

https://www.sciencedirect.com/science/article/pii/S2949839224000385#:~:text=In%20order%20to%20recycle%20ABS,by%20incorporation%20of%20triggerable%20additives.

[265] https://www.agsplasticgranulation.co.uk/services/abs-plastic-recycling/#:~:text=Like%20most%20polymers%2C%20ABS%20is%20totally%20recyclable.

- Unequal quality: Depending on each factory, the screening and production process of recycled ABS plastic will be different, so the uniformity and overall quality of the output cannot be guaranteed.
- Difficult to control purity: During the screening process, it may not be possible to remove all impurities, thereby affecting the quality of the output product.
- Not easy to maintain: Recycled ABS plastic is easily damaged under the influence of sunlight, requiring manufacturers to invest in the preservation period.

ELIX [266]

Since 2020, ELIX Polymers works in partnership with Repsol (Spain) and AnQore (Netherlands) to produce feedstock materials to help produce 100 percent recycled-content ABS plastic. Styrene and butadiene are produced from chemically recycled postconsumer scrap and in some cases from bio-circular raw materials from used cooking oil.

LIFE ABSolutely Circular project (2020-2024) [267]

Indaver (Belgium), a leader in sustainable waste management, and INEOS Styrolution (Germany), global leader in styrenics, have teamed up as technology partners in a project funded by the EU LIFE programme. The project, called LIFE ABSolutely Circular aims at demonstrating the environmental and economic benefits of using advanced recycling technologies to close the loop of plastic recycling.

An initial key objective of the project is to demonstrate for the first time the production of ABS based on recycled feedstock taking advantage of advanced recycling technologies. The project is also planned to demonstrate scaling of the solution from lab scale to demo plant and ultimately to commercialisation.

In November 2024, the first Plastics2Chemicals facility at Indaver's Antwerp site was almost ready for operation.

ABSOlEU project (June 2022 – May 2026) [268] [269]

Acrylonitrile butadiene styrene (ABS) is a useful impact-resistant engineering thermoplastic material. It is used in all sorts of durable products, from consumer goods to automotive parts. At least 85 % of end-of-life ABS is incinerated or dumped in landfills due to the presence of additives and fillers that prevent its proper recycling. The EU-funded ABSolEU project will pave the way for its circularity. It will develop technology for the physical recycling of waste ABS [270], providing a clean and safe recyclate that is free of additives and contaminants and

[266] https://www.recyclingtoday.com/news/elix-repsol-anqore-plastic-abs-chemical-recycling-europe/

[267] https://absolutely-circular.com/#:~:text=The%20project%2C%20called%20LIFE%20ABSolutely%20Circular%20aims%20at,technologies%20to%20close%20the%20loop%20of%20plastic%20recycling.

[268] Innovative physical recycling technology for ABS waste. HORIZON.2.4 - Digital, Industry and Space Main Programme, HORIZON.2.4.4 - Advanced Materials, Grant agreement ID: 101058636, DOI 10.3030/101058636, https://cordis.europa.eu/project/id/101058636

[269] ABSolEU project https://absoleu.univ-cotedazur.eu/

[270] Dissolution, or purification, processes stand apart from other molecular recycling methods because they do not break the plastic polymer bonds. Because it is non-chemical, this process is often referred to as "physical recycling." Purification uses solvents to extract colours and additives from single-polymer feedstock or mixed plastics, resulting in virgin-like polymers. These processes maintain the integrity of the material, ensuring a plastic-to-plastic outcome. Additionally, purification is part of molecular recycling technologies, but this specific method does not break the polymeric structure.

ready to be reintroduced into the value chain. ABSolEU will also develop new analytical methods for safety assessment and quality assurance.

ABSolEU aims to pave the way to circularity for the ubiquitous plastic ABS, found in durable products from toys and other consumer goods to automotive components. Despite the potential of this material, at least 85% of end-of-life ABS ends up in landfills or incineration due to the presence of additives and fillers that hamper its proper recycling. ABSolEU will develop and mature to TRL 6 a technology for the physical recycling of waste ABS, providing a clean and safe recyclate that is free of additives and contaminants and ready to be reintroduced into the value chain for value-added, high-performance products.

In parallel, ABSolEU will develop new analytical methods for safety and quality assurance; these will allow project partners to establish a thorough understanding of the composition of ABS waste streams, including the presence of additives and the degree of degradation, as well as monitor these throughout recycling and compounding processes.

In addition, ABSolEU aims to provide the scaffolding to support adoption of physical recycling for ABS and support the uptake of ABS recyclates by industry and consumers. This is achieved through circular value chain labs and explorative citizen labs, investigation of new traceability systems for ABS materials and products, and standardisation of processes for recycling, analysis and traceability.

ABSolEU's research outputs are communicated, disseminated and synthesised into best practices, methodologies, and policy recommendations for ABS recycling to contribute to a resource efficient industry. The project is implemented by a strong consortium that spans the entire ABS value chain. It is led by UCA and involves 10 additional partners: 3 global brand owners, 2 RTOs, an ABS-producing company, a recycler, a traceability solutions company, a standardisation institute and a company specialised in stakeholder engagement. With ABSolEU, the consortium is seeking to lay the first bricks of a sustainable future for ABS plastics.

Study on recycling of coated ABS [271]

Coating plastic components is a widely preferred method to improve their surface properties, but it poses a challenge for reusing or recycling. Foreign substances and all kinds of impurities reduce the performance of the recycled material. Recovery of high-value material can be increased by removing coatings. Coat stripping is not a new process in engineering and plays a significant role in the maintenance and restoration of materials throughout their lifecycle. The authors of the article studied the feasibility of recycling coated ABS materials for use in electrical frame production, aiming to bridge the gap in current recycling practices [271].

One way of achieving debonding is by incorporation of triggerable additives. These additives need to be added to the primer layer, which is in contact with the substrate (ABS), to be able to remove as much coating material as possible.

This study investigated the use of recycled ABS (rABS) material in the remanufacturing of electrical frames. The main purpose of the study was to examine whether the proportional addition of recycled ABS material would change the mechanical properties. It was observed that adding rABS material did not adversely affect the mechanical properties (impact strength, tensile strength) of the ABS polymer and that it passed all the tests required for production.

https://www.plasticsengineering.org/2024/09/solvent-recycling-006376/#!

[271] Material recycling of acrylonitrile butadiene styrene (ABS) from wiring devices using mechanical recycling, Esra ÇETİN, Oytun Tuğçe TÜRKAN, Sustainable Chemistry for the Environment, Volume 6, June 2024, 100095

https://www.sciencedirect.com/science/article/pii/S2949839224000385#:~:text=In%20order%20to%20recycle%20ABS,by%20incorporation%20of%20triggerable%20additives.

This fact reinforces the suitability of the upcycling strategy incorporating impact strength additive to the recyclate compounds and allows to increase the percentage of recyclate rABS above 30% in further developments. Only the tensile modulus property shows more variability and more noticeable decrease down to 15–20% for the rABS recyclates compared to the reference ABS raw grade.

ABS – PS separation

Generally, different polymers are separated based on their density, on waterbeds. However, the separation of ABS from PS requires electrostatic sorting, i.e. high voltage charging and separation using electromagnets [272].

ABS in refrigerator-freezers

For base case COLD7 (refrigerator-freezer combi, representing 53% of annual fridge sales in the EU, section 2.1.3), ABS represents 1.4% of the plastics mass and 0.6% of the overall fridge mass. ABS is used in 13 small parts, with masses from 3 to 67 grams each.

In the APPLiA average BoM for freezers, ABS is 4.3% of the total mass (section 5.2.2), and in the average BoM for refrigerators 2.6%.

According to APPLiA's 2022-2023 statistical report, of the recyclate produced from WEEE, 49.5% is PP, 30.3% PE, 18.1% (HI)PS and only 2.1% ABS.

ABS from fridges is being recycled, but most recycled ABS comes from small domestic appliances and ICT products [273]. As far as known, no recycled ABS is used in fridges.

4.2.6 Recycling of polyvinyl chloride (PVC)

Polyvinyl chloride (PVC) is a type of plastic commonly used in construction, packaging, and other consumer products, as it's one of the most cost-effective plastics available. Some of its key properties are its durability, resistance to chemicals, heat, water and moisture, low thermal conductivity and electrical insulation. PVC also doesn't rust, degrade easily, or rot, which makes it ideal for applications like pipes, window and door frames, and siding in the construction industry. PVC is available in rigid (RPVC) and flexible (FPVC) forms [274].

The production of PVC is resource-intensive and environmentally damaging, as it relies on chlorine and ethylene, derived from salt and petroleum, respectively. The process releases toxic chemicals like dioxins, harming the environment and human health. These dioxins can persist in the environment for years, contaminating air, water, and soil.

Oil makes up 43% of the raw material required to make PVC.

Looking at waste, 82% of global PVC waste goes to landfill, 15% is incinerated. Only 3% is recycled. The majority of PVC waste comes from the construction industry, which is logical, as 70% of PVC is used in the construction sector.

[272] Study team visit to CoolRec facilities.

[273] E.g. Coolstar ABS uses recycled plastics from small domestic appliances and ICT products (76% recycling rate; >98% purity granulates). Basic grade ABS-E Plus for injection moulding applications. Modified grade ABS-E Master for higher impact strength (Charpy impact strength tested), suitable for thin wall sheet extrusion and for injection moulding.

[274] https://www.front-materials.com/news/can-pvc-be-recycled/#:~:text=The%20short%20answer%20is%20yes%2C%20PVC%20recycling%20is%20possible.

PVC in refrigerator-freezers

For base case COLD7 (refrigerator-freezer combi, representing 53% of annual fridge sales in the EU, section 2.1.3), PVC represent 2.5% of the plastics mass and 1% of the overall fridge mass. This is soft PVC, used for the door gaskets [275].

Older freezer models used more PVC, e.g. the study team has a BoM for a 2004 chest freezer model that used 6 kg PVC (11% of total freezer mass), of which half in the body and half for the lid gasket.

Power cables and electric wiring in the fridge can contain PVC sheathing. External cables are removed during recycling (as prescribed by the WEEE directive) and sent to specialized recyclers, which recover mainly the copper, but may also recycle the PVC [276].

As far as known, PVC from fridges is not being recycled (except maybe from the cables), and no recycled PVC is used in fridges.

PVC recycling

There are challenges associated with recycling PVC compared to other types of plastics due to additives like plasticisers, stabilisers, and fillers used in production. These additives alter its properties and can affect the quality of the recycled material, making it less suitable for certain applications [274].

PVC waste is also often contaminated with other materials, such as adhesives, paints, or metals, which complicates the recycling process and may require extensive cleaning.

One of the main disadvantages of PVC when it comes to recycling, is that the material can release harmful chemicals when it is melted down, which can be detrimental to the environment and human health.

Rigid PVC is often easier to recycle than flexible PVC due to fewer additives. Separating these types of PVC for recycling is necessary, as they cannot be processed together.

With growing environmental concerns, PVC recycling technologies have improved, and there are currently two main ways to recycle PVC products:

1. Mechanical Recycling
2. Chemical Recycling

Mechanical recycling involves shredding the PVC into small pieces and melting it to create new products. There are a lot of steps involved in this process, as the PVC products need to be collected, sorted, shredded, ground, washed and melted, before being able to re-extrude into granules or pellets. These are then used as raw materials for manufacturing new PVC products.

Chemical recycling breaks the PVC into its original chemical components through high-temperature processes. This method is useful for PVC waste that cannot be mechanically recycled due to contamination or complex additives.

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[275] CoolRec answers 14/3/2025: PVC from the door rubbers partly ends up in the steel fraction (because of the magnetic strip which is inserted in the profile). Partly it goes to the plastic fraction, where it ends up in the sorting residues. We did a few tests in the past to investigate possible recycling of this fraction (into flooring tiles for sports halls and playgrounds), but analysis showed presence of restricted biocides, so the project was stopped.

The rest of the PVC (mostly rigid) ends up in the sorting residues of our plastics process. Considering PVC is a very small share in that fraction, there is no economic interest into separating it. No information on presence of regulated substances.

[276] CoolRec answers 14/3/2025: PVC from cable sheathing is going to the cable recyclers since we remove the cables as a whole at the beginning of the process. Most cable recyclers recycle this PVC, but this recycling is currently at risk because of ever reducing limit values in REACH and POP.

In addition to traditional recycling methods, some companies specialise in recycling PVC specifically, such as Pretty Plastic [277]. They have developed innovative technologies that allow them to recycle PVC more efficiently and safely.

In cases where recycling is not feasible due to contamination, degradation or the high costs involved with separate waste collection, PVC waste may be incinerated to recover energy.

The incineration of PVC can release toxic gases like dioxins and hydrogen chloride, which require advanced filtration systems to prevent environmental harm. Therefore, energy recovery is typically considered a last resort for PVC disposal.

PVC recycling initiatives in Europe

VinylPlus® [278] is the European PVC industry's Commitment to sustainable development. Through VinylPlus, the European PVC industry is creating a long-term sustainability framework for the entire PVC value chain, improving PVC products' sustainability and circularity and their contribution to a sustainable society. It covers the EU-27, Norway, Switzerland and the UK.

VinylPlus is committed to recycling at least 900,000 tonnes per year of PVC waste into new products by 2025 and 1 million tonnes by 2030.

In 2023, 737,645 tonnes of PVC waste were recycled within the VinylPlus framework [279], of which 61.7% was pre-consumer waste and 38.3% post-consumer waste. This was 24.3% of the total PVC waste generated in EU27, Norway, Switzerland and the UK.

The recycled PVC was used for windows and profiles (39%), floor covering (26%), traffic management (18%), pipes (10%), other building and construction applications (6%), horticultural equipment (1%), coils and mandrels (0.2%), packaging (0.2%).

Unrelated to industry's best efforts, recycled PVC volumes decreased due to several factors:

- the persistent competitive prices of virgin material, including low-priced imports,
- the economic downturn in the building and construction (B&C) sector and
- the impacts of European regulations on legacy additives.

In 2023, recycling and converting activity declined overall in Europe – and not just in the PVC sector. This applied both to pre-consumer recycling, where lower industrial production reduced the amount of waste available, and to post-consumer recycling, which was significantly affected by a decline in the construction industry. Flooring and pipes sectors registered the most consistent decline, particularly in pre-consumer waste recycling.

PVC recycling future

While PVC is a widely used and versatile material in many industries, its recyclability remains a topic of debate as the recycling process is complex and not widely implemented.

[277] https://www.prettyplastic.nl/

[278] https://www.vinylplus.eu/

[279] This increased from near zero in 2002 to approximately 730 thousand tonnes in 2018 and remained more or less stable in the 2018 – 2023 period. See the Vinylplus progress report 2024.

PVC recycling has the potential to improve significantly with advances in recycling technology and increased environmental awareness. Some promising developments include innovative sorting technologies, additive-free PVC development and chemical recycling innovations.

For example, optical sorting technologies can help improve the efficiency of separating PVC from other materials, reducing contamination. Advanced chemical recycling technologies, such as depolymerisation and pyrolysis, may allow for more effective recycling of mixed or contaminated PVC waste.

4.2.7 Recycling of polycarbonate (PC)

Polycarbonate is used in a variety of application areas, including [280]:

- Automotive industry: headlight lenses, instrument panels, and exterior trims.
- Electronics industry: computer and phone cases, LCD screens, and printer components.
- Medical industry: IV components, syringes, and surgical instruments.
- Construction industry: roofing sheets, windowpanes, and skylights.
- Eyewear: eyeglasses and sunglasses due to PC's high impact resistance and clarity.
- Water bottles: reusable water bottles due to PC's durability and resistance to shattering.
- Toys: toys and children's products due to PC's safety and strength.

PC in refrigerator-freezers

For base case COLD7 (refrigerator-freezer combi, representing 53% of annual fridge sales in the EU, section 2.1.3), PC represent 0.1% of the overall fridge mass. It is used for some user-interface components.

In the APPLiA average BoM for freezers, polycarbonate is 0.9% of the total mass (section 5.2.2).

As far as known, PC from fridges is not being recycled, and no recycled PC is used in fridges.

Recycling of Polycarbonate

Polycarbonate is a recyclable plastic but is not as widely recycled as other plastics due to its relatively low demand in the recycling market. Polycarbonate products can be recycled into various products, including automotive parts, construction materials, and electronic components [280].

4.2.8 Recycling of polyamides (PA, nylon)

Recycling polyamide (PA) can be difficult due to its complex molecular structure, which makes it difficult to break down and process. However, PA can be recycled mechanically and chemically. The recycling of polyamide is becoming increasingly important as the demand for sustainable materials grows [281].

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[280] https://www.recycledplastic.com/pc-polycarbonate/

[281] https://www.recycledplastic.com/pa-polyamide-nylon/#:~:text=The%20recycling%20of%20polyamide%20is,including%20mechanical%20and%20chemical%20recycling.

Mechanical recycling involves shredding the PA/Nylon waste and melting it to create new products. The process involves the following steps [281]:

- Sorting: PA/Nylon waste is sorted based on type and colour.
- Shredding: The sorted PA/Nylon waste is shredded into small pieces.
- Melting: The shredded waste is then melted and extruded into pellets.
- Manufacturing: The pellets are then used to create new products.

Mechanical recycling of PA/Nylon has several advantages, including:

- Reduced Energy Consumption: The recycling process requires less energy than virgin PA/Nylon production.
- Reduced Landfill Waste: Mechanical recycling reduces the amount of PA/Nylon waste in landfills.
- Cost-Effective: Using recycled PA/Nylon can reduce production costs, making it an attractive alternative to virgin PA/Nylon.

Mechanical recycling of PA/Nylon also has some disadvantages, including:

- Reduced Quality: The quality of recycled PA/Nylon is lower than that of virgin PA/Nylon due to degradation during the recycling process.
- Limited Recycling Options: PA/Nylon cannot be recycled indefinitely, and the quality of the recycled material decreases with each cycle.

Chemical recycling involves breaking down the PA/Nylon waste into its constituent components to create new polymer products. The process involves the following steps [281]:

- Depolymerisation: The PA/Nylon waste is broken down into its constituent monomers using heat and chemicals.
- Purification: The monomers are purified to remove any impurities.
- Polymerisation: The purified monomers are then polymerised to create new PA/Nylon.

Chemical recycling of PA/Nylon has several advantages, including:

- High-Quality Material: The recycled material produced through chemical recycling is of high quality and can be used to produce new products.
- Reduced Environmental Impact: Chemical recycling reduces the environmental impact of PA/Nylon production by reducing greenhouse gas emissions and waste.

Chemical recycling of PA/Nylon also has some disadvantages, including:

- High Cost: Chemical recycling is currently more expensive than mechanical recycling and producing virgin PA/Nylon.
- Technical Challenges: The depolymerisation process can be technically challenging and may require additional research and development.

PA in refrigerator-freezers

For base case COLD7 (refrigerator-freezer combi, representing 53% of annual fridge sales in the EU, section 2.1.3), PA represent 0.4% of the plastics mass and 0.1% of the overall fridge mass. It is used for cabinet feet, spacers, cable ties and slider brackets.

In the APPLiA average BoM for freezers, polyamide is 1.2% of the total mass (section 5.2.2).

As far as known, PA from fridges is not being recycled, and no recycled PA is used in fridges.

4.3. Glass recycling technologies

Refrigerators contain different types of glass, primarily tempered glass, laminated glass, and frosted glass. Tempered glass, which is mainly used in shelves, accounts for approximately 60-90% of the total glass content. Laminated glass constitutes about 10-30% of the glass components. Frosted glass, if present, is typically found in doors and is used for crisper covers and similar applications.

4.3.1 Tempered glass recycling process

a) Challenges in Recycling

1. **High Melting Point**: Tempered glass does not melt like regular glass and has a significantly higher melting point (above 760°C). If not reheated evenly, it shatters into small fragments. Specialized equipment and a gradual heating process are necessary to relieve internal stresses before liquefaction.
2. **Irreversible Structure**: Once broken, tempered glass cannot be remoulded.
3. **Difficult Handling & Sorting**: The glass breaks into small, pebble-like pieces, making sorting challenging. Additionally, the risk of contamination is high.
4. **Complexity of Frosted and Laminated Glass Recycling**: Coatings and plastic layers in these glass types further complicate recycling.
5. **Limited Market for Alternative Uses**: There are restricted applications for recycled tempered glass, limiting economic feasibility.

b) Recycling Process

1. **Glass Separation and Extraction**: Refrigerators are manually or mechanically dismantled to separate glass components.
2. **Sorting**: The recovered glass is categorized into tempered glass, laminated glass from doors, and other decorative glass panels.
3. **Cleaning**: Residual food particles, adhesives, coatings, and contaminants are removed.
4. **Shredding & Crushing**:
    - Tempered glass does not melt conventionally but is designed to break into small fragments. The glass is crushed into cullet (small pieces) for further processing.
    - **Thermal Treatment**: High-temperature kilns (above 600°C) are used to reverse the tempering process.
    - **Chemical Treatment**:
        - **Acid Treatment**: Strong acids like hydrofluoric or sulfuric acid remove coatings and films.
        - **Alkali Treatment**: Sodium hydroxide or potassium hydroxide weakens the molecular bonds, bringing the glass closer to annealed glass behaviour.
        - **Ion Exchange Process**: Experimental methods use reverse ion exchange to alter stress balance, allowing remelting and reshaping.
5. **Processing and Repurposing**: Recycled tempered glass is repurposed into various materials, including:

- Fiberglass insulation
- Glass tiles and countertops
- Abrasive materials for sandblasting
- Artificial sand for industrial applications
- Water filtration media
- Reflective road paint and micro glass beads for highway markings
- Solar panel glass, glass bottles, and packaging
- Construction materials such as road base and concrete aggregate

4.3.2 Laminated glass recycling process

a) Challenges in Recycling

1. **Plastic Interlayer Contamination**: The interlayers made of Polyvinyl Butyral (PVB) and Ethylene Vinyl Acetate (EVA) hold the layers of glass together, providing strength, insulation, and safety. However, these interlayers must be separated before the glass can be recycled. This requires chemical baths, heat treatments, or mechanical grinding, making the process energy intensive.
2. **Melting Difficulties**: The plastic interlayers can burn during the melting process, leaving unwanted residues in the furnaces, which complicates recycling.

b) Recycling Process

1. **Glass Separation**: Laminated glass is broken into small pieces through shredding or crushing.
2. **Heat Treatment or Chemical Processing**: Low-heat furnaces (200-300°C) or chemical baths (alcohol or alkaline solutions) are used to soften the plastic inner layer. The glass and plastic are then separated and processed differently. The recovered glass is crushed into cullet and reused in construction materials, fiberglass, or new glass products.
3. **High-Temperature Processing**: In this method, laminated glass is melted in specialised furnaces, burning off the plastic layer. The remaining glass is then used in industrial applications such as insulation materials, foam glass, and road bases.

4.4. CRM recycling technologies

See the general, horizontal part of the study report on recycled content and CRMs.

See also section 2.2.6.

5. MEErP Task 5, Environment and Economics

5.1. Base Cases

The base cases of Table 12 are proposed for the study (see section 1.2). These are the same base cases as used in previous Ecodesign studies, with the addition of minibars [282]:

- COLD 0 minibars (net volume < 60 litres)
- COLD 1 single-door refrigerators, except wine storage and minibars; EPREL reference: 1-compartment fresh food
- COLD 2 wine storage appliances
- COLD 7 fridge-freezers combis, except minibars; EPREL reference: fresh-food compartment + 4-star freezer compartment
- COLD 8 upright freezers (door opening on front; EPREL reference height > 1000 mm)
- COLD 9 chest freezers (lid opening on top; EPREL reference height < 1000 mm)

The study focuses on COLD 7 (combis), being the base case with the highest sales share.

Table 12 Base case characteristics

Base case characteristics	**COLD 0**	**COLD 1**	**COLD 2**	**COLD 7**	**COLD 8**	**COLD 9**	**total**
	minibar	**refrig**	**wine**	**combi**	**upright**	**chest**	**EU27**
net refrigerated volume (litres) [283]	31	225	182	222			
net frozen volume (litres)	7			88	243	197	
net total volume (litres)	37	225	182	309	243	197	
free-standing	YES	YES	YES	YES	YES	YES	
defrost	manual	auto	auto	auto	auto	manual	
low-noise	any	no	no	no	no	no	
annual energy consumption (kWh/unit/a)	107	120	140	235	238	220	
average EEI	119	105	158	103	103	109	
energy label class	E	E	G	E	E	E/F	
sales EU27 2024 (thousand units)	1169	2236	1372	9044	1270	1835	16919
share in EU27 sales 2024 [284]	7%	13%	8%	53%	8%	11%	
stock EU27 2024 (thousand units)	14280	35853	9223	148403	21686	33078	262523
share in households	0%	92%	75%	92%	92%	92%	
stock per household, 2024	0.00	0.17	0.03	0.69	0.10	0.15	1.14

5.2. Bills-of-Materials (old ERT)

[282] In its 2025-04-04 answers, APPLiA has suggested different base cases, based on their in-house database. Except for the wine storage appliances (class F), APPLiA suggests using class D appliances as the base case. However, based on the EPREL database this is far from the current market average. APPLiA itself writes that class D or better appliances represent only 10-20% for the combis. The follow-up study will discuss this further with APPLiA.

[283] Averages derived from December 2024 EPREL database.

[284] The shares are based on model counts in the EPREL December 2024 database, for models still on the market on 1/1/2025.

5.2.1 Bills-of-Materials in the EIA

Table 13 shows the Bill-of-Materials (BoM) per base case from the Ecodesign Impact Accounting 2024. These BoMs originally derive from a manufacturer questionnaire, as elaborated in the 2007 preparatory study. The BoMs were adjusted in the 2016 Ecodesign review study and 2019 impact assessment. The BoM for minibars (COLD 0) has been added, scaled from the one for refrigerators (COLD1) considering net volume difference and difference in external to internal volume ratio [285].

These BoMs are relatively old and need updating.

Table 13 Currently available BoMs, from previous studies (using the material types from the old EcoReportTool), as collected in the EIA

Current BoMs	COLD 0	COLD 1	COLD 2	COLD 7	COLD 8	COLD 9
(masses in grams)	minibar	refrig	wine	combi	upright	chest
01-LDPE	18	76	57	236	69	48
02-HDPE	13	56	42	96	677	53
04-PP	219	950	713	1751	2187	883
05-PS	1347	5837	4378	10059	12058	2310
06-EPS	1	3	2	44	2	0
08-PVC	81	352	264	398	618	2117
09-SAN	0	0	0	0	1440	0
10-ABS	179	775	581	950	1167	206
11-PA 6	13	58	44	22	64	43
12-PC	6	26	20	11	24	10
15-Rigid PUR	1384	5996	4497	10090	10857	10431
21-St sheet galv.	2468	10693	8020	14157	14728	9459
22-St tube/profile	653	2830	2123	1559	2373	2029
23-Cast iron	2528	10956	8217	17407	15908	13662
25-Stainless 18/8 coil	15	63	47	971	156	0
26-Al sheet/extrusion	218	945	2002	1518	829	3360
29-Cu wire	63	275	206	308	316	275
30-Cu tube/sheet	426	1847	1385	2139	1887	1242
39-powder coating	15	65	42	224	144	100
44-big caps & coils	0	2	2	22	11	8
54-Glass for lamps	1720	7452	19153	6966	0	0
92-Refrigerant	8	33	25	49	65	83
98-controller board1 [286]	19	84	63	200	320	27
98-controller board2 [287]	34	149	112	165	90	134
99-Others1 [288]	36	154	116	209	187	250
99-Others2 [289]	29	126	95	143	136	150
product mass excl. packaging	**11494**	**49803**	**52206**	**69694**	**66313**	**46880**
56-cardboard	366	1588	1271	2940	2129	1619

[285] Minibars are often low-noise and use an ammonia absorption cycle instead of a vapor compression cycle, so their BoM could be quite different from the one for 1-compartment refrigerators.

[286] PWBs, switches, lamps

[287] Thermostats and sensors

[288] Lubricating oil

[289] Other plastics, adhesive tape, desiccant, glue, magnet, thermopaste, etc.

Current BoMs (masses in grams)	COLD 0 minibar	COLD 1 refrig	COLD 2 wine	COLD 7 combi	COLD 8 upright	COLD 9 chest
57-paper	45	197	197	307	185	120
6-EPS	262	1137	910	1383	1151	1902
1-LDPE	63	273	218	283	361	596
4-PP	8	34	27	39	53	70
packaging mass	**745**	**3229**	**2623**	**4952**	**3879**	**4307**
product mass incl. packaging	**12239**	**53032**	**54829**	**74646**	**70192**	**51187**

5.2.2 Bills-of-Materials, comparison EIA - APPLiA

Table 14 shows the difference in BoM shares (without packaging) between the Ecodesign Impact Accounting (EIA) and APPLiA annual statistic reports. EIA data are sales-weighted [290] averages over the refrigerator base cases (COLD 0, 1, 2, 7, including wine storage and minibars), respectively over the freezer base cases (COLD 8, 9).

Compared to APPLiA data, EIA BoMs have a lower share of plastics, a higher share of metals, and a higher share of glass for refrigerators. Unfortunately, APPLiA data are not expressed in terms of masses, and it is not specified what is or is not included.

Table 14 Comparison of EIA BoMs with APPLiA annual statistics reports

	Refrigerators				Freezers	
Comparison of BoM shares between the EIA and APPLiA	EIA weighted average 0,1,2,7	APPLiA statistics report 2022-2023	APPLiA statistics report 2021-2022		EIA weighted average 8,9	APPLiA statistics reports
Acrylonitrile butadiene styrene (ABS)	1.4%	2.6%	7.1%		1.9%	4.3%
High impact polystyrene (HIPS)		8.4%				0.0%
Polystyrene (PS)	13.2%	9.5%	17.4%		10.4%	27.7%
Polyamide (PA)	0.1%	0.1%	0.1%		0.1%	1.2%
Polycarbonates (PC)	0.0%	0.1%	0.1%		0.0%	0.9%
Polyethylene (PE)	0.4%	0.2%	3.0%		0.6%	1.7%
Polyoxymethylene (POM)		0.1%				0.0%
Polypropylene (PP)	2.2%	5.8%	6.7%		2.5%	11.8%
Polyurethane (PU)	13.3%	10.6%	9.7%		19.8%	10.9%
Polyvinyl chloride (PVC)	0.6%	1.1%	1.1%		3.0%	0.9%
Other plastics	0.0%	3.4%	1.0%		0.0%	0.0%
sum plastics share	**31.2%**	**41.9%**	**46.2%**		**38.3%**	**59.4%**
Ferro	46.7%	33.6%	38.4%		52.1%	27.2%
Stainless steel	1.0%	5.9%	3.7%		0.1%	4.3%
Aluminium	2.3%	1.9%	2.1%		4.7%	5.0%
Copper	3.6%	1.1%	1.4%		3.3%	4.0%
sum metal share	**53.6%**	**42.5%**	**45.6%**		**60.2%**	**40.5%**
Electronics	0.5%	0.6%	0.4%		0.5%	0.0%
Glass	13.9%	8.6%	6.5%		0.0%	0.0%
Other	0.8%	6.2%	1.3%		1.1%	0.0%
sum misc shares	**15.2%**	**15.4%**	**8.2%**		**1.5%**	**0.0%**

[290] Sales shares based on EPREL December 2024 model counts, see base case characteristics.

	Refrigerators				Freezers	
Comparison of BoM shares between the EIA and APPLiA	EIA weighted average 0,1,2,7	APPLiA statistics report 2022-2023	APPLiA statistics report 2021-2022		EIA weighted average 8,9	APPLiA statistics reports
sum overall	100.0%	99.8%	100.0%		100.0%	99.9%

5.2.3 Bills-of-Materials, trends

In the EIA, the average unit mass of RFs reaching EoL is 86% of the average unit mass of RFs being sold, indicating an increase in average unit mass over time. The 2016 review study [291] states:

> *Compared to the products in the 2007 preparatory study [292], based on an analysis of 2005 models, the products have not only become 10 % larger in net volume, but also heavier. An exact comparison is not possible because the 2005 industry database did not specify the product weight; the 2005 BOMs were based on industry indications of typical products and not on a database average. Nonetheless, from the comparison between the BOM 2005 and the BOM 2014 it is plausible that there has been a 15-20 % weight increase for categories 1 (refrigerators), 7 (fridge-freezers) and 8 (upright freezers). The exception is chest freezers (COLD9), where there has been almost no change.*
>
> *The weight increase is due not only to the larger net volume of the appliance, but even more due to the larger wall thickness especially of fridge-freezers and upright freezers. The amount of PUR insulation material for these categories has increased by 20 % [293]. Also the steel chassis and envelope surface of the cabinet have increased by around 15 %. The PS inner liner has increased by around 10 %.*
>
> *The efficiency of refrigeration cooling systems has improved, leading to weight increase: Condenser and evaporator surfaces are bigger (heavier), more tube-and-fin evaporators are used, circulation fans have become ubiquitous and there are more double thermostat models (plus double compressor or inverter-controlled compressors).*
>
> *Last but not least, over the last decade the steel-wire shelves, that were still common 10 years ago, have been replaced by glass shelves. This substitution adds some 10 % weight to e.g. the average refrigerator (category 1).*

Recycler CoolRec stated that the average mass of fridges arriving from The Netherlands is 42 kg (more built-in, smaller houses), while this is 48 kg in Belgium (larger appliances, larger houses). This is what arrives to the recycler, so for models of 16+ years ago. The weighted average in the EIA (based on the 2016 review study) is around 59 kg (excl. packaging). This seems to confirm the increasing mass trend.

[291] Preparatory/review study, Commission Regulation (EC) No. 643/2009 with regard to ecodesign requirements for household refrigeration appliances and Commission Delegated Regulation (EU) No. 1060/2010 with regard to energy labelling of household refrigeration appliances, FINAL REPORT, VHK, ARMINES, Viegand & Maagøe, Wuppertal Institute, VITO, March 2016

[292] Preparatory Studies for Eco-design Requirements of EuPs, Lot 13 Domestic Refrigerators & Freezers, Final Report Draft Version Tasks 3-5 (plus Annexes), December 2007, ISIS, ENEA, Univ.Bonn

[293] Recycler CoolRec confirmed that existing ecodesign regulations resulted in increased insulation (PUR foam) which is not being recycled now.

Electrolux stated that compared to the BoM of an E-class model, moving to higher energy classes, 4 areas are upgraded (insulation, cooling circuit, compressor and electronics). Only insulation changes have an impact on material composition, through the addition of Vacuum Insulation Panels, containing glass fibres or fumed silica.

5.3. Bill-of-Materials for base case COLD 7 (combi)

Table 15 gives the Bill of Materials (BoM) for an energy label class E refrigerator – freezer combi (COLD 7) with 194 litres refrigerated volume and 62 litres frozen volume. It reflects a real model, registered in the EPREL database, from a major European manufacturer. This BoM has been used for the assessment of environmental impacts in this study.

The total mass is 60.3 kg excluding packaging and scrap [294], of which 41% is plastic, 45% ferrous metal, 3.4% non-ferrous metal (2.1% aluminium, 1.3% copper), 9.6% glass, 0.5% electronic components [295], and 0.7% others (adhesives, refrigerant, lubrication oil). These shares are close to those for refrigerators from the APPLiA statistical report 2022-2023 reported in Table 14.

In terms of components, 43% of the total fridge mass is in the body, 12% in the doors, 10% in the cooling system, 11% in the compressor, 20% in interior shelves, drawers and accessories, 2% in internal airflow components, and 2% in electric and electronic components [296].

The study uses the new 2024 EcoReportTool (ERT) [297], developed for use in studies under the ESPR. The material types that can be selected in the ERT for definition of the Bill-of-Materials (and for which datasets of unit environmental impacts are provided) differ from those of the old 2014 ERT presented above. Different from the 2014 ERT, for most material types the new ERT offers a virgin material (V) and a recycled material (R), each with their own dataset of unit environmental impacts. Table 15 indicates the chosen ERT datasets for the virgin and recycled materials for the BoM of the combi fridge-freezer, see notes following the table. For the factors R1 (recycled content), R2 (recycling output rate) and A (allocation factor), see section 5.4.

Table 15: Bill of Materials for base case COLD 7 (combi) [298] and corresponding entries in the EcoReportTool

Component	Mass kg	Material category	Virgin material dataset	Recycled material dataset	R1 (BaU)	R2	A
Body - PP	0.982	01-Plastics	16-Polypropylene (PP), petrochemical based polymerisation of bio-fossil propylene production mix, at plant petrochemical based	35-Polypropylene, recycled, post-consumer washing, drying, shredding, pelletizing production mix, at plant Erec/ErecEoL, efficiency 90%	0%	49%	50%
Cooling - PP	0.170						
Compressor - PP	0.052						
Interior - PP	1.009						
Electric - PP	0.271						
Total PP	**2.484**						

[294] Packaging mass is 1.45 kg. The original BoM additionally includes 1.65 kg of HIPS scrap, which has not been used here. Scraps for other material types were not reported on the original BoM.

[295] In the inputs for the ERT this includes only main board PCB, UI board PCB, cables and wiring, and 9 LED light sources on 3 boards

[296] Contains not only the strict electronic parts of the previous footnote but also related plastic components.

[297] MEErP _Ecoreport tool_v1.7.xlsx
European Commission, Joint Research Centre, Eynard, U., Ardente, F., Gama Caldas, M., Spiliotopoulos, C. and Mathieux, F., Ecoreport tool - Manual, Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/473257, JRC133597.

[298] The BoM is for a built-in combi with 194 l refrigerated volume and 62 l freezer volume of energy class E. The model was placed on the Union market from 29/11/2021, by a major European manufacturer.

Component	Mass kg	Material category	Virgin material dataset	Recycled material dataset	R1 (BaU)	R2	A
Cooling - GPPS	0.090	01-Plastics	302-HIPS and GPPS for fridge, identical to 17-Polystyrene production, high impact polymerisation of styrene production mix, at plant 1.05 g/cm3	303-Recycled HIPS and GPPS for fridge	0%	49%	50%
Airflow - GPPS	1.095						
Interior - GPPS	4.571						
Total GPPS	**5.756**						
Body - HIPS	6.438	01-Plastics	302-HIPS and GPPS for fridge, identical to 17-Polystyrene production, high impact polymerisation of styrene production mix, at plant 1.05 g/cm3	303-Recycled HIPS and GPPS for fridge	0%	49%	50%
Door - HIPS	1.390						
Cooling - HIPS	0.005						
Interior - HIPS	0.126						
Electric - HIPS	0.323						
Total HIPS	**8.282**						
Body - PU	5.050	01-Plastics	304-Rigid PUR foam, modified ODP impact, rest identical to 21-Polyurethane rigid foam from methylene diisocyanate (MDI) and polyols production mix, at plant 18- 53 kg/m3,	not available	0%	0%	50%
Door - PU	1.530						
Electric - PU	0.001						
Total PU	**6.581**						
Body - ABS	0.061	01-Plastics	1-Acrylonitrile Butadiene Styrene (ABS) emulsion polymerisation, bulk polymerisation or combined processes production mix, at plant	36-Recycling plastic Acrylonitrile-butadiene-styrene (ABS), waste management, technology mix	0%	49%	50%
Airflow - ABS	0.021						
Interior - ABS	0.202						
Electric- ABS	0.054						
Total ABS	**0.338**						
Body - PET	0.065	01-Plastics	12-Polyethylene terephthalate (PET), petrochemical based polymerisation of ethylene glycol and terephthalic acid production mix, at plant petrochemical based	41-Polyethylene terephthalate (PET) granulate secondary ; no metal fraction from post-consumer waste, via washing, granulation, pelletization production mix, at plant 90% recycling rate	0%	0%	50%
Door-PET	0.025						
Total PET	**0.090**						
Electric - PBT	**0.085**	01-Plastics	308-Polybutylene terephtalate (PBT) {GLO} | polymerisation of terephthalic acid (TPA) and 1,4-butanediol (BDO) | production mix, at plant | petrochemical based | LCI result	not available	0%	0%	50%
Body - PC	0.044	01-Plastics	14-Polycarbonate (PC) granulate Technology mix, dipenyl carbonate route and phosgene route production mix,	33-Polycarbonate (PC), recycled, post-consumer chemical recycling, depolymerisation, hydrolysis production mix, at plant	0%	0%	50%
Electric - PC	0.044						
Total PC	**0.088**						

Component	Mass kg	Material category	Virgin material dataset	Recycled material dataset	R1 (BaU)	R2	A
			at plant 1.20–1.22 g/cm3	Erec/ErecEoL, efficiency 80%			
Body - PVC	0.043	01-Plastics	22-PVC granulates, low density polymerisation of vinyl chloride production mix, at plant 62 g/mol per repeating unit	37-Recycling plastic (PVC), waste management, technology mix, at plant	0%	0%	50%
Door - PVC	0.573						
Total PVC	**0.616**						
Cooling - EPS	0.028	01-Plastics	5-EPS Beads from styrene polymerization and foaming production mix, at plant 0.96-1.04 g/cm3	not available	0%	0%	50%
Airflow - EPS	0.011						
Electric - EPS	0.001						
Total EPS	**0.040**						
Body - PA	0.053	01-Plastics	11-Nylon 6 fiber extrusion into fiber production mix, at plant 5% loss, 3,5 MJ electricity	31-Nylon fibre, recycled, mechanical, post-consumer washing, drying, shredding, drum rotating spinning production mix, at plant Erec/ErecEoL, efficiency 90%	0%	0%	50%
Door - PA	0.024						
Interior - PA	0.027						
Total PA	**0.104**						
Body - POM	0.004	01-Plastics	306-Polyoxymethylene (POM) {GLO} | polymerisation of formaldehyde and polymerisation of trioxane with a small volume of co-polymer | production mix, at plant | petrochemical based | LCI result	not available	0%	0%	50%
Door - POM	0.012						
Total POM	**0.016**						
Cooling - EPDM	0.037	01-Plastics	6-Ethylene propylene dien elastomer (EPDM) copolymerization of ethylene and propylene production mix, at plant 69% ethylene, 38% propylene	39-Recycling of post-industrial waste EPDM rubber	0%	0%	50%
Airflow - EPDM	0.004						
Body - Synthetic Rubber	0.022						
Compressor - Synthetic Rubber	0.005						
Total EPDM/ rubber	**0.068**						
Total plastics	**24.548**	**40.7%**					
Body - Galvanized steel	12.254	02-Metals	89-Steel hot dip galvanised steel sheet hot dip galvanization single route, at plant 1.5 mm sheet thickness, 0.02 mm zinc thickness	126-Secondary steel slab electric arc furnace route, from steel scrap, secondary production single route, at plant carbon steel	30%	76%	20%
Door - Galvanized steel	3.512						
Cooling - Galvanized steel	0.222						
Compressor - Galvanized steel	0.002						
Interior - Galvanized steel	0.522						
Total Galvanized steel	**16.512**						

Component	Mass kg	Material category	Virgin material dataset	Recycled material dataset	R1 (BaU)	R2	A
Body - Low-alloy steel	0.007	02-Metals	90-Steel sheet cold rolling - thickness 2.5mm steel cold rolling process single route, at plant thickness 2.5 mm	126-Secondary steel slab electric arc furnace route, from steel scrap, secondary production single route, at plant carbon steel	30%	76%	20%
Door - Low-alloy steel	0.016						
Cooling - Low-alloy steel	0.023						
Compressor - Low-alloy steel	4.751						
Airflow - Low-alloy steel	0.006						
Total low-alloy steel	**4.803**						
Body - Unalloyed steel	**0.715**	02-Metals	87-Steel cold rolled coil blast furnace route single route, at plant carbon steel	126-Secondary steel slab electric arc furnace route, from steel scrap, secondary production single route, at plant carbon steel	30%	76%	20%
Body - Carbon steel	0.060	02-Metals	87-Steel cold rolled coil blast furnace route single route, at plant carbon steel	126-Secondary steel slab electric arc furnace route, from steel scrap, secondary production single route, at plant carbon steel	30%	76%	20%
Airflow - Carbon steel	0.006						
Interior - Carbon steel	0.016						
Total Carbon steel	**0.082**						
Cooling System - Gray cast iron	3.660	02-Metals	87-Steel cold rolled coil blast furnace route single route, at plant carbon steel	128-Steel cast part alloyed electric arc furnace route, from steel scrap, secondary production single route, at plant carbon steel	30%	76%	20%
Compressor - Gray cast iron	1.445						
Total Cast iron	**5.105**						
Door - Ferrite	**0.008**	02-Metals	68-Ferrite (iron ore) iron ore mining and processing production mix, at plant 5.00 g/cm3	not available	30%	76%	20%
Total Ferrous	**27.225**	**45.1%**					
Cooling - ALMg3	0.806	02-Metals	49-Aluminium ingot (silicon and magnesium main solutes) primary production, aluminium casting and alloying single route, at plant 2.7 g/cm3	120-Secondary aluminium ingot (silicon and magnesium main solutes) secondary production, aluminium casting and alloying single route, at plant 2.7 g/cm3	30%	70%	20%
Cooling - AL casting	0.406	02-Metals	51-Aluminium ingot (zinc main solute) primary production, aluminium casting and alloying single route, at plant 2.7 g/cm3	122-Secondary aluminium ingot (zinc main solute) secondary production, aluminium casting and alloying single route, at plant 2.7 g/cm3			
Compressor - AL (unspecified)	0.042	02-Metals	49-Aluminium ingot (silicon and magnesium main	120-Secondary aluminium ingot (silicon and magnesium main			

Component	Mass kg	Material category	Virgin material dataset	Recycled material dataset	R1 (BaU)	R2	A
			solutes) primary production, aluminium casting and alloying single route, at plant 2.7 g/cm3	solutes) secondary production, aluminium casting and alloying single route, at plant 2.7 g/cm3			
Total Aluminium	**1.254**						
Cooling - Copper	0.668	02-Metals	61-Copper Concentrate (Mining, mix technologies); copper ore mining and processing; single route, at plant; Copper - gold - silver - concentrate (28% Cu; 22.3 Au gpt; 37.3 Ag gpt)	124-Recycling of copper from clean scrap; collection, transport, pretreatment; production mix, at plant; copper content in input scrap 90%, copper losses 1%	37%	74%	20%
Compressor - Copper	0.111						
Total Copper	**0.779**						
Total Non-ferrous	**2.033**	**3.4%**					
Interior - Glass	**5.796**	02-Metals	72-Flat glass, uncoated cut, Pilkington process, from sand and soda ash production mix, at plant 2500 kg/m3	116-Recycling glass, waste management, technology mix, at plant collection, sorting, transport, recycling production mix, at plant glass waste, efficiency 95%	5%	48%	20%
Total Glass	**5.796**	**9.6%**					
Electric - UI board PCB	0.056 kg 0.042 m2	03-Electronics	164-Printed wiring board (PWB) (2-layer) via the subtractive method (as opposed to additive method) production mix, at plant 2-layer, 1.32 kg	195-End of life of Populated Printed wiring board (PWB) (2-layer) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	52%	50%
Electric - Main board PCB	0.121 kg 0.092 m2	03-Electronics	164-Printed wiring board (PWB) (2-layer) via the subtractive method (as opposed to additive method) production mix, at plant 2-layer, 1.32 kg	195-End of life of Populated Printed wiring board (PWB) (2-layer) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	52%	50%
Electric - wiring	0.100 kg 1.667 m	03-Electronics	133-Cable, three-conductor cable technology mix production mix, at plant three-conductor cable, 1m, 60 g/m	177-End of life of cable, three-conductor cable Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	62%	50%
Electric - UI cable	0.010 kg 0.167 m				0%	62%	50%

Component	Mass kg	Material category	Virgin material dataset	Recycled material dataset	R1 (BaU)	R2	A
Electric - LED	0.00315 kg 9 items	03-Electronics	151-Light Emitting Diode (LED) front-end and back-end processing of the wafer, including Czochralski method of silicon growing production mix, at plant 5 mm, 350 mg	190-End of life of Light Emitting Diode (LED) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	52%	50%
Electric – LED board x3	0.01395 kg 0.008977 m2	03-Electronics	164-Printed wiring board (PWB) (2-layer) via the subtractive method (as opposed to additive method) production mix, at plant 2-layer, 1.32 kg	195-End of life of Populated Printed wiring board (PWB) (2-layer) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	52%	50%
Total Electric	**0.302**	**0.5%**					
Body - Adhesives	0.203	01-Plastics	4-Epoxy plastic polymerisation of liquid epoxy resins with a latent hardener (amine) production mix, at plant petrochemical based	not available	0%	0%	50%
Door - Adhesives	0.031						
Cooling - Adhesives	0.000						
Total adhesives	**0.234**						
Cooling - refrigerant	0.048	04-Others	229-Refrigerant R600a; iso-butane	not available	0%	0%	50%
Compressor - Lubrication oil	0.139	04-Others	214-Bitumen at refinery from crude oil production mix, at refinery 38.7 MJ/kg net calorific value	not available	0%	0%	50%
Compressor - paper	0.002	04-Others	223-Kraft paper, uncoated Kraft Pulping Process, pulp pressing and drying production mix, at plant <120 g/m2	238-Recycling paper and cardboard, waste management, technology mix, at plant collection, sorting, transport, recycling production mix, at plant paper waste, efficiency 90,9%	0%	0%	50%
Total Other	**0.423**	**0.7%**					
Body	**26.000**	**43.1%**					
Door	**7.120**	**11.8%**					
Cooling System	**6.163**	**10.2%**					
Compressor	**6.549**	**10.9%**					
Interior	**12.268**	**20.3%**					
Internal Airflow	**1.143**	**1.9%**					
Electric (EEC)	**1.081**	**1.8%**					
Total Mass	**60.324**						

Notes on Table 15:

1- The original BoM supplied by the manufacturer was more detailed. The table anyway indicates the main fridge components in which each material type is being used: Body, Door, Cooling system, Compressor, Interior (including accessories), internal Airflow, and Electric and electronic components (EEC).

2- Of the total fridge mass, 20% is for internal components and accessories, which are drawers, shelves and accessories like the egg tray, ice tray, bottle shelf, usually removable. Most of these are in plastic, metal wire or glass.

3- Another 10% is in the hermetic compressor, which is typically removed before shredding, and separately processed by recyclers.

4- Polypropylene (PP) is mainly used for drawers and body reinforcements. Many other small parts, related mainly to water drain, ice-contact or humidity control.

5- General Purpose Polystyrene (GPPS) is mainly used for drawers, shelves, some covers, housings and ducts of the internal airflow system, and some small components of the cooling system.

6- High-Impact Polystyrene (HIPS) is mainly used for the body inner liner and the door liner, but in total there are 23 components in this material.

7- The ERT does not distinguish between GPPS and HIPS. For the virgin material, dataset 17 (for polystyrene) is used for both [299]. For the recycled material, the ERT offers dataset 40. However, from the description this set is for recycled PP [300] [301], and the ERT uses it as recycled material dataset for several types of plastic [302]. The EoL impacts of dataset 40 have negative values for several parameters, which raised doubts.
It has therefore been preferred to use a specific dataset for recycling of PS from WEEE, taken from the WEEE LCI database [303]. This dataset has been added to the ERT as user-defined set 303, associated to the user-defined virgin PS dataset 302, which is identical to the original set 17.

Table 16: WEEE LCI dataset for polystyrene recycled from WEEE

Damage category	Unit	Polystyrene (rPS), granulate, recycled plastic from WEEE
Acidification	mol H+ eq	0,003125
Climate change	kg CO2 eq	0,607365
Ecotoxicity, freshwater	CTUe	2,376058
Particulate matter	disease inc.	2,67E-08

[299] An LCA specialist in Viegand Maagøe used datasets for GPPS and HIPS from Ecoinvent 3.11 using the EF 3.1 LCIA method to compare the environmental impacts of GPPS and HIPS. The results show that, on average, HIPS has about 6% higher impacts than GPPS, though this varies across different impact categories. Overall, the difference between the two materials is typically around 10% in some categories, but this falls within the general uncertainties of LCA studies. Given the many assumptions already made in LCAs, using GPPS as a stand-in for HIPS isn't unreasonable.

[300] But for recycled PP the ERT uses dataset 35, not 40. For many parameters, set 40 has negative impacts (benefits) while set 35 does not have these: all impacts are positive in set 35.

[301] The study team asked an LCA specialist in Viegand Maagøe for an opinion on this. He answered that:

In LCA, recycled materials are typically modelled as burden-free, meaning that the environmental impact of producing the original plastic is not included in the dataset. Instead, only the recycling process itself—which covers collection, sorting, washing, extrusion, and pelletization—carries an environmental burden.
Since the recycling process for PP and HIPS is quite similar, it's common to use the same dataset for both. However, there are some minor differences between the two:
• Extrusion temperatures (for repelletization) can vary, with some polymers requiring higher or lower temperatures than others. For example, the melting point of HIPS is approximately 37.5% higher than that of PP, meaning that HIPS generally requires higher processing temperatures.
• HIPS waste might need less washing compared to PP but could require more dismantling, depending on the source of the waste

[302] Dataset 40 is also used for recycled Aramid fiber, PMMA, PTFE, and various polyvinyls (but not for PVC).

[303] https://weee-lci.ecosystem.eco/

Eutrophication, marine	kg N eq	0,000599
Eutrophication, freshwater	kg P eq	2,54E-05
Eutrophication, terrestrial	mol N eq	0,007134
Human toxicity, cancer	CTUh	2,43E-11
Human toxicity, non-cancer	CTUh	3,46E-10
Ionising radiation	kBq U-235 eq	0,086487
Land use	Pt	1,037459
Ozone depletion	Kg CFC11 eq	7,04E-08
Photochemical ozone formation	kg NMVOC eq	0,001677
Resource use, fossils	MJ	12,33017
Resource use, minerals and metals	kg Sb eq	1,79E-07
Water use	m3 depriv.	0,2586

8- The original BoM does not report masses for Polyurethane foam (PU, PUR), but separate masses for methylene diphenyl diisocyanate, polyol and blowing agent cyclopentane. These masses have been summed to PUR mass. PUR is used as insulation foam in the body and in the door.

The ERT dataset 21 for rigid PUR foam leads to very high ozone depletion impacts (ODP). This has been examined with assistance from an Electrolux LCA specialist, comparing with datasets from other sources, which have much lower impacts for ODP [304]. The conclusion was that the ERT dataset must still be assuming use of a legacy CFC-containing blowing agent. As modern fridges use cyclopentane, which is not ozone depleting, a new user dataset 304 was created, identical to ERT dataset 21, but with 1.11E-7 ODP impacts instead of 4.6E-6 kgCFC11eq / kg foam. This ODP impact might still be on the high side.

9- ABS (Acrylonitrile Butadiene Styrene) is used in 13 small parts, with masses from 3 to 67 grams each.

10- PET (Polyethylene Terephthalate) is used in a valve assembly and in 4 tapes, with masses from 10 to 27 grams per part. Small total mass.

11- PBT (Polybutylene Terephthalate) is used in a high fan component. The ERT does not have a dataset for PBT, so the same dataset used in the analyses for personal computers and imaging equipment was added as user-defined set 308 (without recycled material). Small total mass.

12- PC (Poly Carbonate) is used for user interface components. Small total mass.

13- PVC (Polyvinyl Chloride) is used for the door gaskets of both refrigerator and freezer. This is soft PVC.

14- EPS (Expanded Polystyrene) is used as an insulator in the cooling system, and in fan-related components. Small total mass[305].

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[304] The impacts for PUR foam were computed from those for polyol, MDI and cyclopentane, applying the BoM masses for these components, summing the impacts and then normalizing to impacts per kg. This was done for 'market data' impacts (including transports) and for 'production impacts' (excluding transports). In addition, an alternative dataset directly for PUR foam was available for comparison. ERT dataset 21 impacts are closest to those derived from 'production impacts' (excluding transports), except for ODP where the ERT uses 4.6E-6 kgCFC11eq/kg foam and the alternative dataset has 2.6E-12 kgCFC11eq/kg foam. Using the ERT dataset, practically all ODP impact for the fridge come from PUR foam. Using the alternative dataset these impacts would completely vanish. As a compromise, the ODP impact of 1.11E-7 for 'market data' impacts (including transports) has been used. Those ODP impacts seem to derive from the transports of MDI. The third alternative dataset (direct PUR foam) has ODP impacts of 1.87E-7.

It was noticed that market-type impacts are much higher than production-type impacts, especially for 'human toxicity, cancer', 'eutrophication, freshwater', and 'resource use, minerals and metals'. ERT dataset 21 seems to use production-type impacts.

[305] Most EPS is used in packaging, not considered here.

15- PA6 and PA66 (Polyamide, nylon) are used in 8 small parts, ranging from 1 to 48 grams. Small total mass.

16- POM-H (Homopolymer Polyoxymethylene) is used for 7 hinge bushings. The ERT does not have a dataset for POM, so the same dataset used in the analyses for personal computers and imaging equipment was added as user-defined set 306 (without recycled material). Negligible total mass.

17- EPDM (Terpolymer Ethylene-Propylene-Diene) is used for rubber spacers and dampers. The mass of synthetic rubber has been added to the mass for EPDM. Small total mass.

18- Galvanized steel is used for the outer panels of body and doors, but also for several reinforcement bars. In total there are 23 components using this material. Available information indicates hot-dip galvanization, not electro galvanization, but this might not be true for all 23 components. To be noted that the BoM refers to a built-in model: free-standing models would probably use painted / coated sheets instead of galvanized. For recycled steel (of any type) the ERT offers a choice between 2 recycled material datasets [306]. Set 126 was selected by lack of further information.

19- Low-alloy steel is used mainly in the compressor. For the virgin material a choice had to be made between two datasets [307]. Set 90 was selected for lack of further information. For the recycled material, the same applies as in the previous point.

20- Unalloyed steel is used for bars, hinges and supports in the body. For the virgin material a choice had to be made between two datasets [307]. Set 87 was selected for lack of further information. For the recycled material, the same applies as in the previous points.

21- Carbon steel is used only for screws and nuts. Same ERT datasets used as for unalloyed steel. Small total mass.

22- Gray cast iron is used for the wire-on-tube (WOT) condenser assembly and for the compressor. The ERT does not have a specific dataset for cast iron, so that set 87 for cold rolled steel was used, together with recycled material dataset 128.

23- Ferrite is used for the magnet inside the door gaskets. Negligible mass.

24- Aluminium is used mainly in the evaporator of the cooling system, and some in the compressor. The ERT requires choosing from 7 different aluminium alloys. For AlMg3 the ERT datasets 49 (virgin) and 120 (recycled) seem adequate. For Al casting the ERT datasets 51 (virgin) and 122 (recycled) have been chosen. The manufacturer indicated a tendency to replace copper with aluminium in the cooling system, to reduce costs.

25- Copper is used in various parts of the cooling system, and in the compressor. The latter probably refers to the winding wire of the motor.

26- Glass (tempered) is used for shelves inside the fridge.

27- Electric and electronic components (EEC) are 1.8% of the total fridge mass, but most of this mass is plastic, and accounted as such in the ERT. The components listed as ’03 – Electronics’ in the ERT are 0.5% of the total fridge mass and include the UI board PCB, the main board PCB, electric wiring, UI cable, and LED light sources with their boards. Although the mass of these components is low, their environmental impacts are relatively high for many parameters (see the results section), and hence the choice of the ERT datasets, and of the correct associated masses, is important.

[306] 126-Secondary steel slab electric arc furnace route, from steel scrap, secondary production single route, at plant carbon steel
128-Steel cast part alloyed electric arc furnace route, from steel scrap, secondary production single route, at plant carbon steel

[307] 87-Steel cold rolled coil blast furnace route single route, at plant carbon steel
90-Steel sheet cold rolling - thickness 2.5mm steel cold rolling process single route, at plant thickness 2.5 mm

28- Initially, for the main board PCB, virgin dataset 141 for Controller board and corresponding recycled dataset 206 were used. These datasets resulted in very high impacts, which were judged too high by LCA specialists from Viegand Maagøe and from the fridge manufacturer. The latter provided their in-house environmental impact results for the electronic board. Using virgin dataset 164 for a 2-layer printed wiring board, and corresponding recycled dataset 195, ERT results are closer to those of the manufacturer. The ERT requires input in square meters: with a conversion factor of 1.32 kg/m2 the mass of 0.121 kg gives 0.092 m2 [308]. See section 6.2.4 for a detailed modelling of PCBs based on an assumed material composition.

29- For the UI board PCB, virgin dataset 164 for a 2-layer printed wiring board has been selected. It is unknown if this is representative of the UI board, but the ERT alternative for an 8-layer PWB seems worse. The corresponding recycled dataset is 195. The ERT requires input in square meters: with a conversion factor of 1.32 kg/m2 the mass of 0.056 kg gives 0.042 m2.

30- For the electric wiring and cable, virgin dataset 133 for a 3-conductor cable and corresponding recycled dataset 177 are the best available choice in the ERT. The ERT requires input in meters: with a conversion factor of 0.06 kg/m the mass of 0.100 + 0.010 kg gives 1.667 + 0.167 m.

31- Initially, for the LED light source, virgin ERT dataset 153 for a low-power LED and corresponding recycled dataset 192 were chosen. The ERT requires input in number of items: with a conversion factor of 0.000059 kg/item the mass of 0.005 kg gave 84.7 items. The resulting impacts were judged much too high, probably because the mass of 5 g is not all LED, but mostly the board on which the LED is mounted.

Investigating this in depth together with the fridge manufacturer, it turned out that in reality there are 9 LEDs, mounted on 3 separate boards of 15.9 cm2 each. The 9 LEDs were represented in the ERT as 9 items of 350 mg each in ERT datasets 151 and 190. The LED-boards were separately modelled using datasets 164 and 195 (the same as used for the main board and the UI-board), with a total area of 90 cm2 (to match the total board mass of 15 g – 9*0.350 g = 13.95 g)

32- The refrigerant is isobutane (R600a) for which a specific virgin dataset 229 is available in the ERT. There is no corresponding recycled material dataset.

33- The mineral lubrication oil for the compressor has been modelled using virgin dataset 214 for bitumen, by lack of a better choice. There is no corresponding recycled dataset.

34- Adhesives are used in several positions in the fridge, but most of the mass is in the fridge body. Virgin dataset 4 for epoxy plastic has been used, by lack of a better choice. There is no corresponding recycled dataset.

35- The study team added new datasets for PS, PU, POM and PBT in the category ‘Other’ instead of ‘Plastic’ to avoid anomalous behavior of the ERT in calculating the recycling benefits for electronics. The issue has been reported to the ERT team.

5.4. Recycling parameters for the EcoReportTool

[308] For comparison, the manufacturer declared board dimensions of 120x110 mm = 132 cm2 = 0.0132 m2, with 9.17 kg/m2, so quite different from the ERT dataset characterization.

5.4.1 Simplified Circular Footprint Formula

The 2024 ERT calculates the environmental impacts of raw materials, excluding the end-of-life (EoL) phase, using a simplified version of the Circular Footprint Formula (CFF) [309] [310]:

(1-R1) x Ev + R1 x (A x Erec + (1-A) x Ev).

The impacts at end-of-life due to material recycling are computed from:

(1-A) x R2 x Erec.

The benefits at end-of-life due to material recycling (avoidance of virgin material use) are computed from:

For non-electronics: - (1-A) x R2 x Ev

For electronics: - CF x Amount x (1-A) x R2 x SUM (Credits for Cu, Au, Pd, Pt, Ag)

Where:

Ev the virgin material impact for the environmental parameter, computed as the total input material mass (kg) multiplied by the unit impact for the applicable virgin material dataset for the environmental parameter (impact/kg).

Erec the recycled material impact for the environmental parameter, computed as the total input material mass (kg) multiplied by the unit impact for the applicable recycled material dataset for the environmental parameter (impact/kg).

R1 (recycled content): the proportion of material in input to the production that has been recycled from a previous system

R2 (recycling output rate): the proportion of the material in the product that will be recycled in a subsequent system. R2 considers the efficiencies in the collection and recycling processes. R2 shall be measured at the output of the recycling plant.

A the allocation factor of burdens and credits between supplier and user of recycled materials. The “A” factor in the CFF allows to allocate impacts and/or benefits between the use of recycled materials as input (i.e. recycled content) and recycling at the end-of-life (i.e. recycling output rate). It avoids potential double counting due to recycled materials coming from fridges being subsequently used in other products, or vice versa [311].

For electronics, a more complex formula is used to compute recycling benefits:

- For electronics the amount of material in input to the production is often defined in m2, m or items. A conversion factor CF is used to convert the amount to a mass in kg.

[309] MEErp _Ecoreport tool_v1.7.xlsx
European Commission, Joint Research Centre, Eynard, U., Ardente, F., Gama Caldas, M., Spiliotopoulos, C. and Mathieux, F., Ecoreport tool - Manual, Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/473257, JRC133597.

[310] The ERT does not consider the impacts from incineration (with or without heat recovery), nor of landfilling, fugitive, or missing masses at EoL.

[311] If R1=R2 (e.g. all recycled material coming from fridges is reused for fridges)

- R1 x A x Erec is counted in raw material input impacts
  (1-A) x R2 x Erec is counted as EoL impact
  Hence, if R1=R2, the entire Erec (impact from recycled materials) is counted.
- (1 - R1 x A) x Ev is counted in raw material input impacts
  -(1 - A) x R2 x Ev is counted as EoL benefit (avoided virgin materials)
  Hence, if R1=R2, (1-R1) x Ev (impact from virgin materials) is counted.

- Each virgin material dataset for electronics has material credits defined for copper (Cu), gold (Au), palladium (Pd), platinum (Pt) and silver (Ag). These credits can be interpreted as mass shares. E.g. for dataset 133 (cable), the credit for copper is 0.195.
- Each material credit is multiplied by the unit impact for the considered parameter in the virgin material dataset for Cu (61), Au (75), Pd (81), Pt (82) or Ag (84), and the sum is multiplied by the recycled mass share CF x Amount x (1-A) x R2.
- Hence, for electronics, the recycling benefit is not related to e.g. avoided virgin cables, PWBs or LEDs, but to avoided virgin Cu, Au, Pd, Pt and Ag.

The ERT provides default values for R1, R2 and A that the user can accept or overwrite. The values for these parameters are discussed in the following sections. The values used are shown in Table 15.

5.4.2 Allocation factor A

The current study uses the default values for allocation factor A, which are 50% for all material types except metals, and 20% for metals. Hence, for recycling of metals, only 20% of the benefits are assigned to the production phase, and 80% to the EoL phase. For plastic, electronics, and other materials this is 50%-50%.

5.4.3 Factor R1, recycled content

For plastics, the ERT default value for factor R1 (recycled content) is 0%.

PlasticsEurope [312] states that EEE products consumed 3.1 Mt of plastics in 2022, of which 3.2% (0.1 Mt) came from post-consumer recycled plastic. It is uncertain if this share would also be representative for refrigerators and freezers.

For polyurethane insulation foam (PUR), which covers 20-27% of the plastics mass in refrigerators and freezers, the factor R1 is certainly 0%, because PUR is currently not being recycled. In future, if chemical recycling becomes economically viable, this can change.

For (HI)PS, PP and ABS, which are being recycled, the factor R1 could already be slightly higher than 0%, but food contact material regulations limit the use. Although some fridge models already use 70% recycled HIPS as input for the inner liner production (section 4.2.1), the default 0% seems close to the overall current situation and has thus been used as reference scenario. In ECO scenarios setting minimum requirements on recycled plastics content, the factor R1 has been increased and the differences in environmental impacts registered

For aluminium, the default for R1 (recycled content) in the ERT is 30%. For copper and steel, the default is 0%. The reason for this difference is unknown.

Eurostat [313] provides data for the contribution of recycled materials to raw materials demand, e.g. end-of-life recycling input rates (RIR, Table 17). The shares vary over the years, but the 30% for aluminium could come from here.

[312] https://plasticseurope.org/wp-content/uploads/2024/11/PE_TheFacts_24_digital-1pager.pdf
https://plasticseurope.org/knowledge-hub/the-circular-economy-for-plastics-a-european-analysis-2024/

[313] Eurostat online database cei_srm010, accessed January 2025.

An IAI Factsheet [314] confirms that in 2018 the global Recycling Input Rate (RIR) of aluminium was 32%, including recycled pre- and post-consumer scrap contained in the produced aluminium, but not run-around scrap.

According to the world steel organisation, in 2021, around 70% of the total metallic input to steel production globally was derived from iron ore, with scrap making up the other 30% [315]. This corresponds well with the data from Eurostat (RIR, Table 17). Based on these data, 30% has also been used for steel.

Table 17: End-of-life recycling input rates (source: Eurostat cei_srm010)

	2013	2016	2019	2022
aluminium	35%	12%	12%	32%
copper	20%	55%	17%	55%
iron	22%	24%	32%	31%
nickel	32%	34%	17%	16%

For copper, values in Table 17 vary over the years, with an average of 37%.

The 2024 Factsheet on copper recycling from the Kupferverband [316] confirms that on average, copper products worldwide contain more than 30 percent recycled content. The share of recycled materials in copper production (classic recycling rate) is around 40 percent in Europe, significantly higher than the global average. The value of 37% has been used in the analyses.

The same factsheet specifies that (see also graph in the source):

> *Scrap that can be reused in the same process in which it arises is generally not considered pre-consumer scrap. Both pre- and post-consumer scraps may require processing before they can be reintroduced into the material cycle. Both types of recycled materials are used in the production of goods and determine their recycled content. A physical separation of these scrap types is therefore useless in terms of their recyclability.*
>
> *Recyclers purchase and collect both types of scrap until economically viable batch sizes are reached, allowing them to transport the loads to processors or larger scrap dealers. The distinction and sorting of scrap are therefore based solely on its quality, such as copper content or material purity, in order to optimize the use of the scrap in follow up refining or remelting processes.*

In a meeting with the study team, a large EU copper recycler [317] confirmed that it is impossible for them to distinguish between pre-consumer and post-consumer inputs for the recycling, because all copper scrap or granules arrive as a mix from both types. To make the distinction, scrap collectors would have to certify (if feasible for them) the proportions pre- and post-consumer scrap that they supply to upstream recyclers.

For glass, the default for R1 (recycled content) in the ERT is 0%. The amount of post-consumer cullet used as input for flat glass production is 5% (section 2.2.4) but might be lower for the tempered float glass for food contact applications used in fridges. If pre-consumer cullet is also counted, the share would be 26%. As the present study focuses on post-consumer recycled material, for the baseline 5% cullet has been used.

[314] https://international-aluminium.org/wp-content/uploads/2024/03/wa_factsheet_final.pdf

[315] https://worldsteel.org/wp-content/uploads/Fact-sheet-on-scrap_2021.pdf

[316] https://kupfer.de/wp-content/uploads/2024/10/2024_Factsheet_Recycling_EN.pdf

[317] https://www.montanwerke-brixlegg.com/

For all electronics, the default for R1 (recycled content) in the ERT is 0%, and no information is available to change this.

For all other materials, no default is available in the ERT. For adhesives, refrigerant and lubrication oil, the study used R1=0% [318].

5.4.4 Factor R2, recycling output rate

The ERT specifies that the value for R2 (recycling output rate) shall consider the efficiencies in the collection and recycling processes.

Based on information presented in section 2.1.5, it can be estimated that for refrigerators and freezers reaching end-of-life in 2024, 60% is separately collected and 18% is complementary collected. The total collection rate of 78% is lower than the 85% (of WEEE generated) required by the WEEE directive, so it could further increase in future, but for the analyses in this study it is assumed to remain constant.

Plastics

Based on information from a major European fridge recycler, for PS, PP and ABS, 80% of the separately collected mass is recycled. For complementary collected mass the recycling rate is lower. Based on data from PlasticsEurope (section 2.1.5.6) this rate is estimated to be 4%.

For PS (including GPPS and HIPS), PP and ABS, the factor R2 has therefore been set to 60%*80% + 18%*4% = 49%.

PVC is recyclable and has a moderate mass in fridges (1% of the total mass, 2.5% of the plastics mass). On the BoM for combis in Table 15, almost the entire PVC mass is for soft PVC, which has more recycling issues due to additives. As there is no evidence that PVC is being recycled from fridges [319], it has been preferred to maintain R2=0%.

Polyurethane (PU) from fridges is currently not being recycled but mainly incinerated with heat recovery [320]. The analyses therefore assume that nothing is recycled, e.g. R2=0%.

There are other plastic types that are recyclable, but their masses in fridges are low and spread over many small components, so that it does not seem worthwhile to apply separation processes for them during EoL fridge processing. The analyses therefore assume that nothing is recycled, e.g. R2=0%.

Metals

[318] From a study team visit to Coolrec fridge recycling facilities, it was understood that refrigerants are recovered and treated as F-gases, for use in acids production. Many fridges that now arrive to recycling facilities still contain F-gases, which will not be re-used as refrigerant in new products. This might change in future, when most fridges arriving at recyclers will contain isobutane.

[319] Cables are removed at the beginning of the fridge recycling process and go to specialized cable recyclers. Most of them recycle the PVC from cable sheathing, but this recycling is currently at risk because of ever reducing limit values in REACH and POP. In the ERT, this PVC would be included in the cable and electric wiring mass, not as a plastic component.

PVC from the door rubbers partly ends up in the steel fraction (because of the magnetic strip which is inserted in the profile). Partly it goes to the plastic fraction, where it ends up in the sorting residues. The possibility of recycling this fraction (into flooring tiles for sports halls and playgrounds) has been investigated by recyclers, but analysis showed presence of restricted biocides, so the project was stopped.

The rest of the PVC (mostly rigid) ends up in the sorting residues of the fridge plastics process. Considering PVC is a very small share in that fraction, there is no economic interest into separating it. No information on the presence of regulated substances.

[320] The 2024 ERT does not consider impacts or benefits from incineration with heat recovery.

For aluminium and steel, the ERT gives a default value for R2 of 85%. For fridges, considering the 78% total collection, this is too high. Based on information presented in section 2.1.5.5, for steel it is assumed that 98% of the collected mass is recycled (R2=78%*98%=76%), and for aluminium 90% (R2=78%*90%=70%) [321].

For copper, the ERT gives a default value for R2 of 0%, which is too pessimistic. Based on information presented in section 2.1.5.5, for copper it is assumed that 95% of the collected mass is recycled (R2=78%*95%=74%).

In general, for metals the recycling rates are high, but based on the available information, it is not possible to establish an exact value for metals recycled from fridges. The recycling rates mentioned above are assumed to be valid both for separate and for complementary collection, and for all alloy types.

Glass

For flat glass, the ERT gives a default value for R2 of 0%, which is too pessimistic. According to the information presented in sections 2.1.9.5 and 2.2.4, the flat glass recycling rate from home appliances is 29% of the generated glass waste, or 39% of the collected waste, but this contrasts with information from recyclers and fridge manufacturers, which indicate a recycling rate near 100%. For fridges the rate might be higher than for other home appliances, or there might be a difference in interpretation as to which types of recovery count for the rate [322]. For the analyses, an average of 70% recycling rate for flat glass from separately collected fridges has been assumed. For complementary collected glass this rate has been halved.

This leads to R2 = 60%*70% + 18%*35% = 48%.

Electronics

For all electronics, the ERT gives a default value for R2 of 50%. If total collection is 78%, this implies a recycled vs. collected rate of 64%. Considering the current practice in fridge recycling, for cables and capacitors this is probably higher (90% recycled vs. separately collected assumed) [323] [324]. Printed circuit boards from household fridges (including the smaller ones with LEDs), are typically shredded with the rest of the appliance, and then (partially) recovered from the plastics fraction during the separation processes (75% recycled vs. separately collected assumed) [325]. For recycling from complementary collection these values have been halved.

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[321] An IAI factsheets states a global Recycling Efficiency Rate (RER) of aluminium of 76%. The RER defines how efficiently aluminium is recycled throughout the value chain. It is an indicator used to estimate the amount of recycled aluminium produced annually from pre- and post-consumer scrap, as a percentage of the total amount of available scrap sources. This rate includes collection, processing and melting losses, but runaround scrap (re-used in the same process that produced it) is not included. Europe has the highest Recycling Efficiency Rate (RER) of any region in the world, recycling 81% of the aluminium scrap potentially available in the region. https://international-aluminium.org/wp-content/uploads/2024/03/wa_factsheet_final.pdf

[322] Maximum 5% of the post-consumer recycled glass re-enters flat glass production, the rest is recovered as e.g. Fiberglass insulation, Glass tiles and countertops, Abrasive materials for sandblasting, Artificial sand for industrial applications, Water filtration media, Reflective road paint and micro glass beads for highway markings, Solar panel glass, glass bottles, and packaging, Construction materials such as road base and concrete aggregate

[323] External power cords are removed before shredding and contain valuable copper, so recycling rate is likely high. Capacitors are also removed before shredding (but they are not explicitly listed on the BoM used here).

[324] It is not rare that fridges arrive to recyclers without the cables (and other copper parts), being scavenged along the waste collection route. However, in some way or the other, also these 'stolen' cables will most likely be recycled.

[325] Commercial and professional appliances have relatively large electronic boards, which are manually removed before shredding (especially when this is easily done), or hand-picked after pre-shredding. Household fridges have smaller boards which are not always easily accessible. These boards are typically shredded together with the rest of the appliance, ending up in the mixed plastic fraction. These boards (or more correctly, the flakes of these boards) are removed on the water separation tables. In all three instances, the circuit boards will end up in special smelters like Umicore, Boliden and their likes.

For PCBs and LEDs this gives R2 = 60%*75%+18%*37.5% = 52%.

For cables and capacitors: R2 = 60%*90%+18%*45% = 62%.

These percentages apply to the end-of-life mass of the electronics and are used in the ERT to compute the EoL benefits for avoided use of virgin Cu, Au, Pd, Pt and Ag (section 5.4.1). Typically, 50-60% of the electronic board mass is for the reinforced plastic support structure, which is often not recycled.

Other materials

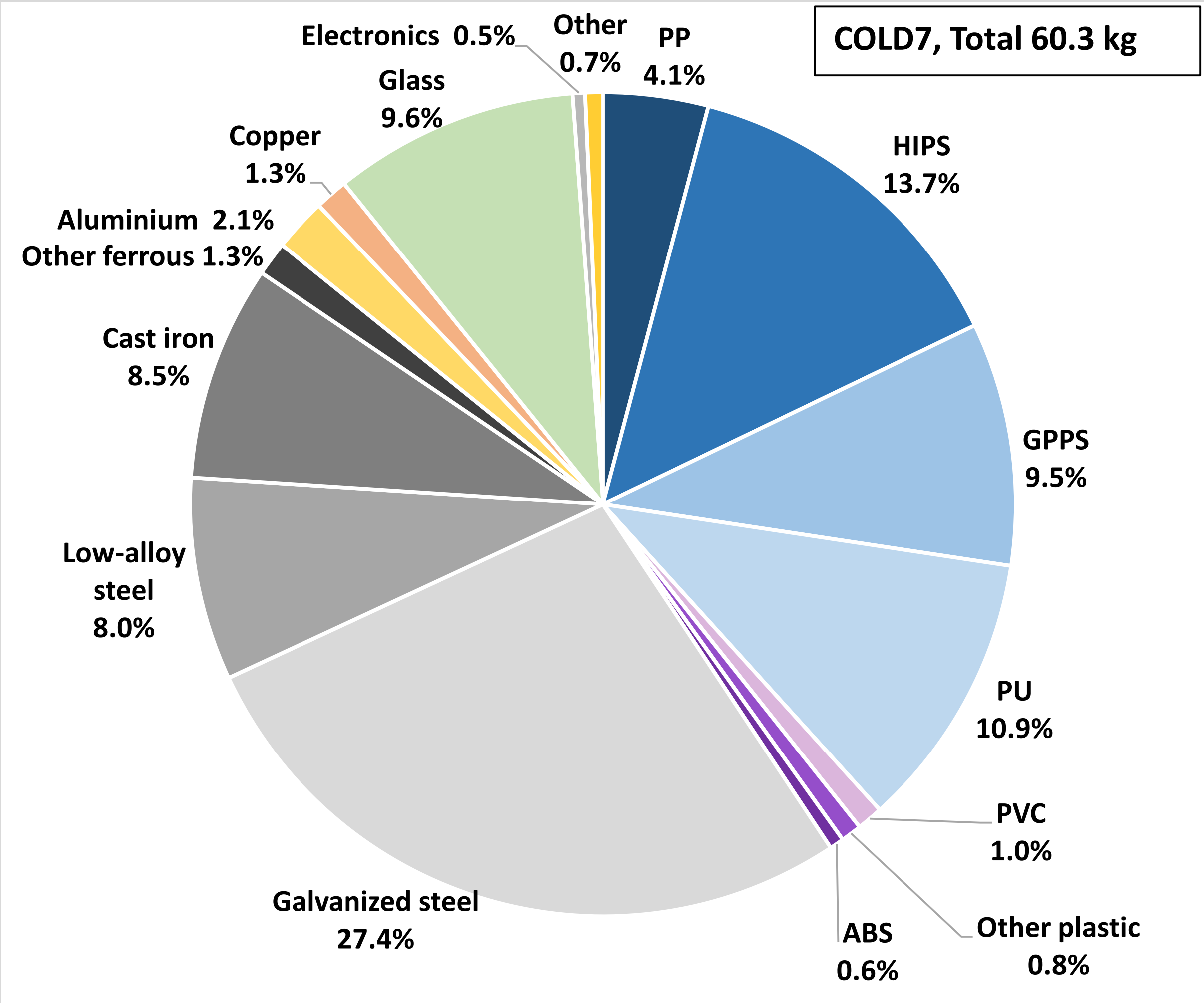
For all other materials, where no default R2 value is available from the ERT, R2=0% has been assumed.

5.5. Mass distributions for the baseline

Figure 21 shows the distribution of masses over the material types for base case COLD7 (combi), for the Bill-of-Materials of section 5.3.

Applying the baseline factors R1 (recycled content) of section 5.4.3, Figure 22 shows the proportions of virgin (blue) and recycled (orange) materials in input. Overall, in the baseline 15% of the input mass is recycled content (all from metals, and some glass).

Applying the baseline factors R2 (recycling output rate) of section 5.4.4, Figure 23 compares the total material inputs (red) to the recycling outputs (green). Overall, 55% of the input mass is recycled at end-of-life (most from metals, but also from PP, PS, ABS, Glass, and some electronics [326]).



[326] For electronics the recycling output mass refers to the electronic components available after fridge shredding and separation processes. The amount of recovered Cu, Au, Pd, Pt, Ag and other CRMs is smaller.

Figure 21: Masses per material type for base case COLD7 (combi)

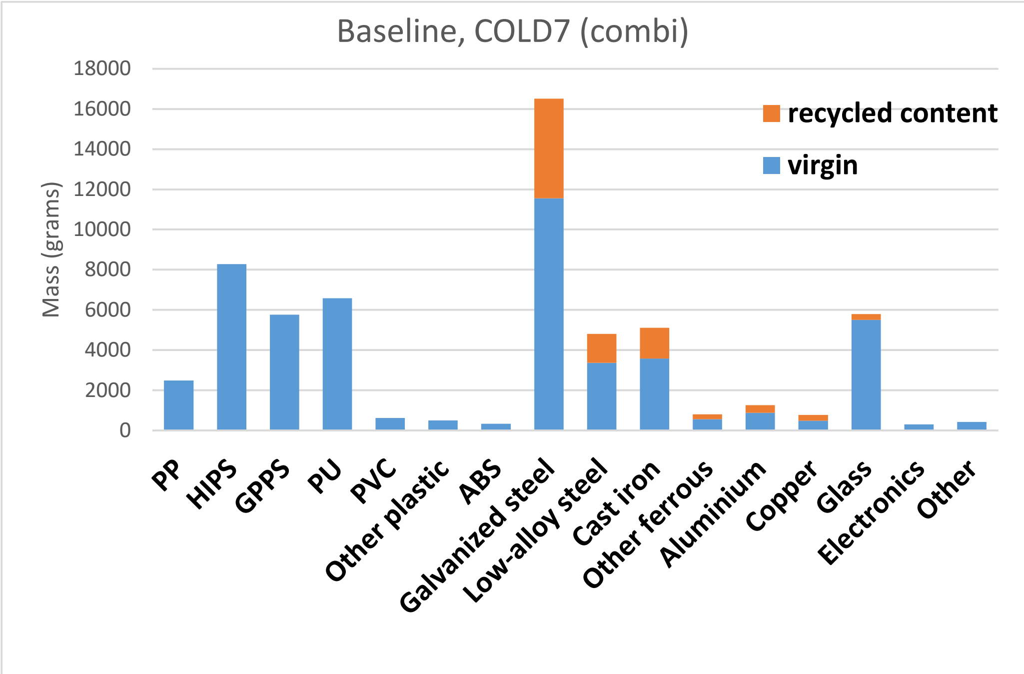


Figure 22: Virgin and recycled material in input, baseline, base case COLD7 (combi)

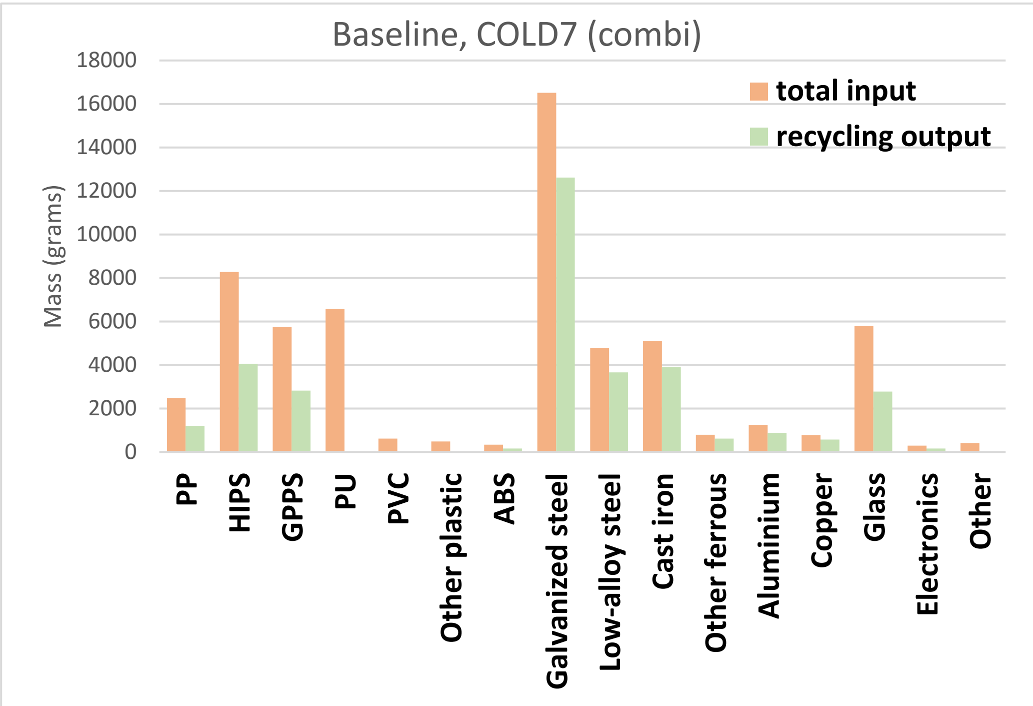


Figure 23: Total material input and recycled material output, baseline, base case COLD7 (combi)

5.6. Environmental impacts for the baseline

5.6.1 Impacts from all materials

The baseline environmental impacts for base case COLD 7 (combi) in Table 18 and Figure 24 have been computed using the 2024 EcoReportTool. They are based on the BoM and factors R1, R2 and A of Table 15. Only impacts from raw materials and end-of-life impacts and credits have been considered [327].

Table 18 is split in two parts. The first part gives the mass and the impacts for the first 7 environmental parameters; the second part gives the impacts for the remaining 8 parameters [328]. The table shows the total impacts, i.e. the sum of raw material impact, EoL impact and EoL credit for virgin material avoidance (negative impact), and the impact shares, per material category. The impacts are for a unit product (over its lifetime). Impact shares larger than 30% have been highlighted in cyan.

Figure 24 gives the shares of each material category in the total environmental impacts.

For most environmental impact categories, the highest impacts come from plastics. 'Ozone depletion' impacts derive for 88.8% from plastics (see section 5.6.3).

Although electronic components (PCBs, cables, LED) represent only 0.5% of the total fridge mass, they have relatively high environmental impact shares for many parameters (green bars). The highest share for electronics regards 'resource use, minerals and metals' (54.8%). For 'land use' the impact from electronics is negative (and therefore not visible in the graph), see remarks in section 5.6.5.

Ferrous metals have the highest impact share for 'human toxicity, non-cancer' (39.8%) and 'ionising radiation' (44.9%). Non-ferrous metals have the highest share for 'land use' (99.9%, see comments later), and glass for 'particulate matter' (40.5%).

[327] The current study focuses on material aspects. The impacts from manufacturing, distribution, use and repair and maintenance will be added later in the ongoing review study. They are assumed not to change due to requirements on recycled material content or recyclability.

[328] Impacts for 'primary energy consumption' are not shown, because here they are the same as for 'resource use, fossil'.

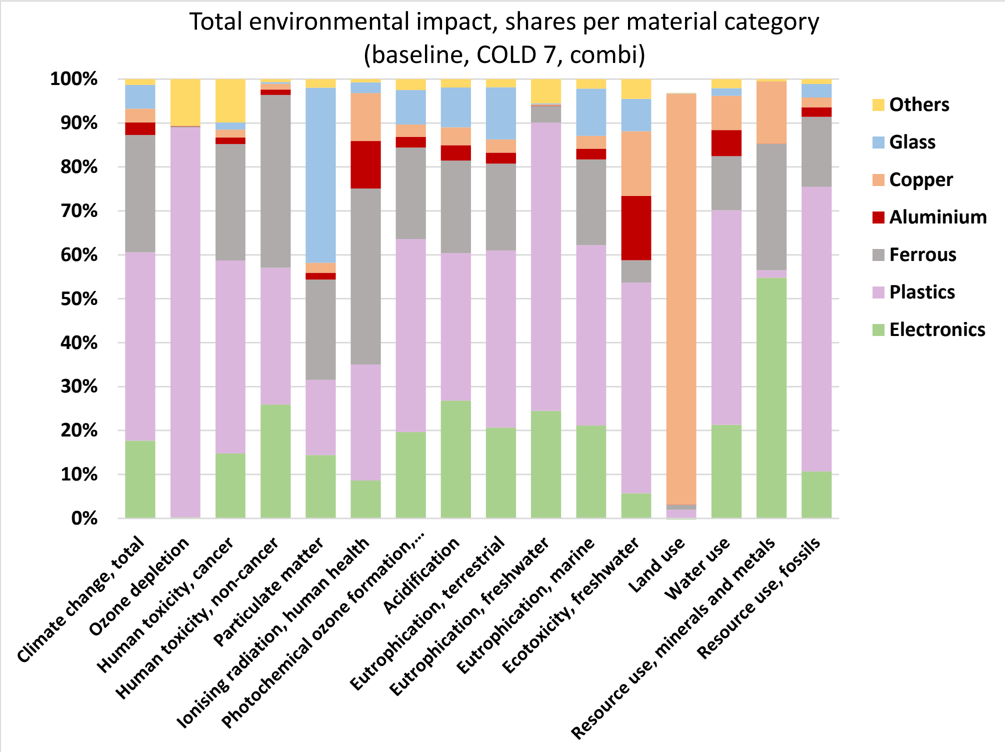


Figure 24: Shares in total environmental impacts per material category, for base case COLD 7 (combis), for the baseline.

Table 18: Baseline Environmental impacts for base case COLD 7 (combi), computed using the 2024 EcoReportTool. This considers only impacts from raw materials and end-of-life impacts and benefits. Impacts per unit product (over its lifetime).

material	Mass [g]	Climate change, total [kg CO2 eq]	Ozone depletion [kg CFC-11 eq]	Human toxicity, cancer [CTUh]	Human toxicity, non-cancer [CTUh]	Particulate matter [disease incidence]	Ionising radiation, human health [kBq U235 eq]	Photo-chemical ozone formation, human health [kg NMVOC eq]	Acidifi-cation [mol H+ eq]
Plastics	49.9	1.0E-06	2.3E-08	6.4E-07	1.5E-06	2.19	0.119	0.13	49.9
share	44.2%	88.8%	44.6%	31.5%	17.3%	29.6%	45.0%	34.8%	44.2%
Ferrous	27225	31.1	2.6E-09	1.4E-08	8.1E-07	2.1E-06	3.32	0.056	0.08
share	45.1%	27.5%	0.2%	26.9%	39.8%	23.2%	44.9%	21.4%	21.8%
Non-Ferrous	2033	3.6	8.5E-10	9.4E-10	2.7E-08	2.1E-07	0.90	0.008	0.02
share	3.4%	3.2%	0.1%	1.8%	1.3%	2.3%	12.2%	2.9%	4.2%
Glass	5796	6.3	1.5E-10	8.7E-10	8.1E-09	3.6E-06	0.20	0.021	0.04
share	9.6%	5.6%	0.0%	1.7%	0.4%	40.5%	2.8%	8.0%	9.4%
Electronics	302	20.6	2.7E-09	7.8E-09	5.4E-07	1.3E-06	0.71	0.053	0.11
share	0.5%	18.2%	0.2%	15.0%	26.2%	14.7%	9.7%	20.2%	27.8%
Other	423	1.6	1.2E-07	5.2E-09	1.4E-08	1.8E-07	0.06	0.007	0.01
share	0.7%	1.4%	10.6%	10.0%	0.7%	2.0%	0.8%	2.5%	2.0%
Total	**60328**	**113.0**	**1.1E-06**	**5.2E-08**	**2.0E-06**	**8.9E-06**	**7.4**	**0.264**	**0.38**

material	Eutrophi-cation, terrestrial [mol N eq]	Eutrophi-cation, freshwater [kg P eq]	Eutrophi-cation, marine [kg N eq]	Ecotoxicity, freshwater [CTUe]	Land use [pt]	Water use [m3 water eq. of deprived water]	Resource use, minerals and metals [kg Sb eq]]	Resource use, fossils [MJ]
Plastics	0.37	6.2E-04	0.035	689	97.6	13.9	5.5E-05	1464
share	41.3%	65.7%	42.1%	56.2%	2.1%	52.0%	1.7%	66.2%
Ferrous	0.18	3.6E-05	0.017	74	58	3.5	9.3E-04	361
share	20.3%	3.8%	20.0%	6.0%	1.2%	13.1%	28.8%	16.3%
Non-Ferrous	0.03	2.4E-06	0.002	212	4739	2.2	0.000	51
share	3.1%	0.3%	3.0%	17.3%	99.9%	8.3%	14.2%	2.3%
Glass	0.11	2.3E-06	0.009	106	4.9	0.5	3.7E-07	69
share	12.2%	0.2%	11.1%	8.6%	0.1%	1.8%	0.0%	3.1%
Electronics	0.19	2.3E-04	0.018	82	-159	6.0	1.8E-03	241
share	21.2%	24.5%	21.6%	6.7%	-3.4%	22.6%	54.8%	10.9%
Other	0.02	5.2E-05	0.002	65	3	0.6	0.000	25
share	1.9%	5.5%	2.2%	5.3%	0.1%	2.2%	0.5%	1.1%
Total	**0.88**	**9.5E-04**	**0.083**	**1227**	**4743**	**26.7**	**0.003**	**2211**

5.6.2 Impact comparison, materials versus use-phase electricity

Table 19 and Figure 25 compare the baseline material and end-of-life impacts with the impacts from electricity use over the lifetime of the fridge-freezer combi (for 235 kWh/year, 15.7 years lifetime, electricity grid mix dataset 243 [329]). The table also indicates the share of material impacts in the sum of material and electricity impacts. For 'ozone depletion' (67%) and 'resource use minerals' (89%), material impacts are dominant. For ionising radiation (1.1%) and water use (4.8%), material impacts are relatively small. For other impact categories, the material impact shares vary from 6.8% (climate change) to 41.6% (land use).

[329] Dataset of the MEErP_Ecoreport tool_v1.7.2.xlsx, https://circabc.europa.eu/ui/group/418195ae-4919-45fa-a959-3b695c9aab28/library/3fb62627-0843-44df-b038-444cd1ac79b4?p=1&n=10&sort=modified_DESC , 243: Electricity grid mix 1kV-60kV technology mix consumption mix, to consumer 1kV - 60kV. Impacts per kWh electricity:
climate change: 4.19E-01 kgCO2eq
ozone depletion: 1.56E-10 kgCFC-11eq
human toxicity cancer: 6.96E-11 CTUh
human toxicity non-cancer: 1.40E-09 CTUh
ionizing radiation, human health: 1.78E-01 kBq U235 eq
photochemical ozone formation, human health: 6.86E-04 kg NMVOC eq
acidification: 1.27E-03 mol H+ eq
eutrophication, terrestrial: 2.56E-03 mol N eq
eutrophication, freshwater: 8.54E-07 kg P eq
eutrophication, marine: 2.42E-04 kg N eq
ecotoxicity freshwater: 1.91E+00 CTUe
land use: 1.80E+00 pt
water use: 1.43E-01 m3 water eq of deprived water
resource use, minerals and metals: 1.07E-07 kg Sb eq
resource use, fossils: 7.29E+00 MJ
primary energy consumption: 7.56E+00 MJ

Table 19: Baseline Environmental impacts for base case COLD 7 (combi), comparison of impacts from raw materials and end-of-life impacts and benefits with impacts from electricity consumption during use. Impacts per unit product (over its lifetime).

Life phase	Mass [g]	Climate change, total [kg CO2 eq]	Ozone depletion [kg CFC-11 eq]	Human toxicity, cancer [CTUh]	Human toxicity, non-cancer [CTUh]	Particulate matter [disease incidence]	Ionising radiation, human health [kBq U235 eq]	Photo-chemical ozone formation, human health [kg NMVOC eq]	Acidifi-cation [mol H+ eq]
Mat & EoL	60328	113.0	1.1E-06	5.2E-08	2.0E-06	8.9E-06	7.4	0.264	0.38
Electricity use		1545.5	5.7E-07	2.6E-07	5.2E-06	4.9E-05	656.7	2.531	4.70
Mat & EoL vs Sum of impacts		6.8%	66.6%	16.8%	28.3%	15.3%	1.1%	9.4%	7.6%

Life phase	Eutrophi-cation, terrestrial [mol N eq]	Eutrophi-cation, freshwater [kg P eq]	Eutrophi-cation, marine [kg N eq]	Ecotoxicity, freshwater [CTUe]	Land use [pt]	Water use [m3 water eq. of deprived water]	Resource use, minerals and metals [kg Sb eq]]	Resource use, fossils [MJ]
Mat & EoL	0.88	9.5E-04	0.083	1227	4743	26.7	0.003	2211
Electricity use	9.46	3.2E-03	0.892	7038	6655	527.7	3.9E-04	26880
Mat & EoL vs Sum of impacts	**8.5%**	**23.1%**	**8.5%**	**14.8%**	**41.6%**	**4.8%**	**89.2%**	**7.6%**

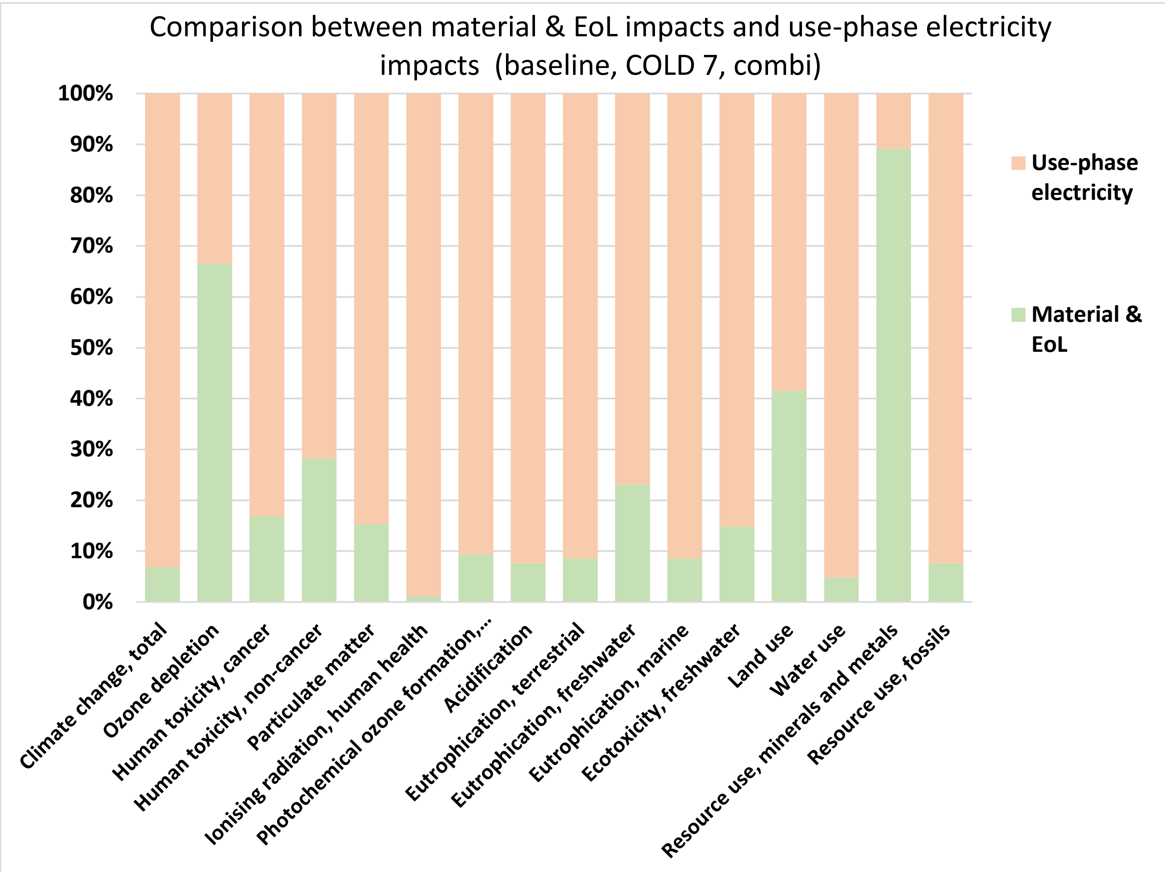


Figure 25: Impact shares from materials & end-of-life and from use-phase electricity consumption, per environmental impact category, for base case COLD 7 (combis), for the baseline.

5.6.3 Impacts from plastics

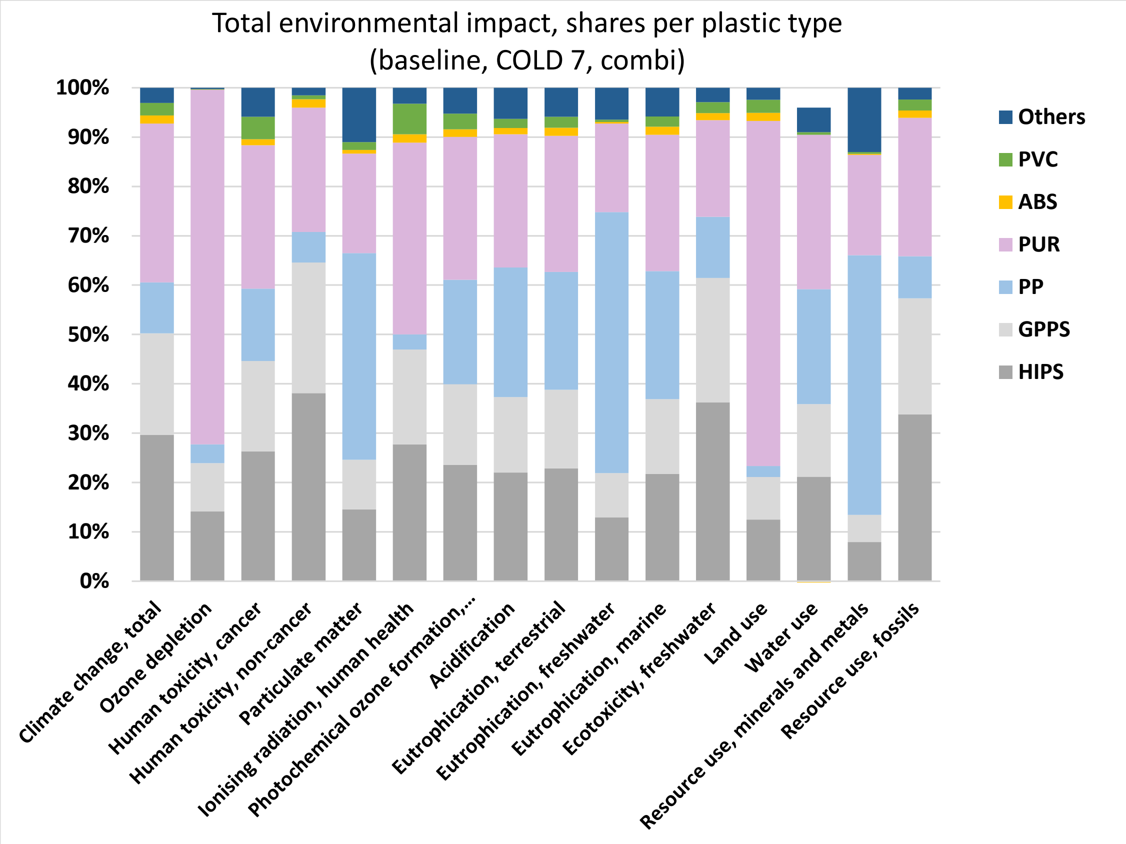
Table 20 shows details for the impacts from plastics. Like the previous table, it is split in two parts, covering different parameters. For the major types of plastics used in fridges, the table shows the raw material impact (mat), the end-of-life impact (eol-i), the end-of-life credit (eol-c), the sum of these (total), and the share of the total impact in the overall impact from all materials (including also non-plastics; in blue).

Figure 26 shows the shares in total environmental impacts from plastics per type of plastic (top), and the shares per plastic type in total environmental impacts of all materials.

Comments:

- The large impact of plastics on ozone depletion derives mainly from polyurethane foam (PU). The ERT dataset 21 impact for ODP has been substituted by the study team [304] because it considered legacy CFC-containing blowing agents that are no longer being used. Nowadays, cyclopentane is used as blowing agent, which is not ozone depleting. The new ODP impact value is uncertain and could still be too high. It reflects impacts for MDI transports. The ERT dataset for PU should be verified for this.
- The large impact of plastics on 'eutrophication, freshwater' derives for a large part (34.8% of the 65.7%) from polypropylene (PP).
- For ABS, the impact of virgin material on 'water use' is negative and consequently, the EoL credit is positive [330]. No evidence was found that the production of ABS produces water. The ERT datasets for ABS should be verified for this.
- In the baseline, no recycling at EoL is assumed for PU, PVC and other plastics. Consequently, EoL impacts and credits are zero for these plastic types.

[330] For this reason the bar graph for water use does not total 100%



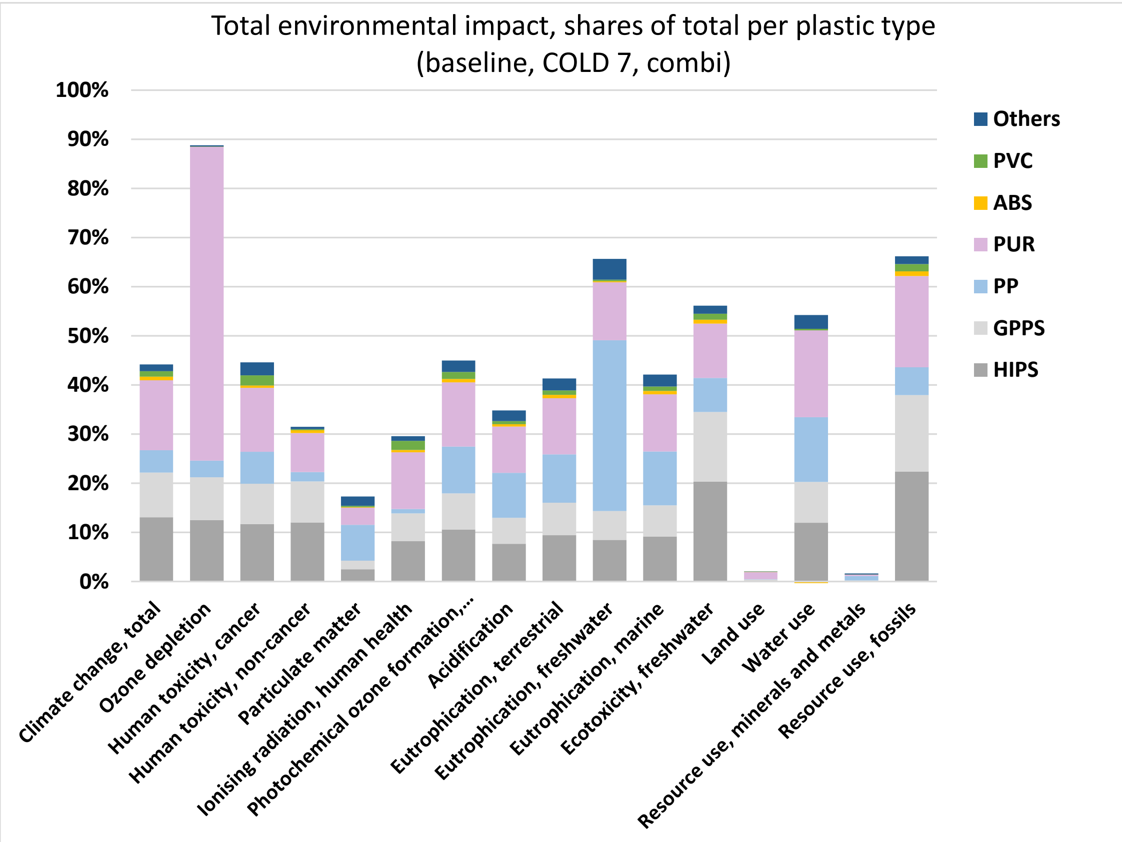


Figure 26: Shares in total environmental impacts from plastics per type of plastic (top), and shares per plastic type in total environmental impacts, for base case COLD 7 (combis), for the baseline.

Table 20: Baseline Environmental impacts from plastics for base case COLD 7 (combi).

material	Mass [g]	Climate change, total [kg CO2 eq]	Ozone depletion [kg CFC-11 eq]	Human toxicity, cancer [CTUh]	Human toxicity, non-cancer [CTUh]	Particulate matter [disease incidence]	Ionising radiation, human health [kBq U235 eq]	Photo-chemical ozone formation, human health [kg NMVOC eq]	Acidifi-cation [mol H+ eq]
PP - mat		6.4	5.1E-08	4.3E-09	5.1E-08	8.0E-07	0.086	0.033	0.045
PP – eol-i		0.3	2.8E-10	1.5E-10	1.5E-09	4.7E-08	0.001	0.001	0.001
PP – eol-c		-1.6	-1.3E-08	-1.1E-09	-1.2E-08	-2.0E-07	-0.021	-0.008	-0.011
PP - total	2484	5.1	3.9E-08	3.4E-09	4.0E-08	6.5E-07	0.066	0.025	0.035
PP - share	4.1%	4.6%	3.4%	6.6%	1.9%	7.3%	0.9%	9.5%	9.1%
HIPS - mat		18.0	2.8E-10	8.0E-09	3.2E-07	2.3E-07	0.57	0.033	0.03
HIPS – eol-i		1.2	1.4E-07	4.9E-11	7.0E-10	5.4E-08	0.18	0.003	0.01
HIPS – eol-c		-4.4	-6.9E-11	-2.0E-09	-7.9E-08	-5.5E-08	-0.14	-0.008	-0.01
HIPS - total	8282	14.8	1.4E-07	6.1E-09	2.5E-07	2.2E-07	0.61	0.028	0.03
HIPS - share	13.7%	13.1%	12.5%	11.7%	12.0%	2.5%	8.2%	10.6%	7.7%
GPPS - mat		12.5	2.0E-10	5.6E-09	2.3E-07	1.6E-07	0.40	0.023	0.021
GPPS – eol-i		0.9	9.9E-08	3.4E-11	4.9E-10	3.8E-08	0.12	0.002	0.004
GPPS – eol-c		-3.1	-4.8E-11	-1.4E-09	-5.5E-08	-3.9E-08	-0.10	-0.006	-0.005
GPPS - total	5756	10.3	9.9E-08	4.2E-09	1.7E-07	1.6E-07	0.42	0.019	0.021
GPPS - share	9.5%	9.1%	8.7%	8.2%	8.3%	1.8%	5.7%	7.4%	5.3%
ABS - mat		1.04	3.0E-11	3.5E-10	1.4E-08	1.5E-08	4.1E-02	2.3E-03	2.2E-03
ABS – eol-i		0.03	5.0E-12	4.2E-12	9.0E-11	6.3E-10	5.9E-03	1.0E-04	7.1E-05
ABS – eol-c		-0.26	-7.4E-12	-8.7E-11	-3.5E-09	-3.7E-09	-1.0E-02	-5.6E-04	-5.3E-04
ABS - total	338	0.82	2.8E-11	2.7E-10	1.1E-08	1.2E-08	3.7E-02	1.8E-03	1.7E-03
ABS - share	0.6%	0.7%	0.0%	0.5%	0.5%	0.1%	0.5%	0.7%	0.4%
PU - mat		16.1	7.3E-07	6.7E-09	1.6E-07	3.1E-07	8.5E-01	3.4E-02	3.6E-02
PU – eol-i		0	0	0	0	0	0	0	0
PU – eol-c		0	0	0	0	0	0	0	0
PU - total	6581	16.1	7.3E-07	6.7E-09	1.6E-07	3.1E-07	8.5E-01	3.4E-02	3.6E-02
PU - share	10.9%	14.2%	63.8%	13.0%	7.9%	3.5%	11.5%	13.0%	9.4%
PVC - mat		1.3	8.0E-10	1.1E-09	5.2E-09	2.4E-08	0.14	3.8E-03	2.5E-03
PVC – eol-i		0	0	0	0	0	0	0	0
PVC – eol-c		0	0	0	0	0	0	0	0
PVC - total	616	1.3	8.0E-10	1.1E-09	5.2E-09	2.4E-08	0.14	3.8E-03	2.5E-03
PVC - share	1.0%	1.1%	0.1%	2.0%	0.3%	0.3%	1.8%	1.4%	0.6%
Other - mat		1.5	3.0E-09	1.4E-09	9.8E-09	1.7E-07	0.07	0.006	0.01
Other – eol-i		0	0	0	0	0	0	0	0
Other – eol-c		0	0	0	0	0	0	0	0
Other - total	491	1.5	3.0E-09	1.4E-09	9.8E-09	1.7E-07	0.07	0.006	0.01
Other - share	0.8%	1.4%	0.3%	2.6%	0.5%	1.9%	1.0%	2.4%	2.2%
Sum- mat		56.8	7.9E-07	2.7E-08	7.9E-07	1.7E-06	2.15	0.134	0.15
Sum – eol-i		2.4	2.4E-07	2.4E-10	2.7E-09	1.4E-07	0.30	0.006	0.01
Sum – eol-c		-9.3	-1.3E-08	-4.5E-09	-1.5E-07	-2.9E-07	-0.27	-0.022	-0.02
Sum- total	**24548**	49.9	1.0E-06	2.3E-08	6.4E-07	1.5E-06	2.19	0.119	0.13
Sum - share	**40.7%**	44.2%	88.8%	44.6%	31.5%	17.3%	29.6%	45.0%	34.8%

material	Eutrophi-cation, terrestrial [mol N eq]	Eutrophi-cation, freshwater [kg P eq]	Eutrophi-cation, marine [kg N eq]	Ecotoxicity, freshwater [CTUe]	Land use [pt]	Water use [m3 water eq. of deprived water]	Resource use, minerals and metals [kg Sb eq]]	Resource use, fossils [MJ]
PP - mat	0.113	4.3E-04	0.012	112	1.4	4.5	3.7E-05	163
PP – eol-i	0.002	4.0E-06	0.000	1	1.1	0.1	8.8E-07	2
PP – eol-c	-0.028	-1.1E-04	-0.003	-27	-0.3	-1.1	-9.0E-06	-40
PP - total	0.087	3.3E-04	0.009	85	2.2	3.5	2.9E-05	125
PP - share	9.9%	34.8%	10.9%	7.0%	0.0%	13.1%	0.9%	5.6%
HIPS - mat	0.09	3.8E-05	0.008	325	13.3	3.5	5.3E-06	623
HIPS – eol-i	0.01	5.2E-05	0.001	5	2.1	0.5	3.6E-07	25
HIPS – eol-c	-0.02	-9.3E-06	-0.002	-80	-3.3	-0.9	-1.3E-06	-153
HIPS - total	0.08	8.0E-05	0.008	250	12.2	3.2	4.3E-06	495
HIPS - share	9.5%	8.5%	9.2%	20.4%	0.3%	12.0%	0.1%	22.4%
GPPS - mat	0.064	2.6E-05	0.006	226	9.3	2.5	3.7E-06	433
GPPS – eol-i	0.010	3.6E-05	0.001	3	1.5	0.4	2.5E-07	17
GPPS – eol-c	-0.016	-6.5E-06	-0.001	-55	-2.3	-0.6	-9.0E-07	-106
GPPS - total	0.058	5.6E-05	0.005	174	8.5	2.2	3.0E-06	344
GPPS - share	6.6%	5.9%	6.4%	14.2%	0.2%	8.3%	0.1%	15.6%
ABS - mat	7.9E-03	2.4E-06	7.5E-04	13.0	2.0	-0.82	1.7E-07	28
ABS – eol-i	2.2E-04	9.1E-08	2.0E-05	0.1	0.1	0.01	5.5E-09	0
ABS – eol-c	-1.9E-03	-6.0E-07	-1.8E-04	-3.2	-0.5	0.20	-4.3E-08	-7
ABS - total	6.1E-03	1.9E-06	5.9E-04	9.9	1.6	-0.61	1.4E-07	22
ABS - share	0.7%	0.2%	0.7%	0.8%	0.0%	-2.3%	0.0%	1.0%
PU - mat	1.0E-01	1.1E-04	9.7E-03	135	68.3	4.7	1.1E-05	410
PU – eol-i	0	0	0	0	0	0	0	0
PU – eol-c	0	0	0	0	0	0	0	0
PU - total	1.0E-01	1.1E-04	9.7E-03	135	68.3	4.7	1.1E-05	410
PU - share	11.4%	11.8%	11.6%	11.0%	1.4%	17.7%	0.3%	18.6%
PVC - mat	8.0E-03	3.2E-06	7.2E-04	15	2.5	0.1	2.0E-07	33
PVC – eol-i	0	0	0	0	0	0	0	0
PVC – eol-c	0	0	0	0	0	0	0	0
PVC - total	8.0E-03	3.2E-06	7.2E-04	15	2.5	0.1	2.0E-07	33
PVC - share	0.9%	0.3%	0.9%	1.2%	0.1%	0.3%	0.0%	1.5%
Other - mat	0.02	4.0E-05	0.002	20	2.4	0.7	7.1E-06	35
Other – eol-i	0	0	0	0	0	0	0	0
Other – eol-c	0	0	0	0	0	0	0	0
Other - total	0.02	4.0E-05	0.002	20	2.4	0.7	7.1E-06	35
Other - share	2.4%	4.2%	2.4%	1.6%	0.1%	2.8%	0.2%	1.6%
Sum- mat	0.41	6.5E-04	0.039	846	99.2	15.3	6.4E-05	1725
Sum – eol-i	0.03	9.1E-05	0.002	9	4.8	1.0	1.5E-06	45
Sum – eol-c	-0.07	-1.2E-04	-0.007	-165	-6.4	-2.4	-1.1E-05	-305
Sum- total	0.37	6.2E-04	0.035	689	97.6	13.9	5.5E-05	1464
Sum - share	41.3%	65.7%	42.1%	56.2%	2.1%	52.0%	1.7%	66.2%

5.6.4 Impacts from metals

Table 21 shows details for the impacts from ferrous metals, aluminium and copper. The type of information is the same as in the previous table for plastics.

Figure 27 shows the shares in total environmental impacts from metals per type of metal (top), and the shares per metal type in the total environmental impacts of all materials.

Note that for metals, the baseline assumes 30% (aluminium, steel) or 37% (copper) recycled content in input (R1=30%/37%) and that the allocation factor A is 20% (i.e. 20% of the impacts/benefits of EoL recycling is assigned to the inputs for the production, and 80% to the EoL processing). This means that the raw material impacts ('mat') are a mix of the impacts from virgin materials e.g. (1-R1*A = 1-30%*20% = 94%) and recycled materials e.g. (R1*A = 30%*20% = 6%). In addition, for metals, the recycling output rate R2 is high (70-76%).

Comments:

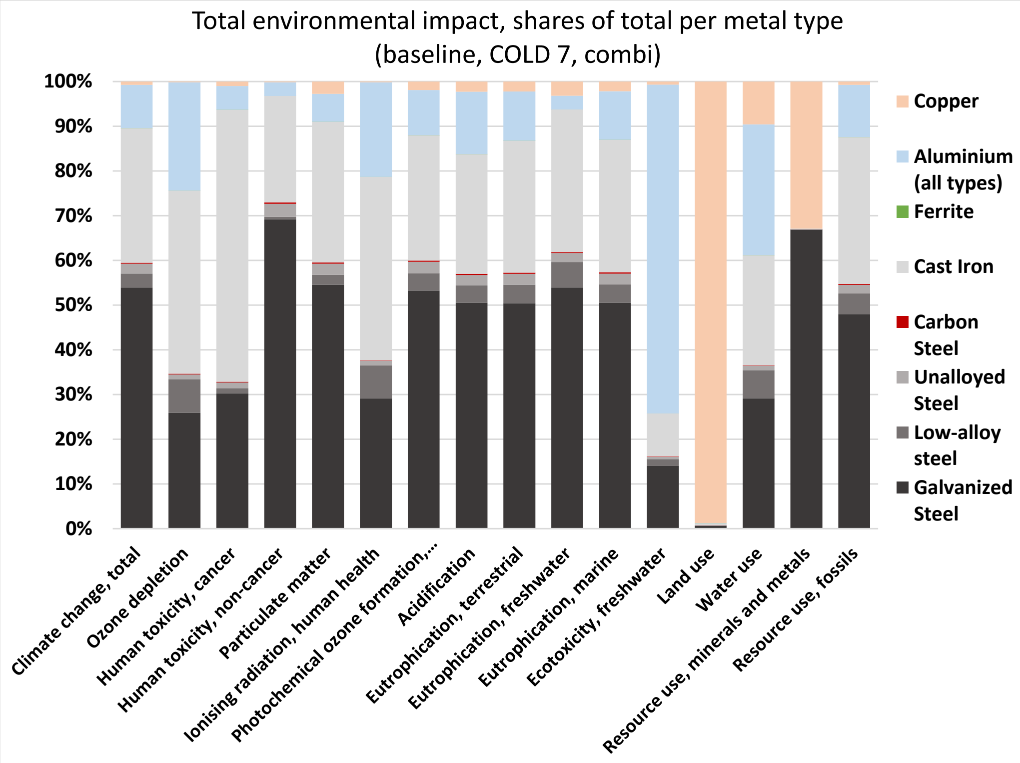
- For steel, the share of environmental impacts in the total impact from all materials is lower than its mass share (45.1%) for most impact categories. The highest shares are found for 'human toxicity, non-cancer' (39.8%) and 'ionising radiation' (44.9%). Highest contributions are from cast iron and galvanized steel.
- For aluminium, the highest shares in the total impact from all materials are for 'ionising radiation' (12.1%), 'ecotoxicity, freshwater' (17.1%), and 'water use' (6.3%).
- For copper, the share of environmental impacts in the total impact from all materials is lower than its mass share (1.3%), except for 'land use' (99.9%) and 'resource use, minerals and metals' (14.2%). The high 'land use' share for non-ferrous signalled in Table 18 comes from the copper. The ERT dataset 61 should be verified for this [331].

[331] The study team compared the ERT dataset 61 for copper against datasets from other sources. In the other datasets, land use impacts are 2 or 3 orders of magnitude lower than in the ERT. However, the other datasets have much higher impacts for most of the other impact categories, especially for ozone depletion, ionising radiation and eutrophication freshwater.

In comments following the 4th SH meeting of 1 July 2025, a stakeholder noted that:

Copper is indicated to have a strong land use impact. The Ecoreport tool assigns to 1 kg of copper a value of 5.6E+04 pt in this category, which is 20,000 times higher than the value we find in other databases, such as the LCA tool "Life Cycle for Experts" from Sphera (2.8E+00 pt). Such a high value completely distorts the LCA results and leads to wrong conclusions, such as establishing minimum recycled content requirements to limit land use impact.

Furthermore, this impact category has a low robustness (level III, EU Commission Environmental footprint method recommendation), indicating that it should be utilized with caution. It's important to highlight that the Land Use impact category has undergone updates in the transition from the EF 2.0 to the EF3.1 impact assessment method, and its testing has been limited at this point. Consequently, the OEFSR for copper production (https://internationalcopper.org/resource/copperoefsr/) acknowledge reservations about deeming this impact category sufficiently robust for decision support.



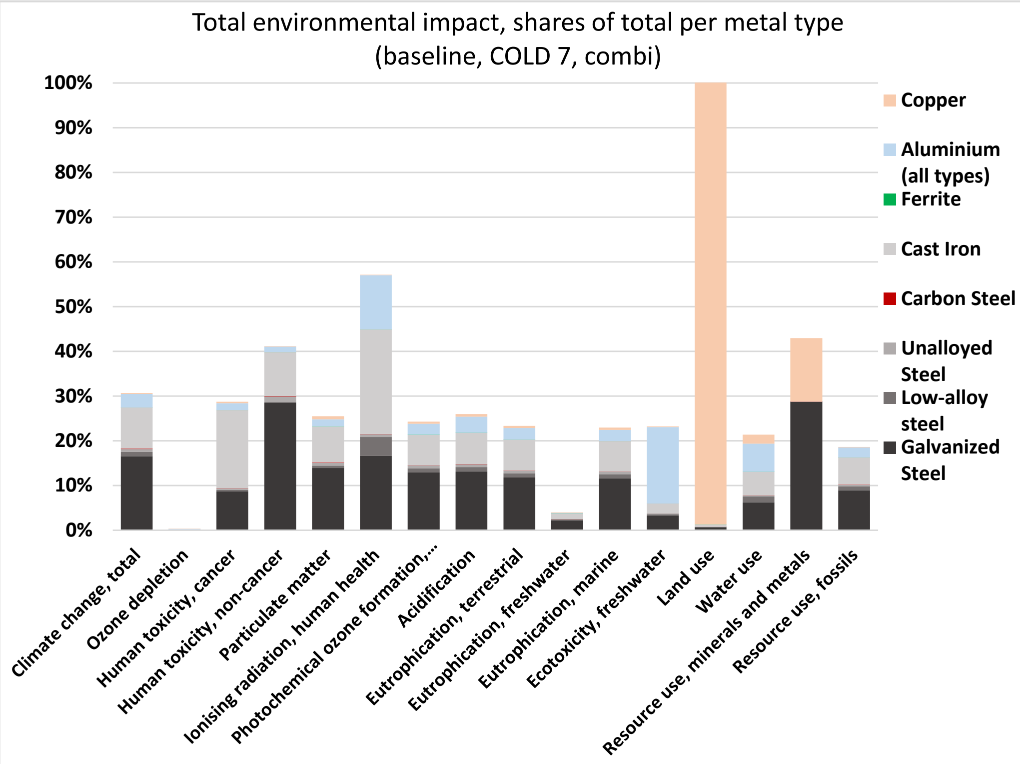


Figure 27: Shares in total environmental impacts from metals per type of metal (top), and shares per metal type in total environmental impacts, for base case COLD 7 (combis), for the baseline.

Table 21: Baseline Environmental impacts from ferrous metals, aluminium and copper for base case COLD 7 (combi).

material	Mass [g]	Climate change, total [kg CO2 eq]	Ozone depletion [kg CFC-11 eq]	Human toxicity, cancer [CTUh]	Human toxicity, non-cancer [CTUh]	Particulate matter [disease incidence]	Ionising radiation, human health [kBq U235 eq]	Photo-chemical ozone formation, human health [kg NMVOC eq]	Acidifi-cation [mol H+ eq]
Fe - mat		58.6	2.0E-10	1.6E-08	2.2E-06	4.3E-06	0.77	0.104	0.15
Fe – eol-i		9.9	2.4E-09	7.9E-09	4.6E-08	5.3E-07	2.87	0.019	0.03
Fe – eol-c		-37.5	2.3E-11	-9.9E-09	-1.4E-06	-2.8E-06	-0.32	-0.067	-0.10
Fe - total	27225	31.1	2.6E-09	1.4E-08	8.1E-07	2.1E-06	3.32	0.056	0.08
Fe - share	45.1%	27.5%	0.2%	26.9%	39.8%	23.2%	44.9%	21.4%	21.8%
Al - mat		8.0	2.1E-09	1.9E-09	6.3E-08	3.5E-07	2.19	1.5E-02	3.4E-02
Al – eol-i		0.1	9.5E-12	1.9E-11	2.7E-10	3.1E-09	0.01	3.1E-04	3.5E-04
Al – eol-c		-4.8	-1.2E-09	-1.1E-09	-3.8E-08	-2.1E-07	-1.31	-9.1E-03	-2.0E-02
Al - total	1254	3.4	8.4E-10	7.9E-10	2.6E-08	1.4E-07	0.89	6.5E-03	1.4E-02
Al - share	2.1%	3.0%	0.1%	1.5%	1.3%	1.6%	12.1%	2.5%	3.6%
Cu - mat		0.7	4.3E-12	4.1E-10	3.5E-09	1.7E-07	5.0E-03	3.3E-03	6.2E-03
Cu – eol-i		0.0	4.1E-12	3.6E-12	1.5E-10	5.7E-10	4.7E-03	4.3E-05	6.2E-05
Cu – eol-c		-0.4	-2.4E-12	-2.6E-10	-2.2E-09	-1.1E-07	-2.8E-03	-2.1E-03	-3.9E-03
Cu - total	779	0.3	6.0E-12	1.5E-10	1.4E-09	6.3E-08	6.9E-03	1.2E-03	2.3E-03
Cu - share	1.3%	0.2%	0.0%	0.3%	0.1%	0.7%	0.1%	0.5%	0.6%

material	Eutrophi-cation, terrestrial [mol N eq]	Eutrophi-cation, freshwater [kg P eq]	Eutrophi-cation, marine [kg N eq]	Ecotoxicity, freshwater [CTUe]	Land use [pt]	Water use [m3 water eq. of deprived water]	Resource use, minerals and metals [kg Sb eq]]	Resource use, fossils [MJ]
Fe - mat	0.31	5.2E-05	0.029	102	55	1.6	2.7E-03	526
Fe – eol-i	0.07	1.6E-05	0.006	36	37	2.8	2.5E-06	167
Fe – eol-c	-0.20	-3.3E-05	-0.019	-64	-33	-0.9	-1.7E-03	-331
Fe - total	0.18	3.6E-05	0.017	74	58	3.5	9.3E-04	361
Fe - share	20.3%	3.8%	20.0%	6.0%	1.2%	13.1%	28.8%	16.3%
Al - mat	5.3E-02	2.5E-06	4.9E-03	515	4.2	4.09	9.5E-07	114
Al – eol-i	1.2E-03	1.5E-07	1.1E-04	2	0.3	0.02	3.0E-08	2
Al – eol-c	-3.2E-02	-1.5E-06	-2.9E-03	-307	-2.5	-2.44	-5.7E-07	-68
Al - total	2.3E-02	1.2E-06	2.1E-03	210	2.0	1.67	4.2E-07	48
Al - share	2.6%	0.1%	2.5%	17.1%	0.0%	6.3%	0.0%	2.2%
Cu - mat	1.2E-02	3.2E-06	1.1E-03	5.5	13163	1.511	1.3E-03	8.1
Cu – eol-i	2.0E-04	4.8E-08	1.8E-05	0.1	0.1	0.004	4.4E-09	0.3
Cu – eol-c	-7.7E-03	-2.1E-06	-7.0E-04	-3.5	-8427	-0.967	-8.2E-04	-5.2
Cu - total	4.6E-03	1.2E-06	4.1E-04	2.1	4737	0.548	4.6E-04	3.2
Cu - share	0.5%	0.1%	0.5%	0.2%	99.9%	2.1%	14.2%	0.1%

5.6.5 Impacts from electronics

Table 22 shows details for the impacts from electronic components, split in printed circuit boards (PCB), cables and LED(s). The sum of these is also shown. The type of information is the same as in the previous tables. In the baseline, for electronics, recycled content (R1) is 0%, recycling output rate (R2) is 52% for PCB and LED, and 62% for cables.

Figure 28 shows the shares per electronic component type in the total environmental impacts of all materials.

It is recalled that in the ERT, for electronic components, the EoL credit for avoided virgin material is not a share of the virgin component impacts (as it is for plastics, metals and glass), but the sum of avoided impacts from virgin Cu, Au, Pd, Pt and Ag (section 5.4.1).

Comments:

- As also observed before, although electronic components are only 0.5% of the total fridge mass, for most parameters they cause a relatively high share of the environmental impacts (see graph). Exceptions are 'ozone depletion' (mainly caused by plastics) and 'land use' (mainly from copper).
- The peak share for 'resource use, minerals and metals' (54.8%) derives mainly from PCBs (main controller board and user-interface board, green bars).
- LEDs have a negligible mass (15 grams, for 9 LEDs and their 3 support boards) but anyway contribute between 0% and 10.1% to the impacts, depending on the parameter (yellow in the graph). Their impacts are higher than those for 110 grams of cable (red in the graph). Note that the 9 LED light sources and the 3 support boards have been declared separately in the ERT (section 5.3, note 31-), but the sum of impacts is shown here.
- For PCBs, the total impacts are identical or slightly smaller than the impacts from input materials (i.e. the EoL impacts and benefits are small), except for 'land use', where the total impact is much smaller, even negative. This is due to the credit for avoided virgin copper, which has a very high impact on 'land use' (see previous table). Note that the EoL recycling benefit for avoided virgin Cu, Au, Pd, Pt and Ag is much higher than the total virgin impact of the boards for 'land use'. The ERT should be checked for this.
- For cables, the impacts are low for most parameters. Like the PCBs, the EoL impacts and benefits are small, except for the excessive copper benefit for 'land use'.

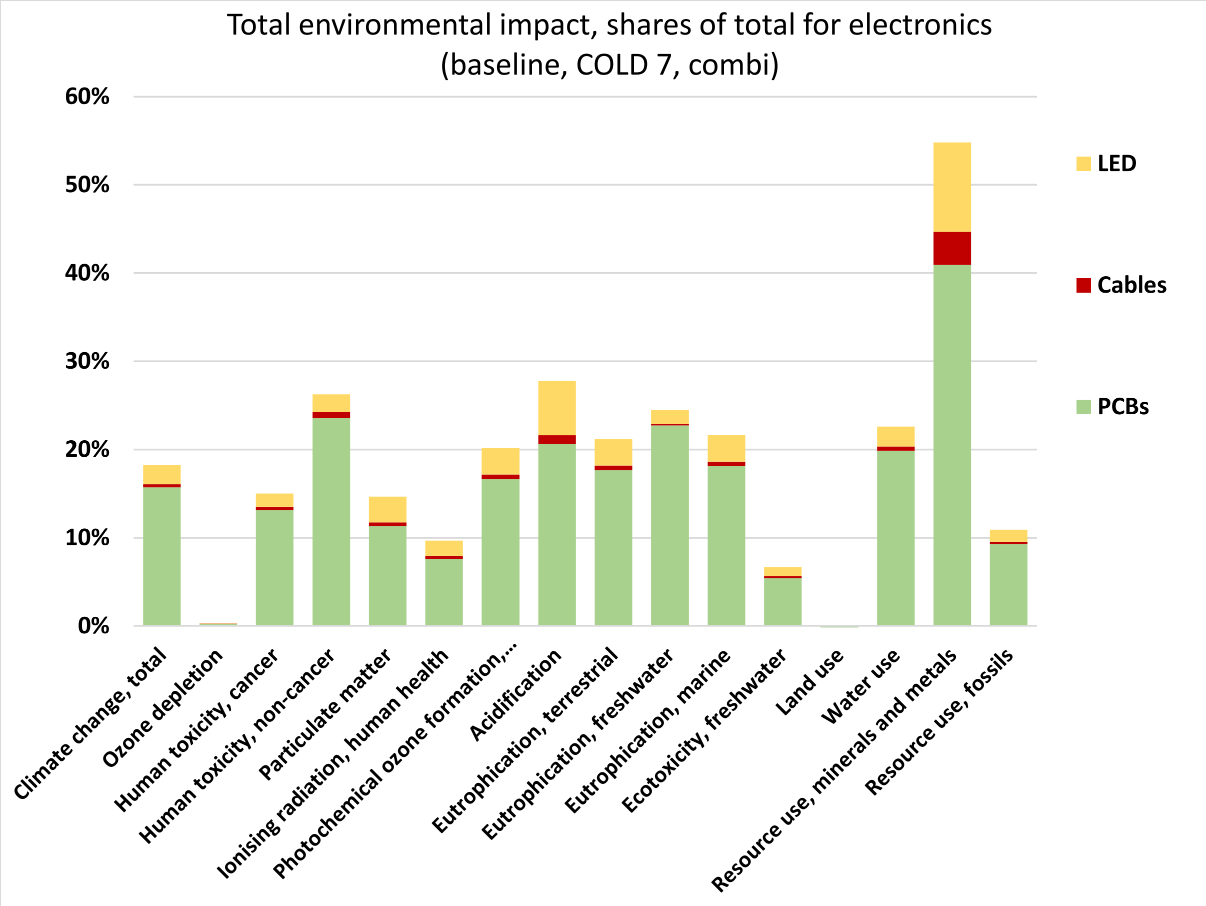


Figure 28: Shares per electronic component type in total environmental impacts, for base case COLD 7 (combis), for the baseline.

Table 22: Baseline Environmental impacts from electronics for base case COLD 7 (combi).

material	Mass [g]	Climate change, total [kg CO2 eq]	Ozone depletion [kg CFC-11 eq]	Human toxicity, cancer [CTUh]	Human toxicity, non-cancer [CTUh]	Particulate matter [disease incidence]	Ionising radiation, human health [kBq U235 eq]	Photo-chemical ozone formation, human health [kg NMVOC eq]	Acidifi-cation [mol H+ eq]
PCB - mat		17.9	2.5E-09	6.8E-09	4.8E-07	1.0E-06	0.56	0.045	0.08
PCB – eol-i		0.0	1.0E-13	2.6E-12	2.7E-10	1.2E-10	1.2E-04	3.1E-05	1.7E-05
PCB – eol-c		-0.1	-2.3E-12	-1.4E-11	-4.6E-10	-1.8E-08	-1.8E-03	-7.1E-04	-1.6E-03
PCB - total	177	17.8	2.5E-09	6.8E-09	4.8E-07	1.0E-06	0.56	0.044	0.08
PCB - share	0.3%	15.7%	0.2%	13.1%	23.5%	11.3%	7.6%	16.6%	20.6%
Cables - mat		0.4	2.2E-11	2.0E-10	1.4E-08	3.8E-08	2.6E-02	1.4E-03	3.9E-03
Cables – eol-i		0.0	2.9E-13	1.3E-12	1.2E-10	8.9E-11	2.3E-04	2.0E-05	1.2E-05
Cables– eol-c		0.0	-3.5E-14	-3.8E-12	-3.2E-11	-1.6E-09	-4.1E-05	-3.0E-05	-5.7E-05
Cables - total	110	0.4	2.2E-11	2.0E-10	1.5E-08	3.6E-08	2.6E-02	1.4E-03	3.9E-03
Cables- share	0.2%	0.3%	0.0%	0.4%	0.7%	0.4%	0.4%	0.5%	1.0%
LED - mat		2.5	1.7E-10	7.8E-10	4.1E-08	2.7E-07	1.3E-01	8.1E-03	2.4E-02
LED – eol-i		0.0	4.2E-15	4.8E-13	5.8E-11	2.0E-11	5.5E-05	3.7E-06	2.4E-06
LED – eol-c		0.0	-7.9E-13	-4.2E-12	-1.6E-10	-5.9E-09	-6.4E-04	-2.4E-04	-5.5E-04
LED - total	15	2.4	1.7E-10	7.7E-10	4.1E-08	2.6E-07	1.2E-01	7.9E-03	2.4E-02
LED - share	0.0%	2.1%	0.0%	1.5%	2.0%	2.9%	1.7%	3.0%	6.2%

Sum - mat		20.7	2.7E-09	7.8E-09	5.4E-07	1.3E-06	0.72	0.054	0.11
Sum – eol-i		0.0	3.9E-13	4.4E-12	4.5E-10	2.3E-10	0.00	0.000	0.00
Sum – eol-c		-0.2	-3.1E-12	-2.2E-11	-6.5E-10	-2.5E-08	0.00	-0.001	0.00
Sum - total	302	20.6	2.7E-09	7.8E-09	5.4E-07	1.3E-06	0.71	0.053	0.11
Sum - share	0.5%	18.2%	0.2%	15.0%	26.2%	14.7%	9.7%	20.2%	27.8%

material	Eutrophi-cation, terrestrial [mol N eq]	Eutrophi-cation, freshwater [kg P eq]	Eutrophi-cation, marine [kg N eq]	Ecotoxicity, freshwater [CTUe]	Land use [pt]	Water use [m3 water eq. of deprived water]	Resource use, minerals and metals [kg Sb eq]]	Resource use, fossils [MJ]
PCB - mat	0.16	2.2E-04	0.015	66	34.6	5.3	1.5E-03	207
PCB – eol-i	1.8E-04	2.7E-08	1.5E-05	2.7E-02	5.9E-02	8.3E-03	2.4E-09	-2.8E-02
PCB – eol-c	-2.6E-03	-4.5E-08	-2.4E-04	-2.1E-01	-75.5	-2.5E-02	-1.2E-04	-1.5
PCB - total	0.16	2.2E-04	0.015	66	-40.8	5.3	1.3E-03	205
PCB - share	17.6%	22.7%	18.1%	5.4%	-0.9%	19.9%	40.9%	9.3%
Cables - mat	4.7E-03	1.3E-06	4.3E-04	3.2	3	1.4E-01	1.3E-04	6.2
Cables – eol-i	1.2E-04	1.8E-08	1.0E-05	0.0	0	5.1E-03	1.5E-09	0.0
Cables– eol-c	-1.1E-04	-3.0E-08	-1.0E-05	-0.1	-122	-1.4E-02	-1.2E-05	-0.1
Cables - total	4.7E-03	1.3E-06	4.3E-04	3.2	-118	1.3E-01	1.2E-04	6.1
Cables- share	0.5%	0.1%	0.5%	0.3%	-2.5%	0.5%	3.8%	0.3%
LED - mat	2.8E-02	1.5E-05	2.6E-03	12.4	4.9E+00	6.0E-01	3.7E-04	30
LED – eol-i	1.9E-05	3.4E-09	1.7E-06	0.0	6.2E-03	9.3E-04	3.3E-10	0
LED – eol-c	-9.0E-04	-1.0E-08	-8.2E-05	-0.1	-5.1E+00	-6.1E-03	-4.2E-05	-1
LED - total	2.7E-02	1.5E-05	2.5E-03	12.3	-1.4E-01	6.0E-01	3.3E-04	30
LED - share	3.0%	1.6%	3.0%	1.0%	0.0%	2.2%	10.1%	1.3%
Sum - mat	0.19	2.3E-04	0.018	82	42	6.1	2.0E-03	243
Sum – eol-i	0.00	4.8E-08	0.000	0	0	0.0	4.3E-09	0
Sum – eol-c	0.00	-8.5E-08	0.000	0	-202	0.0	-1.8E-04	-2
Sum - total	0.19	2.3E-04	0.018	82	-159	6.0	1.8E-03	241
Sum - share	21.2%	24.5%	21.6%	6.7%	-3.4%	22.6%	54.8%	10.9%

5.6.6 Impacts from glass

Table 23 shows details for the impacts from glass. Figure 29 shows the shares of impacts from glass in the total environmental impacts of all materials. Glass causes 40.5% of 'particulate matter' impacts.

In the baseline, for glass, recycled content (R1) is 5%, recycling output rate (R2) is 48%.

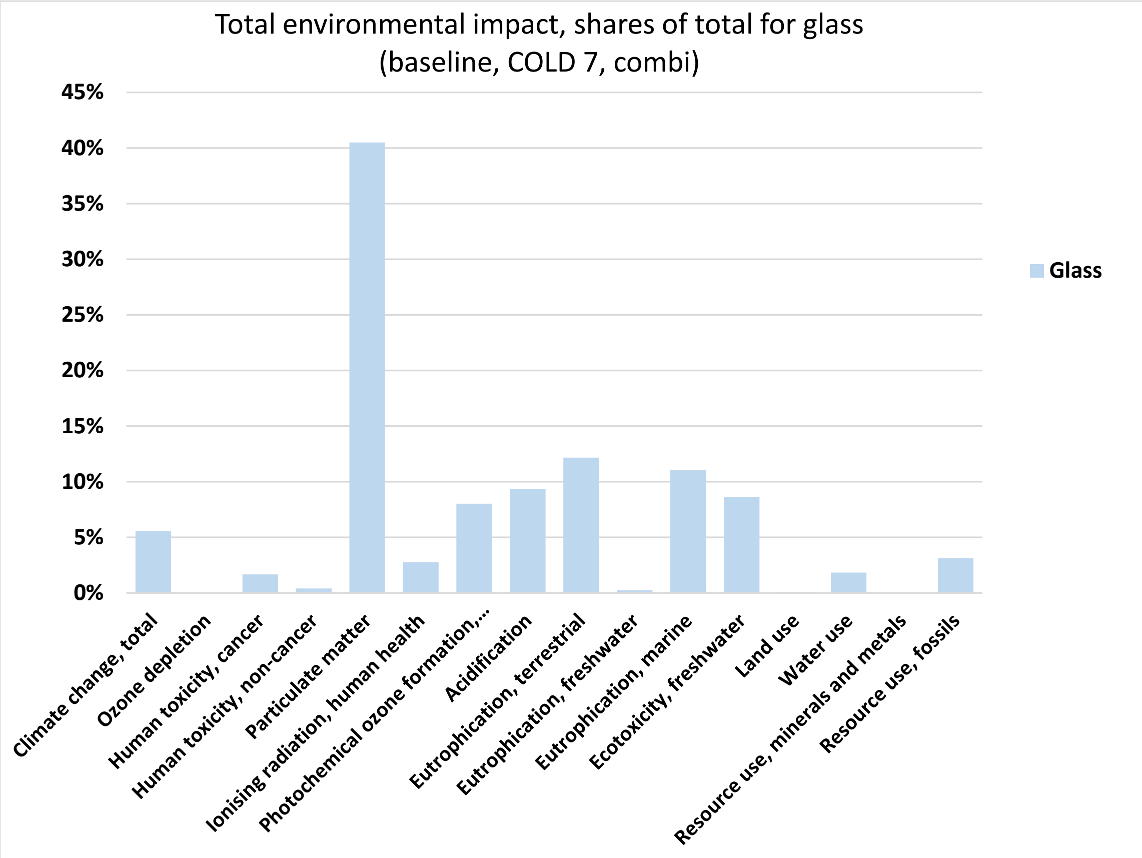


Figure 29: Shares for glass in total environmental impacts, for base case COLD 7 (combis), for the baseline.

Table 23: Baseline Environmental impacts from glass for base case COLD 7 (combi).

material	Mass [g]	Climate change, total [kg CO2 eq]	Ozone depletion [kg CFC-11 eq]	Human toxicity, cancer [CTUh]	Human toxicity, non-cancer [CTUh]	Particulate matter [disease incidence]	Ionising radiation, human health [kBq U235 eq]	Photo-chemical ozone formation, human health [kg NMVOC eq]	Acidifi-cation [mol H+ eq]
Glass - mat		7.8	2.3E-10	5.2E-10	9.5E-09	5.8E-06	0.32	0.023	0.04
Glass – eol-i		1.5	6.3E-12	5.5E-10	2.3E-09	8.7E-08	0.01	0.007	0.01
Glass – eol-c		-3.0	-9.1E-11	-1.9E-10	-3.7E-09	-2.2E-06	-0.12	-0.009	-0.01
Glass - total	5796	6.3	1.5E-10	8.7E-10	8.1E-09	3.6E-06	0.20	0.021	0.04
Glass - share	9.6%	5.6%	0.0%	1.7%	0.4%	40.5%	2.8%	8.0%	9.4%

material	Eutrophi-cation, terrestrial [mol N eq]	Eutrophi-cation, freshwater [kg P eq]	Eutrophi-cation, marine [kg N eq]	Ecotoxicity, freshwater [CTUe]	Land use [pt]	Water use [m3 water eq. of deprived water]	Resource use, minerals and metals [kg Sb eq]]	Resource use, fossils [MJ]
Glass - mat	0.12	3.6E-06	0.010	171	5.5	0.6	5.5E-07	77
Glass – eol-i	0.03	1.1E-07	0.003	1	1.5	0.1	3.3E-08	21
Glass – eol-c	-0.05	-1.4E-06	-0.004	-66	-2.1	-0.2	-2.1E-07	-30
Glass - total	0.11	2.3E-06	0.009	106	4.9	0.5	3.7E-07	69
Glass - share	12.2%	0.2%	11.1%	8.6%	0.1%	1.8%	0.0%	3.1%

5.7. Impact reduction due to recycled content

5.7.1 Reduction of material and end-of-life impacts

This paragraph discusses the reduction in environmental impacts for a unit product when the (post-consumer) recycled content (factor R1) for plastics is raised from 0% (baseline) to 10%, or for glass from 5% to 15%. Data are for a unit product of base case COLD 7 (combi) with the BoM of Table 15. As the reduction increases linearly with the recycled content [332], these data can later be multiplied by a factor to simulate the effect of higher recycled content requirements (see chapter 7 on scenario analysis).

Like the previously reported impacts for the baseline, only impacts from input materials, EoL impacts and EoL benefits are considered (no manufacturing, distribution, use, repair and maintenance).

Compared to the baseline, only the factors R1 for recycled content have been changed. Factors R2 (recycling output) and A (allocation factor) remain the same. This implies that EoL impact and EoL benefit do not change compared to the baseline: only the impact of materials in input to the production changes with R1 [332].

Table 24 gives and overview of the reduction of environmental impacts compared to the baseline, when 10% recycled content (instead of 0%) is used for plastics and 15% recycled content (instead of 5%) for glass. As before, the table is split in two parts, showing results for different impact categories.

The total mass in input to the production is 60.3 kg (section 5.5). In the baseline, 51.2 kg of this is virgin material, and this reduces by 3.0 kg (-5.9%) when increasing the recycled content for all plastics and for glass by 10%. The environmental impacts (from materials and end-of-life) per unit fridge-freezer (COLD 7) decrease between -4.1% and 3.0%, depending on the category. Highest impact reductions are found for 'ecotoxicity, freshwater' (3.0%), 'resource use, fossils' (2.5%) and 'human toxicity, cancer' (1.8%).

The negative reductions (additional impacts due to recycling) for ozone depletion come from HIPS and GPPS, see remarks in section 5.6.

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[332] Input material impact: (1-R1) Ev + R1 x (A Erec + (1-A) Ev) => Ev - R1*A*(Ev - Erec)
EoL contribution is independent from R1: (1-A) x R2 x Erec - (1-A) x R2 x Ev => - (1-A) x R2 x (Ev - Erec)
Total impact in function of R1: Ev - R1*A*(Ev-Erec) - (1-A) x R2 x (Ev - Erec): this is a linear function in R1
Total impact reduction vs BAU: (R1eco - R1bau)*A*(Ev-Erec) (positive value indicates reduction; negative value additional impact)
If R1bau is zero (as for plastics), the reduction is: R1eco*A*(Ev-Erec), so proportional to R1eco, and the relative reduction vs BAU is R1eco*A*(Ev-Erec) / (Ev - (1-A) x R2 x (Ev - Erec))

If R1eco=10%, A=50% (all plastics) and R2 49% (PP, PS, ABS) this becomes 5%*(Ev-Erec) / (75%*Ev +25%Erec).
If Erec is very small compared to Ev (ideally zero), the reduction is 5%/75% = 6.6%
If Erec = Ev/2, the reduction is 2.5%/87.5% = 2.9%

If R1eco=10%, A=50% (all plastics) and R2 0% (all other plastics) this becomes 5%*(Ev-Erec) / (Ev).
If Erec is very small compared to Ev (ideally zero), the reduction is 5%/100% = 5%
If Erec = Ev/2, the reduction is 2.5%/100% = 2.5%

If R1bau=5%, R1eco=15%, A=20% (glass) and R2 48% (glass) this becomes 2%*(Ev-Erec) / (62%*Ev+38%*Erec).
If Erec is very small compared to Ev (ideally zero), the reduction is 2%/62% = 3.2%
If Erec = Ev/2, the reduction is 1%/81% = 1.2%

Note that if Erec is negative (as occurs in some datasets), the relative impact reduction can increase rapidly because the dividend increases while the divisor decreases.

If Erec is larger than Ev, the relative impact will be negative, i.e. additional impacts due to using recycled input.

Table 24: Summary of the reduction of environmental impacts from materials and end-of-life, compared to the baseline, when using 10% recycled content in input to the production for plastics and glass, for base case COLD 7 (combi).

All materials, MAT & EoL impacts, summary	Virgin Mass in input [g]	Climate change, total [kg CO2 eq]	Ozone depletion [kg CFC-11 eq]	Human toxicity, cancer [CTUh]	Human toxicity, non-cancer [CTUh]	Particulate matter [disease incidence]	Ionising radiation, human health [kBq U235 eq]	Photo-chemical ozone formation, human health [kg NMVOC eq]	Acidifi-cation [mol H+ eq]
Baseline impact	**51196**	**113.0**	**1.1E-06**	**5.2E-08**	**2.0E-06**	**8.9E-06**	**7.4**	**0.264**	**0.38**
Savings, R1+10%									
Plastic (R1=10%)	2455	1.5	-4.7E-08	9.4E-10	3.1E-08	3.6E-08	-1.5E-03	3.5E-03	2.8E-03
Glass (R1=15%)	580	0.1	4.4E-12	-1.9E-11	7.2E-11	1.1E-07	6.1E-03	9.8E-05	2.8E-05
Sum savings	**3034**	**1.6**	**-4.7E-08**	**9.3E-10**	**3.1E-08**	**1.5E-07**	**4.7E-03**	**3.6E-03**	**2.8E-03**
Share savings	**5.9%**	**1.4%**	**-4.1%**	**1.8%**	**1.5%**	**1.7%**	**0.1%**	**1.4%**	**0.7%**

All materials, MAT & EoL impacts, summary	Eutrophi-cation, terrestrial [mol N eq]	Eutrophi-cation, freshwater [kg P eq]	Eutrophi-cation, marine [kg N eq]	Ecotoxicity, freshwater [CTUe]	Land use [pt]	Water use [m3 water eq. of deprived water]	Resource use, minerals and metals [kg Sb eq]]	Resource use, fossils [MJ]
Baseline impact	**0.88**	**9.5E-04**	**0.083**	**1227**	**4743**	**26.7**	**0.003**	**2211**
Savings, R1+10%								
Plastic (R1=10%)	9.3E-03	6.6E-06	9.7E-04	33.2	0.42	0.3	2.1E-06	55.8
Glass (R1=15%)	5.7E-04	6.7E-08	3.2E-05	3.4	0.03	4.7E-03	9.5E-09	0.4
Sum savings	**9.8E-03**	**6.7E-06**	**1.0E-03**	**37**	**0.5**	**0.3**	**2.1E-06**	**56**
Share savings	**1.1%**	**0.7%**	**1.2%**	**3.0%**	**0.0%**	**1.1%**	**0.1%**	**2.5%**

5.7.2 Reduction of material, end-of-life and electricity impacts

Table 25 shows the same savings as above but compared to the baseline impacts including also lifetime electricity use (see also section 5.6.2). The impact reductions due to 10% recycled content for all plastic types and for glass range from -0.15% for 'ozone depletion' to 0.44% for 'ecotoxicity, freshwater' and 0.43% for 'human toxicity, non-cancer' [333].

*Table 25: Summary of the reduction of environmental impacts from materials, end-of-life **AND lifetime electricity consumption**, compared to the baseline, when using 10% recycled content in input to the production for plastics and glass, for base case COLD 7 (combi).*

All materials, MAT & EoL & lifetime electricity impacts, summary	Virgin Mass in input [g]	Climate change, total [kg CO2 eq]	Ozone depletion [kg CFC-11 eq]	Human toxicity, cancer [CTUh]	Human toxicity, non-cancer [CTUh]	Particulate matter [disease incidence]	Ionising radiation, human health [kBq U235 eq]	Photo-chemical ozone formation, human health [kg NMVOC eq]	Acidifi-cation [mol H+ eq]
Baseline impact	51196	1658.5	1.7E-06	3.1E-07	7.2E-06	5.8E-05	664.1	2.8	5.1
Sum savings	3034	1.6	-4.7E-08	9.3E-10	3.1E-08	1.5E-07	4.7E-03	3.6E-03	2.8E-03
Share savings	**5.9%**	**0.09%**	**-2.73%**	**0.30%**	**0.42%**	**0.25%**	**0.001%**	**0.13%**	**0.06%**

[333] The primary energy consumption is 30118 MJ, slightly higher than 'resource use, fossils'. The 0.19% reduction is the same.

All materials, MAT & EoL & lifetime electricity impacts, summary	Eutrophi-cation, terrestrial [mol N eq]	Eutrophi-cation, freshwater [kg P eq]	Eutrophi-cation, marine [kg N eq]	Ecotoxicity, freshwater [CTUe]	Land use [pt]	Water use [m3 water eq. of deprived water]	Resource use, minerals and metals [kg Sb eq]]	Resource use, fossils [MJ]
Baseline impact	10.3	4.1E-03	0.98	8265	11398	554	3.6E-03	29092
Sum savings	9.8E-03	6.7E-06	1.0E-03	36.6	0.45	0.3	2.1E-06	56.2
Share savings	**0.10%**	**0.16%**	**0.10%**	**0.44%**	**0.004%**	**0.05%**	**0.06%**	**0.19%**

5.7.3 Reduction per type of plastic and for glass

Table 26 provides details on the environmental impact reduction per type of plastic, when using 10% recycled content in input to the production.

For PU, EPS, PBT and POM, the reductions are zero because there is no dataset for recycled material in the ERT.

For some material – impact category combinations, the reductions are negative (red figures in the table), meaning an additional impact when using 10% recycled plastic in input. This happens for:

- HIPS and GPPS, ozone depletion: the impact per kg for the virgin material (3.4E-11, dataset 17 and 302) is lower than for the recycled material (7.0E-08, dataset 303). See also remarks on the datasets under Table 15.
- HIPS and GPPS, ionising radiation: the impact per kg for the virgin material (0.069, dataset 17 and 302) is lower than for the recycled material (0.086, dataset 303). See also remarks on the datasets under Table 15.
- HIPS and GPPS, eutrophication-freshwater: the impact per kg for the virgin material (4.6E-06, dataset 17 and 302) is lower than for the recycled material (2.5E-05, dataset 303). See also remarks on the datasets under Table 15.
- PP, land use: the impact per kg for the virgin material (0.57, dataset 16) is lower than for the recycled material (1.79, dataset 35) [334].
- ABS, water use: the impact per kg for the virgin material is negative (-2.42, dataset 1) while the one for the recycled material is slightly positive (0.075, dataset 36) [335].
- PET, ionising radiation: the impact per kg for the virgin material (0.066, dataset 12) is lower than for the recycled material (0.086, dataset 41).
- PC, ozone depletion: the impact per kg for the virgin material (3.9E-11, dataset 14) is lower than for the recycled material (1.4E-09, dataset 33). Negative impacts of recycling also appear for ‘eutrophication, freshwater’, ‘land use’ and ‘resource use, minerals and metals’ [336].
- PA: for all categories except ‘ionising radiation’ and ‘resource use, fossils’, the impact per kg for the virgin material (dataset 11) is lower than for the recycled material (dataset

[334] A VMAS LCA expert commented that this could be due e.g. to the electricity modelled for recycled plastic using more wood, and electricity for virgin plastic using more fossil fuels….

[335] Being investigated by the ERT development team.

[336] Dataset 33 further has negative impacts for ‘ionising radiation’ and for ‘resource use, fossils’.

31). Consequently, if these impacts are correct, it is better for the environment not to recycle PA (nylon). The ERT datasets need reviewing.

For 'ozone depletion' and 'ionising radiation', the sum of impact reductions over all plastics is also negative, and this is mainly due to the HIPS and GPPS recycling. Negative impact reductions due to recycling depend on the assumptions made during dataset development on how and where virgin material is produced and how and where the material recycling takes place. Negative impacts can be realistic; they are not per definition errors.

The use of 10% recycled plastics in input (for all types) gives a reduction in environmental impacts due to plastics between -4.6% and 4.8%, depending on the impact category.

The -4.8% is for ozone depletion, which is almost entirely caused by PU, for which no recycled material dataset is available (and which is anyway not being recycled), and hence does not contribute to ODP reduction. As said above, the negative reduction in impacts is due to HIPS and GPPS (like the -0.1% for 'ionising radiation').

The 0.4% for 'land use' is low due to negative contributions (additional impacts due to using recycled material) from PP, PC and PA (see remarks above).

The 1.1% for 'eutrophication, freshwater' is low due to negative contributions (additional impacts due to using recycled material) from HIPS, GPPS, PC and PA (see remarks above).

The highest impact reductions are for 'human toxicity, non-cancer' (4.7%) and 'ecotoxicity, freshwater' (4.8%), with major contributions to the reduction coming from recycled HIPS and GPPS.

Table 26: Reduction of environmental impacts from plastics when using 10% recycled content in input to the production, for base case COLD 7 (combi). (positive value indicates reduction; negative value indicates additional impact)

Plastics, summary	Virgin Mass in input [g]	Climate change, total [kg CO2 eq]	Ozone depletion [kg CFC-11 eq]	Human toxicity, cancer [CTUh]	Human toxicity, non-cancer [CTUh]	Particulate matter [disease incidence]	Ionising radiation, human health [kBq U235 eq]	Photo-chemical ozone formation, human health [kg NMVOC eq]	Acidifi-cation [mol H+ eq]
Baseline impact, R1=0%	**24548**	**49.9**	**1.0E-06**	**2.3E-08**	**6.4E-07**	**1.5E-06**	**2.19**	**0.119**	**0.13**
Savings, R1=10%									
PP	248	0.261	2.5E-09	1.8E-10	2.2E-09	3.0E-08	4.1E-03	1.5E-03	2.0E-03
HIPS	828	0.647	-2.9E-08	3.9E-10	1.6E-08	2.6E-10	-7.3E-03	9.3E-04	2.4E-04
GPPS	576	0.449	-2.0E-08	2.7E-10	1.1E-08	1.8E-10	-5.1E-03	6.5E-04	1.7E-04
ABS	34	0.046	4.8E-13	1.7E-11	7.0E-10	6.2E-10	8.4E-04	9.4E-05	9.4E-05
PVC	62	0.043	3.7E-11	5.1E-11	2.1E-10	8.9E-10	3.6E-03	1.7E-04	9.0E-05
PU	658	0	0	0	0	0	0	0	0
EPS	4	0	0	0	0	0	0	0	0
PET	9	0.011	5.3E-11	1.3E-11	1.1E-10	2.5E-09	-8.5E-05	9.4E-05	1.3E-04
PBT	9	0	0	0	0	0	0	0	0
PC	9	0.014	-5.8E-12	1.7E-11	7.6E-11	1.5E-09	8.6E-04	7.2E-05	8.2E-05
PA	10	-0.001	-4.5E-12	-2.2E-12	-2.6E-11	-6.4E-10	7.2E-04	-5.4E-06	-1.4E-05
POM	2	0	0	0	0	0	0	0	0
EPDM	7	0.011	6.9E-13	3.1E-12	4.9E-11	1.8E-10	9.4E-04	2.1E-05	2.4E-05
Sum savings	**2455**	**1.5**	**-4.7E-08**	**9.4E-10**	**3.1E-08**	**3.6E-08**	**-1.5E-03**	**3.5E-03**	**2.8E-03**
Share savings	**10%**	**3.0%**	**-4.6%**	**4.1%**	**4.7%**	**2.3%**	**-0.1%**	**3.0%**	**2.1%**

Plastics, summary	Eutrophi-cation, terrestrial [mol N eq]	Eutrophi-cation, freshwater [kg P eq]	Eutrophi-cation, marine [kg N eq]	Ecotoxicity, freshwater [CTUe]	Land use [pt]	Water use [m3 water eq. of deprived water]	Resource use, minerals and metals [kg Sb eq]]	Resource use, fossils [MJ]
Baseline impact, R1=0%	**0.37**	**6.2E-04**	**0.035**	**689**	**97.6**	**13.9**	**5.5E-05**	**1464**
Savings, R1=10%								
PP	5.2E-03	2.1E-05	5.5E-04	5.4	-0.15	0.21	1.7E-06	7.8
HIPS	1.6E-03	-8.6E-06	1.8E-04	15.2	0.24	0.07	1.9E-07	26.0
GPPS	1.1E-03	-6.0E-06	1.2E-04	10.6	0.16	0.05	1.3E-07	18.1
ABS	3.5E-04	1.0E-07	3.3E-05	0.6	0.07	-0.04	7.6E-09	1.3
PVC	3.1E-04	7.0E-08	2.7E-05	0.7	0.07	0.00	7.4E-09	1.5
PU	0	0	0	0	0	0	0	0
EPS	0	0	0	0	0	0	0	0
PET	3.5E-04	5.9E-07	3.2E-05	0.2	0.04	0.01	1.6E-07	0.3
PBT	0	0	0	0	0	0	0	0
PC	2.3E-04	-1.3E-07	2.2E-05	0.3	-3.1E-03	0.004	-6.0E-08	0.4
PA	-2.1E-05	-1.6E-07	-3.0E-06	-0.01	-7.8E-03	-0.003	-7.6E-09	0.01
POM	0	0	0	0	0	0	0	0
EPDM	5.9E-05	1.9E-08	5.5E-06	0.2	0.01	0.001	5.2E-09	0.3
Sum savings	**9.3E-03**	**6.6E-06**	**9.7E-04**	**33**	**0.42**	**0.30**	**2.1E-06**	**56**
Share savings	**2.5%**	**1.1%**	**2.8%**	**4.8%**	**0.4%**	**2.1%**	**3.8%**	**3.8%**

Table 27 shows for each plastic type and for glass, the reduction of the environmental impacts when using +10% recycled material in input, as share of the baseline impacts for the same material type. Considering the formula for the relative impact reduction [332], for the values of R1, R2 and A used here, the maximum relative reduction that can be expected for PP, HIPS, GPPS and ABS is 6.6%, for other plastics 5% and for glass 3.2%. Where the percentage reduction is higher (red figures in the table) or negative (black figures in the table), further verification could be opportune (but values are not necessarily wrong) [337].

Table 27: Reduction of environmental impacts from plastics and glass when using 10% recycled content in input to the production, as share of the baseline impacts for the same material type, for base case COLD 7 (combi).

material	Virgin Mass in input [g]	Climate change, total [kg CO2 eq]	Ozone depletion [kg CFC-11 eq]	Human toxicity, cancer [CTUh]	Human toxicity, non-cancer [CTUh]	Particulate matter [disease incidence]	Ionising radiation, human health [kBq U235 eq]	Photo-chemical ozone formation, human health [kg NMVOC eq]	Acidifi-cation [mol H+ eq]
PP	10%	5.1%	6.4%	5.4%	5.6%	4.7%	6.2%	6.1%	5.7%
HIPS	10%	4.4%	-20.4%	6.4%	6.5%	0.1%	-1.2%	3.3%	0.8%
GPPS	10%	4.4%	-20.4%	6.4%	6.5%	0.1%	-1.2%	3.3%	0.8%
ABS	10%	5.7%	1.7%	6.2%	6.4%	5.2%	2.3%	5.1%	5.5%
PU	10%	0%	0%	0%	0%	0%	0%	0%	0%
PVC	10%	3.4%	4.7%	4.8%	4.0%	3.7%	2.6%	4.4%	3.7%
EPS	10%	0%	0%	0%	0%	0%	0%	0%	0%
PET	10%	4.0%	5.0%	4.9%	4.8%	4.9%	-1.4%	4.9%	4.9%
PBT	10%	0%	0%	0%	0%	0%	0%	0%	0%
PC	10%	3.6%	-167.5%	4.3%	3.9%	4.1%	7.4%	4.8%	4.6%
PA	10%	-1.5%	-28.5%	-45.3%	-15.6%	-51.1%	4.1%	-6.2%	-11.7%
POM	10%	0%	0%	0%	0%	0%	0%	0%	0%
EPDM	10%	4.7%	4.7%	5.0%	4.8%	4.9%	4.8%	4.9%	4.9%
All plastics	**10%**	**3.0%**	**-4.6%**	**4.1%**	**4.7%**	**2.3%**	**-0.1%**	**3.0%**	**2.1%**
Glass	10%	1.3%	2.9%	-2.1%	0.9%	3.1%	3.0%	0.5%	0.1%

[337] Negative values (black) indicate that the unit impact for recycling is higher than for the virgin material. Values higher than the maximum expected indicate negative impacts / kg in the recycled material dataset.

material	Eutrophi-cation, terrestrial [mol N eq]	Eutrophi-cation, freshwater [kg P eq]	Eutrophi-cation, marine [kg N eq]	Ecotoxicity, freshwater [CTUe]	Land use [pt]	Water use [m3 water eq. of deprived water]	Resource use, minerals and metals [kg Sb eq]]	Resource use, fossils [MJ]
PP	6.0%	6.3%	6.1%	6.3%	-7.0%	6.0%	5.8%	6.2%
HIPS	1.9%	-10.7%	2.3%	6.1%	1.9%	2.2%	4.4%	5.3%
GPPS	1.9%	-10.7%	2.3%	6.1%	1.9%	2.2%	4.4%	5.3%
ABS	5.7%	5.4%	5.7%	6.4%	4.3%	6.9%	5.5%	6.0%
PU	0%	0%	0%	0%	0%	0%	0%	0%
PVC	3.8%	2.2%	3.8%	4.7%	2.6%	0.6%	3.8%	4.5%
EPS	0%	0%	0%	0%	0%	0%	0%	0%
PET	4.9%	4.9%	4.9%	4.9%	4.4%	4.6%	5.0%	4.7%
PBT	0%	0%	0%	0%	0%	0%	0%	0%
PC	4.7%	-9.0%	4.7%	4.9%	-1.4%	4.1%	-89.5%	5.1%
PA	-6.6%	-141.4%	-10.0%	-4.7%	-4.6%	-47.4%	-42.9%	0.7%
POM	0%	0%	0%	0%	0%	0%	0%	0%
EPDM	4.8%	4.7%	4.8%	5.0%	3.9%	4.5%	4.9%	5.0%
All plastics	**2.5%**	**1.1%**	**2.8%**	**4.8%**	**0.4%**	**2.1%**	**3.8%**	**3.8%**
Glass	0.5%	2.9%	0.3%	3.2%	0.6%	0.9%	2.5%	0.6%

5.8. Economic aspects of recycled content

5.8.1 Material costs

The phase 2 study reports on personal computers and imaging equipment presented price comparisons between virgin and recycled materials for various types of plastics, e.g. from Plastics Information Europe (PIE) and Market Report Plastics (MRT). These data indicated that recycled plastics cost the same or less than virgin plastics, but they were criticized as non-realistic and non-complete by many stakeholders in their comments following the 3rd stakeholder meeting.

From the data presented in those studies, only Figure 30 has been maintained here, as an illustration of the time-fluctuation in prices for virgin and recycled HIPS and ABS. As also observed by stakeholders in comments following the 4th SH meeting, the data of Figure 30 may not accurately reflect the specific grades required for fridges, which must meet stringent performance standards. Due to limited availability, regulatory hurdles, and market instability, suitable recycled materials are often more expensive than virgin plastics.

As described in sections 4.2.1 and 4.2.2, recycled plastics for fridges must meet food-contact specifications (amongst others), and this currently involves specifically prepared r-HIPS from specifically selected WEEE (from fridges to fridges) in r-HIPS supply chains managed by the fridge manufacturer, or by a third party for the manufacturer. The generic market prices for r-HIPS of Figure 30 are not representative for this. Instead, major costs are expected to derive from research, development and testing, see next section.

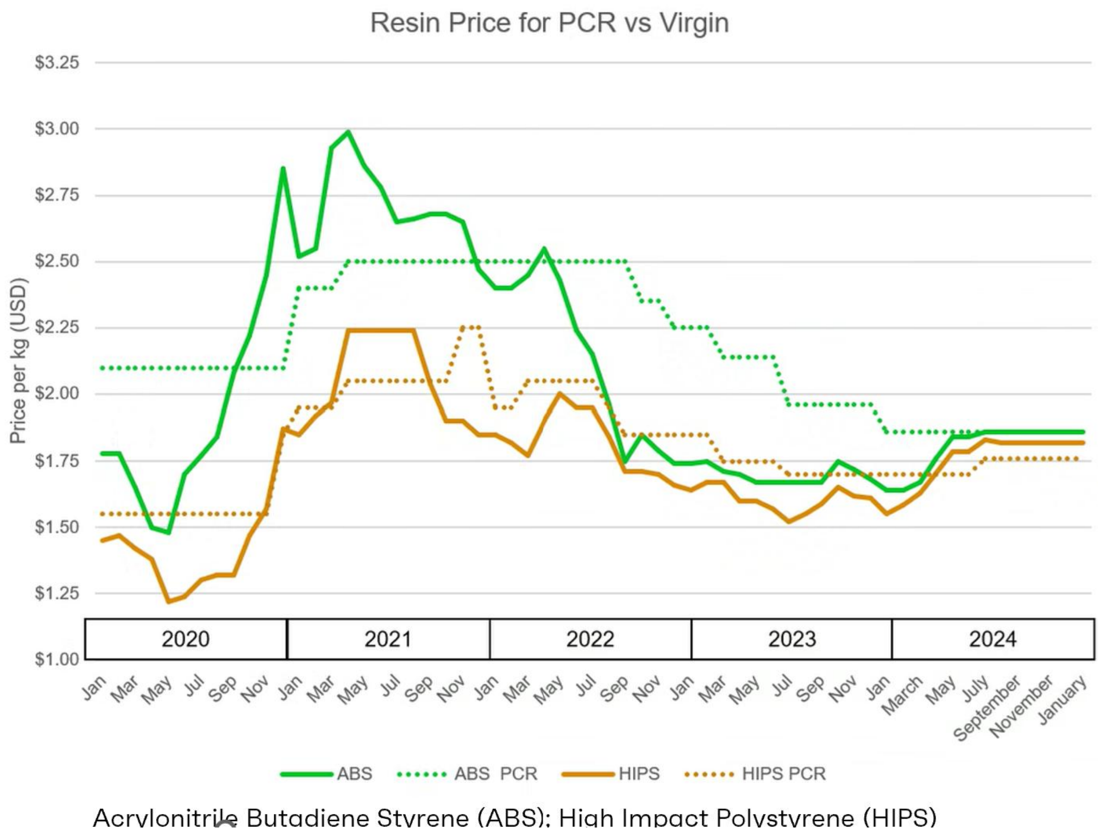

Figure 30: Comparison of prices for virgin and post-consumer recycled materials for HIPS and ABS (source: phase 2 study on imaging equipment and personal computers)

5.8.2 Development and testing costs

Questioned on cost aspects of the use of r-HIPS (section 4.2.1), Electrolux commented that the overall handling and creation of a new material costs more compared to virgin HIPS and does increase complexity. Pricing strategies could not be disclosed, but the appliances with the recycled inner liner are sold at a premium price that is considered interesting by some consumers, and that does not generate a loss to Electrolux.

The solution based on the barrier cap layer required a specifically designed extrusion line, also due to a change in the cap layer thickness. The related investment is in the range of some millions of euros.

In addition, certification costs of € 0.5 million were sustained to be compliant with EU regulation 2022/1616 (section 1.5.7.5).

For virgin material, a continuous material quality monitoring program is not necessary. The use of recycled plastic, especially in a food contact application, requires an ongoing quality monitoring process, with costs up to at least 100,000 €/year, including personnel and certification.

The above costs are for using 70% recycled plastic in one fridge component (the body inner liner) of one fridge model (a fridge-freezer combi), and for one material type (HIPS). As declared by the manufacturer (section 4.2.1) they lead to 13% of the total fridge plastic mass coming from recycled material.

If regulation requirements on recycled plastic content are set higher, e.g. to 20 or 30%, more fridge components and more material types will likely be involved, and costs will increase. The additional costs can at least partially be shared between components of the same product (e.g. using r-HIPS for the door liner will benefit from the work already done for the body inner liner), or between similar products (e.g. built-in and free-standing models, models with different volumes or different energy classes). For a single component, e.g. body inner liner, the development and testing costs are not expected to vary much with the % of recycled content, e.g. it seems to make little difference if the body inner liner contains 30%, 50% or 70% r-HIPS.

The costs per product (potentially affecting the consumer purchase price) of increased use of recycled material depend on the number of products sold per year and on the number of years in which the additional costs are planned to be amortized.

For the estimate of the additional costs per product, it has been assumed that research and development costs are amortized in 3 years and process certification costs in 2 years. Quality monitoring costs will occur every year.

Table 28: Annual development and testing costs for obtaining ≈10% recycled plastic content in fridges

Cost type	Total cost (million euros)	Amortization (years)	Cost per year (million euros)
Research and development	2.5 M€	3	0.83 M€
Process certification	0.5 M€	2	0.25 M€
Quality monitoring			0.10 M€
Sum			**1.18 M€**

The above costs are assumed to be indicative for 10% recycled plastic content.
For 20% recycled content, costs have been multiplied by a factor 1.8.
For 30% recycled content, costs have been multiplied by a factor 2.4.

The annual product sales will differ between large players and smaller companies. The global players can amortize costs also over models sold outside Europe. In 2024, 9 million refrigerator-freezer combis were sold in the EU27 (section 2.1.2), by a large number of different manufacturers. The market research company Mordor Intelligence [338] lists 10 major players on the European refrigeration market: Liebherr, Samsung, Whirlpool, LG, Haier, Bosch, Midea, Electrolux, Miele, Brandt. But there are many others [339]: e.g. GE, KitchenAid, Sub-Zero, Monogram, Siemens, Beko, V-zug, Gorenje, Bauknecht, Sharp, Smeg, Sibir, Severin, Domo. The market is fragmented and competitive.

Estimates for product cost variations due to increased use of recycled material in fridges have been made for 500, 250 and 100 thousand annual sales per manufacturer (regardless of sales being inside or outside EU27). Table 29 shows the resulting potential price increases.

Table 29: Annual development and testing costs per product sold for obtaining 10%, 20% or 30% recycled plastic content in fridges, depending on manufacturer's annual sales

Additional costs for development and testing, per product sold (euros)	Annual sales		
	500 thousand units / year	250 thousand units / year	100 thousand units / year
10% recycled plastic	€ 2.36	€ 4.72	€ 11.80
20% recycled plastic	€ 4.25	€ 8.50	€ 21.25
30% recycled plastic	€ 5.66	€ 11.33	€ 28.30

[338] https://www.mordorintelligence.com/industry-reports/europe-household-refrigerator-market/companies

[339] https://www.topten.eu/private/products/refrigerators

Considering the average purchase price of a refrigerator-freezer combi in 2024 around € 600 (excl. VAT, in 2020 euros), for large players the price increase due to development and testing costs could be 0.5-1.0%, and for small players 2-5% per unit.

6. MEErP Task 6, Design Options

6.1. Introduction and Timeline

This chapter describes design options, linked to potential future Ecodesign requirements, for

- Recycled material content of fridges (section 6.2), subdivided in plastics, metals, glass, electronics and other materials,
- Recyclability of fridges (section 6.3), and
- Critical Raw Materials used in fridges (section 6.4)

The current mini preparatory study on recycled content and CRM for fridges has a limited time-budget. The study therefore provides recommendations, supported by preliminary data gathering and analyses, that will feed into the review study on fridge regulations that started in December 2024 and is projected to end in the Spring of 2027. That study will further complete the data gathering and analysis and integrate the recommendations in a Commission Working Document for a revised regulation.

The timeline of the review study implies that a reviewed regulation containing requirements on recycled content, recyclability and CRMs in fridges could be published in 2028.

As manufacturers will need preparation time (even if they can anticipate), any requirements cannot enter into force before 2030. E.g. a <u>first tier of requirements could be set for 2030, and a second tier for 2033</u>.

Note that requirements on recycled material content will have almost immediate effects in the year from which they apply. Requirements on recyclability will have impacts much later, when the first fridges sold in 2030 reach their end-of-life, on average around 16 years later, i.e. between 2045 and 2050.

6.2. Design options for recycled content

6.2.1 Plastics

6.2.1.1 Introduction

Refrigerators and freezers have been selected for phase 2 of the study mainly for their potential to use recycled plastics in input.

For base case COLD7 (refrigerator-freezer combi, representing 53% of annual fridge sales in the EU, section 2.1.2), plastics represent around 40% of the mass (sections 5.3 and 5.5). Most of this is high-impact polystyrene (HIPS, 13.7%, mainly used for the body and door inner liners) and general-purpose polystyrene (GPPS, 9.5% mainly used for drawers, shelves and accessories), which are recyclable.

Polyurethane (PU, 10.9%, used as foam for thermal insulation) can be recycled only chemically, which is currently not economically viable (section 4.2.3).

Polypropylene (PP, 4.1%, used for drawers, body reinforcements, many small parts) and ABS (0.6%, many small parts) are present in lower quantities, but recyclable.

Polyvinylchloride (PVC, 1.0%, used for door gaskets) is recyclable, but on the reference BoM it is used in its soft form, which has recycling issues.

Other plastics account for 0.8% of the fridge mass.

6.2.1.2 Food contact aspects

Materials used inside fridges have to meet the requirements of food contact material (FCM) regulations (section 1.5.7), which imply additional development, certification and quality monitoring costs for the use of recycled plastics inside the fridges. Electrolux uses a virgin HIPS layer on top of a recycled HIPS layer for its body inner liner (section 4.2.1) to facilitate meeting FCM requirements. However, as shown in the PRIMUS project (section 4.2.2), recycling processes can be designed in such a way that 100% recycled HIPS meets the FCM requirements. Currently, recycled HIPS for use in fridges is produced only from discarded refrigerators and freezers, to ensure a lower degree of contamination and impurities in input to the recycling. This contributes to meeting the FCM requirements.

6.2.1.3 Recycled material sources

It is desirable to require that recycled plastics come from post-consumer sources. The intention of setting requirements on recycled material contents is to stimulate post-consumer waste collection and use by increasing the demand for recycled materials. Pre-consumer waste practices are not expected to benefit from additional requirements. The focus on post-consumer waste is aligned with article 7 of the packaging and packaging waste regulation (PPWR) [340] and article 29 of the Critical Raw Materials Act [341]. However, article 8 of the regulation on batteries and waste batteries [342] refers to materials 'recovered from battery manufacturing waste or post-consumer waste' [343].

If they have not already done so, recyclers would have to set up and maintain an accounting of incoming waste materials, such that they could indicate which share of produced recycled material originates from pre- and post-consumer waste.

It is not desirable to prescribe that recycled plastics have to come from discarded fridges. If it can be demonstrated that recycled plastic from another source can meet the FCM requirements, this should be accepted.

It is not desirable to prescribe that recycled plastics have to come from mechanical recycling processes. Due to its typically higher costs and higher environmental impacts, chemical recycling will be used only where mechanical recycling is not available and can thus be a useful addition. This can be relevant for recycling PUR foam, which is used as thermal insulation material in fridges, represents a significant share of the fridge plastic mass, and can currently not be mechanically recycled.

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[340] REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC, Brussels, 4 December 2024, PE-CONS 73/24

[341] Critical Raw Materials Act: REGULATION (EU) 2024/1252 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020, OJ 3.5.2024

[342] REGULATION (EU) 2023/1542 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC, OJ L 191/1, 28.7.2023

[343] Recycling of CRMs and precious metals, which are typically present in small quantities in products, many collection, transportation and separation steps are necessary. Therefore, at the end of the road recyclers usually do not know which part of the recyclate comes from pre- or post-consumer waste.

6.2.1.4 Application level for recycled content requirements

Requirements regarding the recycled plastic content of fridges can be set on 5 levels:

1. On the fridge as a whole
2. On the total plastic mass in the fridge
3. On a part of the plastic mass in the fridge
4. For specific types of plastic used in the fridge
5. For specific (plastic) components of fridges

These options are further discussed below.

Option 1: Recycled content requirement, entire fridge

At this level, the requirements could be e.g.:

By 1 January 2030, any fridge placed on the market shall contain at least X1% of recycled content recovered from post-consumer waste.

By 1 January 2033, any fridge placed on the market shall contain at least X2% of recycled content recovered from post-consumer waste.

The recycled content share shall be computed as the mass of post-consumer recycled materials contained in the product divided by the total mass of the fridge as sold, excluding packaging.

As shown in section 5.5, in the baseline scenario, 15% of the fridge input mass is recycled material, most from metals (ferrous, aluminium, copper) and some from glass.

X1 could be set to 15%+10% = 25%

X2 could be set to 15% + 30% = 45%

The chosen +10% and +30% are based on the estimated maximum realistic recycled plastic content, see section 6.2.1.5. However, with this type of requirement, the manufacturer would be free to choose how the recycled material content is increased, i.e. using recycled plastics, metals, glass, or even refrigerant or lubrication oil.

The type of requirement could lead to designers preferring types of materials where a high recycled content is easier to obtain, e.g. using metals or glass instead of plastics. This could also increase the overall fridge mass. However, such a behaviour would be limited by functional and cost constraints (material, manufacturing processes, distribution) and possibly by consumer preferences.

This type of requirement is less adequate if the legislator wants to specifically target plastics recycling.

Administrative costs for manufacturers and market surveillance costs will be high, because all materials must be traced for their recycled content, including metals and glass.

Option 2: Recycled content requirement, total plastics mass

At this level, the requirements could be e.g.:

By 1 January 2030, any fridge placed on the market shall contain at least X1% of recycled plastic content recovered from post-consumer waste.

By 1 January 2033, any fridge placed on the market shall contain at least X2% of recycled plastic content recovered from post-consumer waste.

> The recycled content share shall be computed as the mass of post-consumer recycled plastics contained in the product divided by the total plastics mass contained in the fridge as sold, excluding packaging.

In the baseline scenario, 0% recycled plastic content has been assumed.

X1 could be set to 0%+10% = 10%

X2 could be set to 0% + 30% = 30%

The chosen +10% and +30% are based on the estimated maximum realistic recycled plastic content, see section 6.2.1.5. With this type of requirements, the manufacturer would be free to choose for which type of plastic the recycled content is increased, i.e. for HIPS, GPPS, PP, PVC, or even chemically recycled PUR (if available).

Most plastics are now found inside the fridges, where recycled plastics must meet FCM requirements. The type of requirement could lead designers to use plastics instead of metal on the outside of the fridge, where FCM requirements do not apply, and a higher recycled content could be easier and cheaper to realize than inside the fridge. This could lead to an increase of the total plastics mass. However, such a behaviour would be limited by functional (structural strength, rigidity, durability, flammability) constraints, and maybe cost constraints (plastic vs steel), and by consumer preferences. This risk does not seem high.

This type of requirements is less adequate if the legislator wants to specifically target certain types of plastic, e.g. for reasons of verification of recycled content.

It might be necessary to exactly define what is meant by ‘plastic’.

Option 3: Recycled content requirement, part of plastics mass

At this level, the requirements could be e.g.:

> By 1 January 2030, any fridge placed on the market shall contain at least X1% of recycled content for the plastics PS, PP, ABS and PVC together, recovered from post-consumer waste.
>
> By 1 January 2033, any fridge placed on the market shall contain at least X2% of recycled content for the plastics PS, PP, ABS and PVC together, recovered from post-consumer waste.
>
> The recycled content share shall be computed as the mass sum of post-consumer recycled PS, PP, ABS and PVC contained in the product divided by the total mass sum of PS, PP, ABS and PVC contained in the fridge as sold, excluding packaging.

In the baseline scenario, 0% recycled plastic content has been assumed.

X1 could be set to 0%+20% = 20%

X2 could be set to 0% + 40% = 40%

Considering a limited set of plastic types offers the possibility to exclude types that are difficult to recycle, such as polyurethane foam of the fridges, or that are hardly being used in fridges, such as PET, PBT, PC, PA, EPDM, etc. This means that recycled content requirements can be set higher than in the previous option. The chosen +20% and +40% are based on the estimated maximum realistic recycled plastic content when excluding PUR and other plastic masses (see section 6.2.1.5) but cautiously adjusted downwards. This type of requirement focuses on the main plastics used in fridges. The manufacturer would be free to choose for which type of targeted plastic the recycled content is increased, i.e. for HIPS, GPPS, PP, ABS or PVC. However, for the BoM of the refrigerator-freezer combi (Table 15), by far the highest mass is PS, so this would be a mandatory choice. See also remarks per plastic type in the following option. The limits would need further study and discussion.

As different manufacturers might be using different types of plastics in their fridges, the type of requirement could create an unlevel playing field, where some manufacturers have more difficulties in meeting the requirements than others. BoMs of more models would have to be studied to get an impression of the variety of plastics used. Studying a single BoM as done in the current study is not sufficient.

Like the previous option, there could be a (small) risk that designers will explore using the regulated plastic types in non-food-contact locations, e.g. instead of metal on the outside of the fridge, where FCM requirements do not apply, and a higher recycled content could be easier and cheaper to realize than inside the fridge.

In addition, designers could have the tendency to avoid using the regulated plastic types, trying to substitute them by other types of plastics, or by mixtures of plastics not in scope of the requirement, or by metal or glass. It is difficult to judge how large this risk could be.

It will be necessary to adequately define the regulated plastic types.

Option 4: Recycled content requirement, specific plastic types

At this level, the requirements could be e.g.:

> By 1 January 2030, any fridge placed on the market shall contain at least the following percentages of recycled content recovered from post-consumer waste, for the plastic types indicated, if they are present in the product:
>
> - Polystyrene (PS), any type 30%
> - Polypropylene (PP) 20%
> - Acrylonitrile butadiene styrene (ABS) 20%
> - Polyvinylchloride (PVC), any type 10% (?)
>
> By 1 January 2033, any fridge placed on the market shall contain at least the following percentages of recycled content recovered from post-consumer waste, for the plastic types indicated, if they are present in the product:
>
> - Polystyrene (PS), any type 50%
> - Polypropylene (PP) 40%
> - Acrylonitrile butadiene styrene (ABS) 40%
> - Polyvinylchloride (PVC), any type 20% (?)
>
> The recycled content shares shall be computed as the mass of post-consumer recycled plastic contained in the product for the plastic type concerned divided by the total plastic mass contained in the fridge as sold, for the plastic type concerned, excluding packaging.

The difference with the previous option is that masses for each plastic type are considered separately, and not as a sum. This means that recycled content requirements can be differentiated per type, if desired.

For PS, one manufacturer already uses 70% recycled HIPS for the body inner liner for one fridge model (section 4.2.1). For the BoM of the refrigerator-freezer combi (Table 15), this would represent 32% of the total amount of PS in the fridge (considering the sum of HIPS and GPPS). This can be raised to 39% by using 70% r-HIPS also for the door inner liner, or to 56% when using 100% r-HIPS for both liners (section 4.2.2). Alternatively, or in addition, recycled GPPS can be used for (some of the) drawers and shelves, so 50% recycled content should be feasible on the long term. The limits would need further study and discussion. It could be opportune to specify separate limits for HIPS and GPPS, but a generic limit for PS gives more freedom to the manufacturers.

PP and ABS are recyclable, and recycled from fridges, but there is no evidence that recycled PP or ABS is currently being used in fridges. For the BoM of the refrigerator-freezer combi (Table 15), the quantities of PP and ABS are much smaller than those for PS.

PVC is recyclable, but currently not recycled from fridges (except from cable sheathing), and there is no evidence that recycled PVC is currently being used in fridges. PVC contains many additives and consequently there are issues with food contact [344]. For the BoM of the refrigerator-freezer combi (Table 15), the quantity of PVC is modest, and it is soft PVC (used for the door gaskets), which has even more additives, can contain magnetic parts, and is therefore more difficult to separate and recycle. Hard PVC and soft (flex) PVC cannot be recycled together and thus must be separated. Setting limits for recycled content on PVC in fridges might therefore not be opportune.

As regards risks and definitions, the same remarks apply as for the previous option.

A similar requirement for PU could be assessed later (2030) for tier 2 in 2033, depending on the development and economic viability of recycling processes for PU (section 4.2.3), and the use of vacuum insulation panels (section 0).

Option 5: Recycled content requirement, specific (plastic) components

At this level, the requirements could be e.g.:

> By 1 January 2030, the listed components of fridges placed on the market shall contain at least the indicated percentage of recycled material content recovered from post-consumer waste:
>
> - Body inner liner: 30%
> - Door inner liner: 30%
> - Drawers, shelves and accessories: 30%
>
> By 1 January 2033, the listed components of fridges placed on the market shall contain at least the indicated percentage of recycled material content: recovered from post-consumer waste
>
> - Body inner liner: 50%
> - Door inner liner: 50%
> - Drawers, shelves and accessories: 50%
>
> The recycled content share shall be computed as the mass of post-consumer recycled material in the component divided by the total material mass of the component. If the component consists of more than one part, the sum of masses of the parts shall be considered.

If desired, the requirements can be made more specific by replacing material by plastic. If that is done, the situation will have to be addressed where a fridge model does not use plastic for (a part of) the indicated component.

For most fridges, the body and door inner liners are made in plastic (typically HIPS). The risk that the requirement induces designers to choose other material types (metal, glass, wood)

[344] Limit values in REACH and POP continue to be decreased.

seems low. Note that from an environmental point of view, a switch from plastic to metal could also be advantageous.

Drawers and accessories (e.g. egg tray, ice tray, bottles holder) are often made in plastic (e.g. GPPS, PP). Shelves can be made in plastic, glass, metal wires, or combinations of these. Drawers, shelves and accessories are typically separate, mobile components that can be taken out of the fridge, e.g. for cleaning. At end-of-life they are easily removable and separately processable by type of material. Especially for shelves, if the requirement generically refers to recycled material (and not specifically to plastic), designers might have the tendency to prefer metal or glass instead of plastic for ease of reaching the minimum percentage of recycled content.

The limits would need further study and discussion.

It will be necessary to adequately define the regulated components.

6.2.1.5 Indicative maximum recycled plastic content

Table 30 provides an estimate for the maximum recycled content for fridges that can realistically be required in this moment. It is based on:

a- The Bill-of-Materials for the refrigerator freezer combi (COLD7) of Table 15.

b- 8757 thousand fridges reaching end-of-life in 2024 (section 2.1.5.7)

c- A separate collection rate for end-of-life fridges of 60% (section 2.1.5)

d- A complementary collection rate for end-of-life fridges of 18% (section 2.1.5)

e- 80% efficiency for recycling PS, PP and ABS from separately collected fridges

f- 4% efficiency for recycling PS, PP and ABS from complementary collected fridges

g- 0% recycling from fridges for PUR foam, PVC and other plastics.

Guide to the table:

- Row 1: material type mass share (%) in the BoM of Table 15.
- Row 2: corresponding material type mass (kg); total unit fridge mass is 62 kg.
- Row 3: multiplies the unit masses by 8757 fridges reaching EoL in 2024. The total EoL mass from fridges in 2024 in EU27 is 543 kton, of which 230 kton is plastic.
- Row 4: multiplies the EoL mass by the separate collection rate of 60%
- Row 5: multiplies the EoL mass by the complementary collection rate of 18%
- Row 6: total collected mass, sum of rows 4 and 5
- Row 7: share of separately collected mass that is recycled (80% for PS, PP, ABS)
- Row 8: share of complementary collected mass that is recycled (4% for PS, PP, ABS)
- Row 9: total recycled mass: row 4 x row 7 + row 5 x row 8
- Row 10: share of EoL mass that is recycled (row 9 divided by row 3)
- Row 11: share of collected mass that is recycled (row 9 divided by row 6)

Of the 230 kton EoL plastic mass from fridges in 2024, 79 kton (34%) is recycled. For PS, PP and ABS alone, the recycled share is 49% of the EoL mass, or 62% of the collected mass.

The share of 34% (recycled plastic mass vs EoL plastic mass) mainly depends on the separate collection rate (60%), the low recycling efficiency for complementary collection (4%), and the non-recyclability of polyurethane foam.

Increasing the separate collection rate is beyond the scope of this study. The (chemical) recycling of polyurethane depends on economic viability (section 4.2.3), which cannot be resolved in this study.

The share of 34% (recycled plastic mass vs EoL plastic mass) slightly depends on the BoM, even if the order of magnitude does not change. For the EIA BoM for combis (section 5.2.1), it would be 26% (due to a higher mass share for PUR), for the APPLiA BoM for fridges (section 5.2.2) 31%, and for the APPLiA BoM for freezers 36%.

These percentages correspond well to what was indicated by a recycler as a reasonable maximum for recycled plastic content of fridges: between 20% and 30%.

Table 30: Estimate for the maximum recycled plastic contents for fridges that can currently be required.

		PUR	PS	PP	ABS	Other Plastic	Ferro	Alu	Copper	Glass	Elec	Other	sum
BoM for Combi fridge (COLD 7) %		10.6%	25.3%	4.0%	0.5%	1.8%	43.9%	2.0%	1.3%	9.3%	0.5%	0.7%	100.0%
BoM for Combi fridge (COLD 7) (kg)		6.58	15.73	2.48	0.34	1.11	27.22	1.25	0.78	5.80	0.29	0.46	62.0
EoL mass 2024 (kton)		58	138	22	3	10	238	11	7	51	3	4	543
separate collection (kton)	60%	35	83	13	2	6	143	7	4	30	2	2	326
complementary collection (kton)	18%	10	25	4	1	2	43	2	1	9	0	1	98
total collection (kton)		45	107	17	2	8	186	9	5	40	2	3	424
share recycled for separate collection		0%	80%	80%	80%	0%	98%	90%	95%	75%	50%	0%	
share recycled for complementary collection		0%	4%	4%	4%	0%	98%	90%	95%	35%	25%	0%	
recycled material (kton)		0.0	67.1	10.6	1.4	0.0	182.2	7.7	5.1	26.0	0.9	0.0	301
recycled share of EoL mass		0%	49%	49%	49%	0%	76%	70%	74%	51%	35%	0%	55%
recycled share of collected		0%	62%	62%	62%	0%	98%	90%	95%	66%	44%	0%	71%
sum of plastics, EoL mass (kton)	230												
sum of plastics, recycled (kton)	79												
recycled share of plastic EoL mass	34%												

6.2.2 Metals

For base case COLD7 (refrigerator-freezer combi, representing 53% of annual fridge sales in the EU, section 2.1.2), metals represent 48.6% of the mass (sections 5.3 and 5.5). Most of this is ferrous metal (various types of steel and cast iron, 45.2%). Non-ferrous metals are 3.4% of the total fridge mass, split in 2.1% aluminium and 1.3% copper [345].

Various types of steel are used for the outer panels of body and doors, reinforcement bars and supports, hinges, screws and nuts, and in the hermetic compressor. Gray cast iron is used for the wire-on-tube condenser assembly and for the compressor.

Aluminium is used mainly in the evaporator of the cooling system, and some in the compressor.

Copper is used in various parts of the cooling system, and in the compressor. The latter includes the winding wire of the motor [345].

Copper and Aluminium are on the Critical Raw Materials list (section 1.5.5) and thus of special interest in this study.

For the baseline scenario it has been assumed that the recycled metal content in input to fridge manufacturing is 30% for ferrous metal and aluminium, and 37% for copper (see section 5.4.3).

During the stakeholder meeting following phase 1 of the present study, there seemed to be agreement that setting minimum recycled content requirements on metals is not useful. The recycling chain for metals is well established. The total amount of recycled metal traded in the EU is fixed, and if a higher use would be required for e.g. fridges, there would be less recycled metal available for other applications. Hence, such requirements were believed to not assist the recycling industry, resolve waste stream problems, or reduce environmental impacts. Consequently, setting minimum recycled content requirements on metals used in fridges has not been a study focus.

In a meeting with the study team, a specialist EU copper recycler [346] explained that copper is a scarcity market, where demand is higher than supply. The main issue would be to increase end-of-life collection rates and adequately regulate exports of copper scrap and recycled copper, so that the supply of recycled material can be increased. Setting minimum recycled content requirements for copper in e.g. fridges or electric motors was anyway judged positively by the recycler. The main questions would be at which percentage of recycled content, how this percentage would exactly be defined, and if the recycled copper would be available in sufficient quantities. They indicated that, to be meaningful, the required recycled content should be at least 60%, for pre- and post-consumer recycled content together (see also remarks in section 5.4.3 and footnotes in section 6.2.6). For comparison, the battery regulation [347], requires a recycled copper content of 85% from 2031 (sum of pre- and post-consumer recycled).

Table 31 shows the reduction in environmental impacts when increasing the recycled copper content from 37% (baseline) to 60%. The table shows the baseline impacts, the alternative impacts for R1=60%, and the difference between the two (savings). Three savings shares are

[345] Some additional copper is present in the electric cables and wiring, and in the printed circuit boards, but that is counted under electronics, not under metals.

[346] https://www.montanwerke-brixlegg.com/

[347] REGULATION (EU) 2023/1542 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC, OJ L 191/1, 28.7.2023

reported: compared to the baseline copper impacts, compared to the material and end-of-life impacts of the entire fridge, and compared to the material, end-of-life and lifetime electricity impacts of the entire fridge.

The reduction of copper impacts is 11.4%-13.8%, except for ‘ozone depletion’ and ‘ionising radiation’, where the reduction is -2.1% (recycling impact higher than virgin impact).

The reduction of fridge material and EoL impacts is less than 0.28%, except for ‘land use’ (13.8%) [348] and ‘resource use, minerals and metals’ (2.0%).

The reduction of fridge material & EoL & electricity impacts is less than 0.015%, except for ‘land use’ (5.7%) and ‘resource use, minerals and metals’ (1.7%).

Table 31: Summary of the reduction of environmental impacts, compared to the baseline, when using 60% instead of 37% recycled content in input to the production for copper, for base case COLD 7 (combi).

Copper	Virgin Mass in input [g]	Climate change, total [kg CO2 eq]	Ozone depletion [kg CFC-11 eq]	Human toxicity, cancer [CTUh]	Human toxicity, non-cancer [CTUh]	Particulate matter [disease incidence]	Ionising radiation, human health [kBq U235 eq]	Photo-chemical ozone formation, human health [kg NMVOC eq]	Acidifi-cation [mol H+ eq]
Baseline impact for Cu (R1=37%)	**491**	0.26	6.0E-12	1.5E-10	1.4E-09	6.3E-08	6.9E-03	1.2E-03	2.3E-03
Alt. impact for Cu (R1=60%)	**312**	0.23	6.1E-12	1.3E-10	1.3E-09	5.4E-08	7.1E-03	1.1E-03	2.0E-03
Cu impact savings	**179**	0.03	-1.3E-13	2.0E-11	1.6E-10	8.5E-09	-1.5E-04	1.6E-04	3.0E-04
Share savings on Cu impact	**36.5%**	12.4%	-2.1%	13.3%	11.4%	13.6%	-2.1%	13.0%	13.2%
Share saving on material & EoL impact of fridge		0.03%	0.00%	0.04%	0.01%	0.10%	0.00%	0.06%	0.08%
Share saving on material & EoL & electricity impact of fridge		0.0020%	0.0000%	0.0066%	0.0022%	0.0146%	0.0000%	0.0057%	0.0059%

Copper	Eutrophi-cation, terrestrial [mol N eq]	Eutrophi-cation, freshwater [kg P eq]	Eutrophi-cation, marine [kg N eq]	Ecotoxicity, freshwater [CTUe]	Land use [pt]	Water use [m3 water eq. of deprived water]	Resource use, minerals and metals [kg Sb eq]]	Resource use, fossils [MJ]
Baseline impact for Cu (R1=37%)	4.6E-03	1.2E-06	4.1E-04	2.1	4737	0.55	4.6E-04	3.2
Alt. impact for Cu (R1=60%)	4.0E-03	1.1E-06	3.6E-04	1.8	4083	0.47	4.0E-04	2.8
Cu impact savings	5.9E-04	1.6E-07	5.3E-05	0.3	654	0.07	6.3E-05	0.4
Share savings on Cu impact	12.8%	12.9%	12.8%	12.8%	13.8%	13.6%	13.8%	11.9%
Share saving on material & EoL impact of fridge	0.07%	0.02%	0.06%	0.02%	13.8%	0.28%	2.0%	0.02%
Share saving on material & EoL & electricity impact of fridge	0.0057%	0.0038%	0.0054%	0.0032%	5.7%	0.0135%	1.7%	0.0013%

[348] As also reported before, almost the entire land use impact for the fridge comes from copper. This should be verified.

6.2.3 Glass

For base case COLD7 (refrigerator-freezer combi, representing 53% of annual fridge sales in the EU, section 2.1.2), glass represents 9.6% of the mass (sections 5.3 and 5.5). Glass is mainly used for shelves and accessories inside the fridge. Other types of fridges, e.g. wine storage appliances, may have (partially) glass doors in addition.

Considering the relatively high mass share of glass in fridges, it could be worthwhile setting minimum recycled contents requirements, e.g.:

> By 1 January 2030, any fridge placed on the market shall contain at least X1% of recycled glass recovered from post-consumer waste.
>
> By 1 January 2033, any fridge placed on the market shall contain at least X2% of recycled glass recovered from post-consumer waste.
>
> The share shall be computed as the mass of post-consumer recycled glass contained in the product divided by the total glass mass contained in the fridge.

In the baseline scenario, 5% post-consumer recycled flat glass content has been assumed.

X1 could be set to 5%+10% = 15%

X2 could be set to 5% + 30% = 35%

Flat glass producers strongly aim at increasing the amount of post-consumer cullet in the input to their production, advocating a flat-to-flat glass closed recycling loop (section 4.3). However, flat glass from fridges plays only a minor role in this: most post-consumer flat glass waste comes from construction and demolition (windows, facades).

Vacuum Insulation Panels may contain glass fibre as core material, which is currently not being recycled. However, glass fibre is being produced from other waste glass. Including or excluding glass fibre in a recycled content requirement on glass in fridges needs further reflection.

6.2.4 Electronics

For base case COLD7 (refrigerator-freezer combi, representing 53% of annual fridge sales in the EU, section 2.1.2), electronics represents 0.5% of the mass (sections 5.3 and 5.5). This includes the main board, the UI board, power cable and electric wiring, and LED light source and supporting board.

Although the electronics mass share is low, the associated environmental impacts are relatively high (section 5.6), especially for the electronic boards, so the use of recycled materials or the re-use of components in input to the boards' production seems relevant.

Specifying recycled content requirements for <u>cables and electric wiring</u> of fridges does not seem useful: the environmental impacts are relatively low (section 5.6.5), and the contained copper would anyway be expected to have the generic average recycled content of 30-40% (section 5.4.3). Copper in cables and wiring could be part of a more general requirement on recycled content for copper (if set), see section 6.2.2.

<u>Electronic boards</u> are a collection of electronic components using various types of materials, often present in traces, mounted on a support structure. Compared to study phase 1, there is

no new information on the composition of electronic boards specific for fridges [349]. Table 32 shows the generic composition of low-grade PCBs that was used in phase 1. Applying these percentages to the overall mass of electronic boards for refrigerator-freezer combis of Table 15 (177 grams for main board and UI board together), the table indicates the resulting masses per material type.

The support structure accounts for 63% (111 g) of the board mass. Common PCB substrate materials include FR-4 (fiberglass-reinforced epoxy resin) [350], Polyimide [351], Rogers (polymer-ceramic composites) [352], Aluminium [353] [354]. Boards in fridges would be expected to use the most common and low-cost FR-4, a composite of fiberglass and epoxy resin, which cannot be recycled [355] [356] [357], except maybe in a closed-loop during bare board manufacturing [358].

Other relatively large mass fractions are for copper (20%, 35.4 g), iron (9.5%, 16.8 g), aluminium (6.0%, 10.6 g) and tin (0.9%, 1.6 g). For other metals, among which precious metals like gold, silver and palladium and critical raw materials, the boards contain fractions of grams, or fractions of milligrams. The materials Sb, Ba, Be, Co, Au, Ni, Pd, Ag, Sr and Bi together represent 0.24 % of the PCB mass. For the reference combi fridge with 177 g of PCBs this would mean that CRMs and SRMs are less than 0.4 grams per fridge.

Table 32: Assumed composition of electronic boards, not specific for fridges.

For 177 g boards	Sb	Al	Ba	Be	Co	Cu	Au	Fe	Sn	Pb	Cr	Ni
Low-grade PCB	0.10%	6.0%	0.007%	0.0001%	0.0020%	20.0%	0.0053%	9.5%	0.9%	0.2%	0.2%	0.1%
Mass in grams	0.177	10.6	0.012	0.18E-03	3.5E-03	35.4	9.4E-03	16.8	1.59	0.354	0.354	0.177

	Pd	Ag	Zn	Sr	Bi	support
Low-grade PCB	0.002%	0.005%	0.2%	0.0026%	0.0132%	62.76%
Mass in grams	3.5E-03	8.9E-03	0.354	4.6E-03	0.023	111

[349] For the main board, Electrolux did supply to the study team the outcomes of their in-house LCA, based on the sum of impacts of all the components and of the bare board. Comparison with the ERT datasets lead to the choice of ERT dataset 164 for the boards.

[350] FR4 is a type of substrate material commonly used in the manufacture of printed circuit boards. It is made from a composite of fiberglass and epoxy resin, which gives it high mechanical strength and electrical insulation properties.

[351] Polyimide PCB is used in flexible printed circuit boards (Flex-PCBs). It is a popular choice for Flex-PCBs due to its combination of high temperature resistance, chemical resistance, flexibility, lightweight, and improved electrical performance.

[352] Rogers PCB material is made from a combination of polymer and ceramic materials, which gives it unique electrical and thermal properties compared to other PCB substrate materials. It is commonly used in high-frequency, high-performance electronic applications such as microwave and millimetre wave circuits, and is widely recognized for its consistent quality and reliability.

[353] Metal-core PCBs (MCPCBs) are a type of printed circuit board that use a metal base material, such as aluminium or copper, as the substrate instead of a traditional insulating material like fiberglass or plastic. The metal core provides improved thermal conductivity compared to conventional PCBs, making it suitable for applications that generate a lot of heat, such as power electronics or high-power LED lighting.

[354] https://www.pentalogix.com/blog/2023/02/22/materials-used-in-printed-circuit-board-substrates/#:~:text=They%20are%20typically%20made%20of,Polyimide

[355] https://www.sellectronics.co.uk/blog/are-printed-circuit-boards-recyclable/#:~:text=The%20FR4%20epoxy%20glass%20laminate,each%20PCB%20are%20usually%20small.

[356] https://www.newburyelectronics.co.uk/news/can-printed-circuit-boards-be-reused-or-recycled/#:~:text=Recycling%20a%20Populated%20Printed%20Circuit,recycled%20back%20to%20its%20constituents.

[357] https://www.tclelektronika.com/news/214/How-to-recycle-waste-PCBs-and-what-you-need-to-know/#:~:text=PRO%3A%20For%20this%20process%2C%20it,such%20as%20lead%20and%20dioxin.

[358] https://fr4material.com/index.php/the-recyclability-and-reusability-of-fr4-fiber-glass-boards/#:~:text=FR4%20components%20can%20be%20efficiently,aligning%20with%20sustainable%20production%20practices.

For recycling of electronic boards, the 2024 EcoReportTool (ERT) gives benefits for avoided use of virgin material, only for copper, gold, palladium, platinum and silver. Hence, for electronics, the recycling benefit is not related to avoided virgin boards, but to avoided virgin Cu, Au, Pd, Pt and Ag (section 5.4.1). These are precious metals for which recycling is most easily economically viable. In addition, these metals (and potentially others) are typically processed together during the recycling of copper [359] [360].

The recycling credits are defined in the ERT as mass shares (kg/kg). The values for controller boards [361] and 2-layer printed wiring boards differ (Table 33), and they differ also from the values for low-grade PCBs reported above, indicating the uncertainty in electronic board composition, and the need to use accurate datasets and masses in the ERT.

Table 33: End-of-Life benefit shares (mass shares) for avoided virgin Cu, Au, Pd, Pt and Ag due to recycling of electronic boards (2024 EcoReportTool).

	credit copper	credit gold	credit palladium	credit platinum	credit silver
Controller board (set 141)	29%	0.072%	0	0	4.2%
Printed wiring board 2-layer (set 164)	9%	0.005%	3.5E-5%	0	0
Low-grade PCBs (from Table 32), for comparison	20%	0.0053%	0.002%	-	0.005%

In the ERT calculation of environmental impacts for electronics (section 5.6.5), the boards were assessed using datasets 164 (V) and 195 (R) for a 2-layer PWB, total 177 g.

As far as feasible, the ERT calculation has also been performed using the sum of impacts for the individual board materials, using the percentual mass breakdown of Table 32, and the same CFF factors as used in the original analysis, e.g. R1=0%, R2=52% and A=50%. The support structure has been modelled as 70% epoxy resin (dataset 4) and 30% glass fibre (dataset 222). The ERT has no datasets for baryte, beryllium and bismuth, but they represent only 0.02% of the board mass. In addition, there is no recycled material dataset for Fe, Cr, Sr, epoxy resin and glass fibre (Table 34).

The results show that, for all except 2 impact categories, the original impacts are from 2.1 to 58 times (average 11 times) higher than the sum of impacts from the materials. The exceptions are 'ozone depletion' and 'land use', where the ratio of original impact vs sum of material impacts is respectively 0.03 and -0.09 [362].

Although this comparison is very rough and uncertain, it seems to indicate that for most environmental impact parameters the largest part of the electronic board impacts come from board and component manufacturing / assembly / transportation, and not from the raw materials? The former impacts are presumably included in the original ERT impacts of dataset 164, while they are not included in the sum of material impacts. Board and component manufacturing / assembly / transportation impacts would be the same for virgin and recycled

[359] Copper serves as a „carrier metal" for a wide range of other non-ferrous metals. Copper refining and recycling are therefore essential processes for recovering valuable and critical metals. Modern recyclers can recover more than 20 valuable metals, including gold, silver, tin, cobalt, and platinum group metals (PGM) from complex copper products. As a result, copper metallurgy is the preferred method for recycling electronic waste and other complex products. https://kupfer.de/wp-content/uploads/2024/10/2024_Factsheet_Recycling_EN.pdf

[360] Personal communications from a fridge recycler and a copper recycler to the study team.

[361] In the last version of the EcoReportTool analysis, datasets for controller board are no longer used: main board and UI board are now both represented by the datasets for a 2-layer PWB, see notes following Table 15.

[362] The ozone depletion comes entirely from the epoxy resin and the glass fibre of the support structure. The land use impact comes entirely from copper (see also earlier remarks).

materials [363]. If this is true, substituting a part of virgin board and component materials by recycled materials could only have a limited effect on the total electronic board impacts.

As mentioned above, the support structure represents 63% of the electronic board mass. On average this mass (assumed epoxy resin and glass fibre) causes 46% of the environmental impacts in the ERT calculation using the sum of impacts for the individual board materials. Peak support structure impact shares are 100% for ozone depletion, 97% for freshwater eutrophication, 93% for human toxicity cancer, and 75% for freshwater ecotoxicity. Support structure impacts are low for land use (0%, all from copper) and resource use minerals and metals (1%, mainly from Gold, Copper and Antimony). In the current boards recycling practice, the support structure materials typically are lost (in chemical recycling) or incinerated (for heat recovery). This further limits the environmental effects of recycled metal contents in the boards.

The reduction of impacts when assuming 10% recycled content for the boards is 5% (versus baseline board impacts) for nearly all impact categories when using the ERT datasets 164 and 195 for 2-layer PWBs. When using the sum of material impacts, the reduction varies from 0% (for ‘ozone depletion’) to 6.7% (for ‘land use’ and ‘resource use, minerals and metals’).

A recycler stated to the study team that the most important aspect in materials recycling, and in electronics recycling in particular, is economic viability. For metals different from the precious Cu, Au, Pd, Pt, Ag, this is still a problem. This should be resolved first, before setting minimum recycled content requirements on electronics.

For precious and critical raw materials, it is usually not feasible to trace where recycled materials come from because there are too many collection-, transportation-, sorting-, separation- and refining-steps. It would be impossible to distinguish between pre- and post-consumer recycled material.

The re-use of entire boards or of their components (resistances, diodes, capacitors, ICs, etc.) is generally not economically viable.

Fridge electronic boards will on average be 16 years old when they reach end-of-life. In the meantime, the controls, user interfaces and lights used in the fridges will have evolved, and new features requiring electronics have likely been added. Dimensions and interfaces of the boards in new designs may have changed.

The boards and components easily get damaged during EoL processing and thus would require retesting and refurbishment. Considering that the components have already been functioning for 16 years, expected future reliability will also be an issue.

For components, removing them from EoL boards is too labour intensive to be economically competitive with the manufacturing of new components. In addition, board manufacturing processes would typically require any recovered components to be mounted on tapes or reels, and that is too costly.

[363] Depending on what the ERT datasets for the materials exactly cover, there might be additional processes (before the actual board or components manufacturing) that are necessary for the virgin materials while they are avoided for the recycled materials.

Indicatively, recycled material content requirements on electronic boards seem to have limited environmental benefits, but this is uncertain. In addition, costs for the manufacturers to document and certify recycled content (traceability) and costs for market surveillance to verify recycled content claims seem relevant. Except for the precious metals, availability of recycled material can also be an issue. If recycled materials have lower costs, manufacturers will not need legislative requirements to increase the recycled content. For critical raw materials, higher recycled content would be necessary mainly to reduce the supply risk.

Taking all factors together, for the moment no requirements are proposed for the recycled material content of electronic parts in fridges.

Table 34: Assumed Bill of Materials for the main fridge electronic board for impact calculations in the EcoReportTool using the sum of material impacts (the same data apply to the UI board, but with different masses)

Component	Mass kg	Virgin material dataset	Recycled material dataset	R1 (BaU)	R2	A
Antimony (Sb)	0.00012100	54-Antimony technology mix, primary production production mix, at plant 99.5% Antimony	104-Antimony, recycled (post consumer, from lead acid batteries)	0%	52%	50%
Aluminium (Al)	0.00724633	52-Aluminium ingot mix (high purity) primary production, aluminium casting single route, at plant 2.7 g/cm3, >99% Al	123-Recycling of aluminium into aluminium ingot - from post-consumer collection, transport, pretreatment, remelting production mix, at plant aluminium waste, efficiency 90%	0%	52%	50%
Baryte (Ba)	0.00000820					
Beryllium (Be)	0.00000012					
Cobalt (Co)	0.00000239	60-Cobalt hydro- and pyrometallurgical processes production mix, at plant >99% Co	105-Cobalt, recycled (4,77 kg Co-Sulphate heptahydrate as 1 kg Co-Metal content)	0%	52%	50%
Copper (Cu)	0.02420000	61-Copper Concentrate (Mining, mix technologies); copper ore mining and processing; single route, at plant; Copper - gold - silver - concentrate (28% Cu; 22.3 Au gpt; 37.3 Ag gpt)	124-Recycling of copper from clean scrap; collection, transport, pretreatment; production mix, at plant; copper content in input scrap 90%, copper losses 1%	0%	52%	50%
Gold (Au)	0.00000643	75-Gold (primary route) primary route, underground mining and leaching production mix, at plant 19.32 g/cm3	102-Gold, recycled, pre-consumer collection, transport, dismantling, shredding, separation, remelting production mix, at plant 19.32 g/cm3, recycling efficiency 98%	0%	52%	50%
Ferro (Fe)	0.01148475	68-Ferrite (iron ore) iron ore mining and processing production mix, at plant 5.00 g/cm3	not available	0%	52%	50%
Tin (Sn)	0.00108695	94-Tin sand extraction and processing, reduction production mix, at plant 118.71 g/mol	113-Tin, recycled (re-refined, from electronic scrap)	0%	52%	50%
Lead (Pb)	0.00024200	76-Lead (primary) primary production, mining and processing production mix, at plant 11.3 g/cm3	125-Secondary lead secondary production, melting of lead scrap single route, at plant 11.3 g/cm3	0%	52%	50%

Component	Mass kg	Virgin material dataset	Recycled material dataset	R1 (BaU)	R2	A
Chromium (Cr)	0.00024200	278-Chromium oxide production; technology mix; production mix, at plant; 100% active substance	not available	0%	52%	50%
Nickel (Ni)	0.00012100	80-Nickel mining and processing production mix, at plant 8.9 g/cm3, update available	110-Nickel, recycled (4,48 kg Ni-Sulphate hexahydrate represent 1 kg Ni-Content)	0%	52%	50%
Palladium (Pd)	0.00000239	81-Palladium primary production, mining and processing production mix, at plant 11.99 g/cm3	103-Palladium, recycled, post-consumer collection, transport, dismantling, shredding, separation, remelting production mix, at plant 11.99 g/cm3	0%	52%	50%
Silver (Ag)	0.00000608	84-Silver mining, concentration, roasting, refining production mix, at plant 10.49 g/cm3	127-Silver, recycled technology mix production mix, at plant 10.49 g/cm3	0%	52%	50%
Zinc (Zn)	0.00024200	98-Zinc technology mix, primary production consumption mix, to consumer 7.14 g/cm3	114-Zinc, recycled (post-consumer, refining of EAF dust)	0%	52%	50%
Strontium (Sr)	0.00000314	285-Strontium chromate; From sodium dichromate from acidification of sodium chromate; at plant	not available	0%	52%	50%
Bismuth	0.00001572					
Support, epoxy resin	0.05311695	4-Epoxy plastic polymerisation of liquid epoxy resins with a latent hardener (amine) production mix, at plant petrochemical based	not available	0%	52%	50%
Support, glass fibre	0.02276441	222-glass fiber technology mix production mix, at plant 1 kg	not available	0%	52%	50%

6.2.5 Other

Recycled content requirements for e.g. adhesives, refrigerants, lubrication oil and foam blowing agent have not been studied.

6.2.6 Verification of recycled material content

The ESPR introduces a Digital Product Passport (DPP, section 1.5.4). Depending on the chosen type of recycled content requirements (see section 6.2.1.4), fridge manufacturers can declare in the DPP e.g.:

- The total mass of the fridge as sold, excluding packaging.
- The total plastic mass and recycled share present in the fridge.
- The mass and recycled share for each type of plastic present in the fridge.

- Evidence to support the recycled share.

Similar to article 29.2 of the CRM Act (section 1.5.5) and articles 7.6-7.13 of the PPWR (section 1.5.8), the Commission shall establish rules for the calculation and verification of the recycled content. Such rules should ideally be published at the same time as the reviewed ecodesign regulation for fridges, around 2028. It is beyond the scope of this mini preparatory study to develop such rules [364] [365].

6.3. Design options for recyclability

6.3.1 Introduction

To increase the amount of material recycled from end-of-life fridges, the most important factor is the separate collection rate, here intended as the mass share of fridges reaching EoL that is collected, and possibly pre-sorted and pre-processed, in dedicated, well-organized schemes, usually set up by manufacturers or by third parties for them. As shown in section 2.1.5, the separate collection rate for fridges is estimated to be around 60%, with an additional 18% of complementary collection (with a lower recycling efficiency). Increasing the collection rate is outside of the scope of this study.

Another factor is the recycling rate, i.e. the share of collected fridge waste that leaves the recycling plant(s) as ready-to-use recycled material. The removal and sorting of fridge components before shredding is relevant for the recycling rate, although separation of material types after shredding seems to work quite well, and recycling rates for many materials in fridges are already high in the baseline scenario. Aspects of this are discussed below.

6.3.2 Recycler practice

The WEEE directive prescribes the removal before shredding and the separate treatment of certain types of components and materials (section 1.5.6).

For the rest, the decision on separation before shredding is made by recyclers mainly on economic grounds. If a component or material is valuable and easy to access and separate, this will be done, otherwise it will be shredded together with the rest, and the materials will be recovered from post-shredder separation processes as far as possible.

Another reason to choose separation before shredding can be that the component (potentially) causes problems in the shredder (e.g. high-energy Li-ion batteries increasingly found in fridges can cause fires in the shredder).

Separation before shredding is useful especially if the separated components or materials are subsequently sent to a specialist recycler, e.g. for capacitors, hermetic compressors, glass, electronic boards. If the separated components must anyway be processed in-house,

[364] There are companies performing third-party certification of recycled content claims. See e.g. https://www.scsglobalservices.com/services/recycled-content-certification
SCS Certification Standard for Recycled Content SCS-103, version 8.0, May 2024

[365] https://www.wieland.com/en/content/download/18725/file/White-Paper-Recycled-Content-Wieland_01.2023.pdf :
Since the relevant standards for the definition of recycled content leave room for interpretation, further specifications must be made to enable a transparent and comparable product claim regarding the recycled content of semi-finished products made from copper and copper alloys.
This document specifies the method used by the Wieland Group for evaluating the recycled contents in their products. It is also proposed that this methodology be used as a guiding principle across the copper industry to foster comparability. The method follows the approach of EN 45557:2020 and applies the provisions of ISO 14021:2016 to the manufacture of semi-finished products.

additional parallel processing lines would be necessary, or the main processing lines would alternately have to process the different material types. As the common shredding and separation processes seem to work quite satisfactory, separation before shredding may not always be economically advantageous.

A major EU fridge recycler visited by the study team processes 80 fridges per hour in a continuous shift. In the 45 seconds per fridge, in the current situation, recyclers cannot scan labels, check online model information on structure, presence of valuable components and dismountability instructions, and then separate components accordingly. Recyclers handle the various models of EoL fridges by experience. There is no time to carefully unscrew components, preferably they are cut away. This is the case for example for the motor starting capacitor and for the hermetic compressor of fridges. Illustrative in this sense is the recommendation given by a recycler to position fridge electronic boards in a separate box on top of the fridge with a cover in plastic, thus allowing recyclers to use an axe to gain access and eliminating the need for screwdrivers or other tools. Similarly, a permanent magnet recycler explained to the study team that the magnet is not really being dismounted: the corner of the hard disk drive containing the magnet is simply cut away, and the entire corner enters the shredding, separation and refining processes.

Recyclers are also sceptic on the usefulness (for them) of information in the Digital Product Passports introduced by the ESPR (section 1.5.4). They do not have time to consult such information, and they also fear that it may be outdated by the time the fridge reaches EoL.

Notwithstanding the situation sketched above, recyclers anyway seem in favor of measures facilitating the identification and separation of components before shredding. The reason for this is probably that it increases their options for the future, and that it could increase the economic viability for further process automation.

6.3.3 Current recycling rates

Section 5.4.4 estimated the factors R2 (recycling output rate) of the CFF for use in the EcoReportTool baseline scenario. These factors are the combination of fridge collection rates and material recycling rates. Table 35 provides a summary.

For metals, recycling rates are already high. The overall amount of recyclate can only be increased by improving the collection of EoL fridges. Requirements to improve recyclability of metals from fridges do not seem necessary.

For PP, PS (HIPS and GPPS) and ABS, the recycling rate for separate collection is already high (80%) and mainly depends on the efficiency of separation processes after the shredding. The recycling rate for complementary collection is low, but uncertain (see sections 5.4.4 and 2.1.5.6). The overall amount of recyclate can mainly be increased by improving the separate collection of EoL fridges.

For other plastics, 10.9% of the 12.7% mass share is PUR foam, for which (chemical) recycling is currently not economically viable (section 4.2.3). In addition, the foam is part of a sandwich structure (see section 6.3.4.1), and not easily separable before shredding. The increased integration in the PUR of vacuum insulation panels could further complicate PUR recycling.

For glass, the recycling rate from fridges is uncertain, it could be higher than the estimated 70% (separate collection) and 35% (complementary collection). Glass parts are already separate components, or easily identifiable (see sections 6.3.4.2 and 6.3.4.3). For remarks on glass fibre used in vacuum insulation panels, see section 6.2.3.

For cables, the recycling rate is already high. For electronic boards, some improvement seems possible (see section 6.3.4.7).

The 0% recycling rate for other materials is somewhat misleading. Refrigerants are being separated before shredding and subsequently treated and used in acids production. Lubrication oil is also separately recovered and can be used for heat recovery. Blowing agents for the PUR foam are captured during shredding. Ammonia from low-noise adsorption-type fridges (not part of the reference BoM) is also being recovered.

Table 35: Collection rates for fridges and recycling rates for fridge materials

	Mass share in fridge	Separate collection rate	Complementary collection rate	Recycling rate for separate collection	Recycling rate for complementary collection	Recycling output rate (R2 of CFF)
PP, PS and ABS	27.9%	60%	18%	80%	4%	49%
Other plastics	12.7%			0%	0%	0%
Steel	45.2%			98%	98%	76%
Aluminium	2.1%			90%	90%	70%
Copper	1.3%			95%	95%	74%
Glass	9.6%			70%	35%	48%
PCBs and LEDs	0.3%			75%	37.5%	52%
Cables	0.2%			90%	45%	62%
Other materials	0.7%			0%	0%	0%

6.3.4 Fridge components' recyclability

6.3.4.1 Main structure, body and doors

For the reference refrigerator-freezer (section 5.3), 55% of the mass is in the walls, i.e. in the body and the door(s). A large part of this is a sandwich structure, typically made of steel sheet on the outside, a plastic (HIPS) inner liner, and rigid polyurethane (PUR) foam between them (with or without additional vacuum insulation panels). These materials are bonded to each other, which is essential for the structural strength and rigidity and for the thermal insulation. This structure is shredded, with subsequent separation processes recovering the steel, HIPS and PUR. Some PUR ends up in the steel or HIPS fractions, but this does not seem to cause recycling problems.

Requiring dismountability for the main fridge structure is undesirable considering the functions it must perform, and it would not significantly raise the recycling rate. Compared to shredding, dismounting would also be too costly for recyclers [366].

Regardless of the types of materials used in the main fridge structure, it will most likely be shredded anyway, so a marking of the material types does not seem useful. An exception could be a marking for the presence or not of vacuum insulation panels, and of the type of core material used for that panel, so that a recycler can identify products with potential shredding or separation problems. APPLiA voluntarily created such a label scheme and applies it as a mandatory code of conduct for its members [367]. Recyclers have stated to the study team that VIPs might be a problem for future recycling when the quantity increases. They are usually shredded together with the rest, although some recyclers try to separate. They might cause problems for future chemical recycling of PU on large scale.

[366] Following the 4th SH meeting of 1 July 2025, a stakeholder commented that 'requiring dismountability for the main fridge structure would benefit the recuperation of specific materials for recycling (eg. PUR)' and suggested to remove the functional and cost aspects.

[367] Personal communication of Electrolux to the study team & APPLiA answer to questions of 2025-04-04

The use of VIPs should not only consider their material and recycling impacts, but also their contribution to reduction of the lifetime electricity consumption of the fridge.

Blowing agents used for the PUR foam are recovered during shredding.

6.3.4.2 Transparent doors

The reference refrigerator-freezer does not have transparent doors (using glass or plastic), but there are fridge models that have such doors or partially transparent doors, e.g. wine storage appliances, but not only those. Fridges with transparent doors already have separate energy efficiency requirements in Ecodesign regulation 2019/2019.

Door hinges are among the components for which Ecodesign regulation 2019/2019 requires spare parts to be made available to professional repairers and end-users, meaning that the hinges are replaceable and thus that the doors are easily removable during fridge recycling. The same applies to the door handles and gaskets [368].

However, the transparent doors often combine the glass with a frame in metal or plastic, which might also contain PUR insulation foam, like the main fridge structure. The glass itself will typically be double or triple insulation glazing. For flat-to-flat glass recycling, the spacers between the glass layers need to be removed before culleting. The legislator could require that fridges with transparent doors be designed in such a way that the transparent material (glass or other) is easily separable from other door materials at end-of-life.

Ease of separation of glass or other transparent materials from doors could be an aspect to consider for a recyclability index.

6.3.4.3 Shelves, drawers, baskets and accessories

For the reference refrigerator-freezer (section 5.3), 20% of the mass are internal shelves, drawers, baskets and accessories such as egg tray, ice cube tray, butter box or bottle holder. These are typically mobile components that can be taken out of the fridge by users (e.g. for cleaning) and that are thus easily removable also at end-of-life. The components can be in glass, plastic (PP, GPPS, some ABS) or steel (e.g. coated steel wire shelves), or a mix of these [369]. Glass will typically be removed by the collector or recycler before shredding. For plastic and steel components, the recycler can choose whether to separate them or shred them with the rest of the fridge.

Recyclers will probably recognize the type of plastic from experience, but it could be useful to require a marking on the shelves, drawers, baskets and accessories that indicates the type of plastic, like what is done for packaging. However, it is not expected that this will significantly raise the recycling rates, and for economic reasons recyclers might anyway decide to not separate the types of plastic before shredding.

Aiming at recyclability, designers should avoid using a mix of different materials in the same component. In order not to obstruct functionality and innovation, the legislator should not forbid this, but it could be required to design for ease of separation of the material types used in a single component. This is an aspect that could be reflected in a recyclability index.

[368] If recyclers will really remove the doors before shredding will depend on economic considerations.

[369] Coated steel wire shelves and glass shelves can have a glued-on plastic border facing the user. The bottle shelf can use a mix of steel and plastic. A plastic drawer might use a handle in a different type of plastic.

6.3.4.4 Hermetic compressor

For the reference refrigerator-freezer (section 5.3), 11% of the mass is in the hermetic compressor. The WEEE has no requirement for selective treatment of hermetic compressors, and consequently not all fridge recyclers might remove them before shredding, but it seems economically advantageous to do so (and maybe they would also give problems in the shredder). Recycling of compressors was mostly done in Pakistan in a specialized company, but the Basel convention has banned export of WEEE to non-OECD countries from 01.01.2025. The compressors contain steel with a large Cu content that has no demand in the EU. Processing hermetic compressors in the EU would cost €200 / ton extra. The problem is under discussion (status January 2025). In the meantime, compressors are being stocked [370].

A requirement could be set that hermetic compressors have to be separated before shredding and processed separately. This could favor the recyclability of copper, aluminium and permanent ferrite magnets. However, for many recyclers this is probably already common practice, and if the compressors end up in common shredding, a large part of the copper and aluminium can be recovered anyway.

Permanent magnets are increasingly being used in the hermetic compressors of modern fridges. The CRM act in articles 28 and 29 (section 1.5.5) already foresees information and labelling requirements, and future recycled content requirements for products containing permanent magnets (above 0.2 kg).

Lubrication oil is removed from the hermetic compressor under the WEEE directive.

6.3.4.5 Cooling system

For the reference refrigerator-freezer (section 5.3), 10% of the mass (6.2 kg) is in the cooling system (excluding the compressor), of which 5.8 kg for metals. Ferrous metals are 3.9 kg, of which 3.6 kg cast iron for the wire-on-tube condenser. Aluminium is 1.2 kg (most in the evaporator) and copper 0.7 kg (in a heat exchanger and several smaller parts). Plastics are 0.3 kg.

Refrigerants (0.048 kg) are removed before shredding, and treated separately, as prescribed by the WEEE directive.

Some parts of the cooling system are external, e.g. the WOT condenser on the back or bottom of the fridge, but they do not seem to be removed before shredding. Other parts, like the evaporator, are inside the structure and more difficult to separate before shredding. For metals, the recycling rate from fridges is already high (section 6.3.3), and separation of ferrous metals, aluminium and copper after shredding works satisfactorily.

A recycler stated to the study team that there is no benefit in setting requirements on the ease of identifiability and removability of copper and aluminium parts. On the contrary, the ease of removing these parts would lead to more scavenging before and during the collection stage. Already now, many fridges arrive without refrigerant gas because people have cut off copper tubing for its value [371].

There is no significant benefit in setting recyclability requirements on the cooling system.

[370] Personal communication of a fridge recycler to the study team.

[371] CoolRec answers to follow-up questions, 14/3/2025

6.3.4.6 Internal air flow

For the reference refrigerator-freezer (section 5.3), 2% of the mass (1.1 kg) is in internal air flow components. This includes e.g. fans, housings, air flow ducts and outlet covers. The entire mass is listed on the BoM as plastic, most GPPS. This leaves some doubts on where fan motors and control electronics have been counted on the BoM, but associated masses are likely very small.

The number of fans per fridge varies. A manufacturer estimated that 40% of the fridges has two fans, 40% one fan, and 20% no fan. Some have two fans internally and one to assist cooling externally. Fan motors are 1-4 W and can be single speed or variable speed. The latter use a permanent magnet with ferrite or rubber compound magnets with ferrite powders.

Internal air flow components are integrated in the main structure. Considering the low masses and the low value of the components, it does not seem economically viable for recyclers to remove these components before shredding. There is no significant benefit in setting recyclability requirements on the internal (and external) air flow system.

Fans and related motors and control electronics are not on the list of components for which CR 2019/2019 requires spare parts availability (section 1.5.1). This could be considered for the ongoing review study.

6.3.4.7 Electrical and electronic components

For the reference refrigerator-freezer (section 5.3), 2% of the mass (1.1 kg) is in electrical and electronic components. However, 0.8 kg of this is listed on the BoM as various types of plastic (largest masses for PP and HIPS). The 'real' electronics is only 0.5% of the total fridge mass (0.302 kg), of which 0.177 kg for electronics boards, 0.110 kg for cables and wiring, and 0.015 kg for LEDs and their boards. The electronic components have a small mass share but a much higher share in environmental impacts (section 5.6.5).

Printed circuit boards

A fridge recycler stated to the study team that, one way or another, printed circuit boards are always recycled. Commercial and professional appliances have relatively large electronic boards, which are manually removed before shredding (especially when this is easily done), or hand-picked after pre-shredding. Household fridges have smaller boards which are not always easily accessible. These boards are typically shredded together with the rest of the appliance, ending up in the mixed plastic fraction. These boards (or more correctly, the flakes of these boards) are removed on water separation tables. In all three instances, the circuit boards will end up in special smelters like Umicore, Boliden and their likes.

The time necessary for a manual operation (dismantling as well as handpicking) is often independent of the size of the component. Therefore, manual operation is more likely to occur with bigger pieces than with smaller ones. With low value circuit boards, as used in refrigerators, that tipping point is determined by the size of the board and the ease of access.

Ease of removability would change the above-mentioned tipping point, and lead to more separation before shredding, but the impact on the economy and on environmental impacts would be limited, as the boards are already being recycled. However, there is a different reason to require ease of removability, and that is the fact that fridge recyclers increasingly see high-energy (Li-ion) batteries on these boards. These batteries can cause fires in the shredders; a risk that could be avoided if these boards are easy to remove.

The fridge recycler suggested that:

- boards larger than 10cm² and boards containing batteries or wet capacitors should be easily removable[372].
- these boards should preferably be located in a box on the top of the fridge (Figure 31)
- if this is not possible, the box should be marked in such a way that it is easily recognizable from 2-meter distance, using a standardized marking.
- the cover to access the circuit board should be made from plastic (allowing recyclers to use an axe to gain access, eliminating the need for screwdrivers or other tools).

In the context of the Circular Foam project (section 4.2.3), it has been suggested that, to achieve higher recyclability for printed circuit boards in fridges, it would be worth considering changing their plastic board materials to any of the four types of plastics that are recycled from fridges today, if feasible from a functional and safety point of view. As the environmental impact of the board structure is a high share of the total board impact (section 6.2.4) this seems relevant to explore, but further study would be required to check if such technology exists. In this moment, a requirement in this sense cannot be set.

Figure 31: Example of a side-by-side fridge model with electronic boards easily accessible on top of the fridge

Printed circuit boards are among the components in Ecodesign regulation 2019/2019 for which manufacturers shall make spare parts and replacement instructions available to professional repairers. This implies that the boards are accessible and can be removed, but as explained above, it may not be economically viable for recyclers to do so.

A removability requirement like the one suggested by the recycler is recommended, but reflection is needed on how this can be phrased in a regulation. Such a requirement would be

[372] The WEEE directive already requires printed circuit boards greater than 10 square centimetres to be removed (section 1.5.6), but the suggestion of the recycler is to add boards containing batteries or wet capacitors

mainly for safety reasons and to facilitate separating the batteries, but with limited expected gains in recycling rate and environmental impacts.

Cables and electric wiring

External cables are already being removed by fridge recyclers before shredding, as this is prescribed by the WEEE directive (section 1.5.6) [373]. Typically, the cables are sent to specialized processors that recycle the plastic sheathing and the copper.

Internal electric wiring is not removed before shredding, because it is not economically worthwhile for recyclers to do so. They are shredded together with the rest of the fridge, and the copper is recovered from post-shredder separation processes.

There is no significant benefit in setting recyclability requirements on cables and electric wiring.

LEDs

The WEEE directive (section 1.5.6) prescribes that gas discharge lamps shall be removed before shredding and treated separately. Most modern fridges use LED light sources, which are not specifically mentioned in the WEEE directive.

The reference refrigerator-freezer uses 9 LEDs that are mounted on 3 supporting boards of 16 cm2 each. Other models may use different numbers of LEDs and different board sizes, or plug-in or screw-in LED lamps. Top-of-the-range models might use OLED lighting. The WEEE directive requires printed circuit boards greater than 10 cm2 to be removed before shredding.

Printed circuit boards and light sources are among the components in Ecodesign regulation 2019/2019 for which manufacturers shall make spare parts and replacement instructions available to professional repairers. This implies that the boards and light sources are accessible and can be removed, but as explained above, it may not be economically viable for recyclers to do so (see above under printed circuit boards).

It does not seem feasible for recyclers to remove the LEDs from the boards and collect them for separate processing. For the entire boards containing the LEDs, requirements similar to the ones for all PCBs could be set (see above), although in this case positioning the boards in a box on top of the fridge would not be functional.

Capacitors

The WEEE directive (section 1.5.6) prescribes that electrolyte capacitors containing substances of concern (height > 25 mm, diameter > 25 mm or proportionately similar volume), and capacitors containing polychlorinated biphenyls (PCBs) shall be removed before shredding and treated separately. Starting capacitors for the hermetic compressor can fall into this category, and they are indeed being removed by fridge recyclers.

Single phase induction motors used in fridges need capacitors for starting (and some use them also for running). The capacitors are usually electrolytic, and the older ones can contain polychlorinated biphenyls (PCBs). PCBs were banned in Europe in 1987, so by now, very few fridges should arrive to recyclers with PCB containing capacitors.

Electrolytic capacitors can contain CRMs depending on the type: aluminium, tantalum, niobium, manganese oxide or titanium oxide, silver, graphite. Other materials can include

[373] In practice, not all recyclers may remove them. In that case, they are shredded with the rest of the fridge and the copper is recovered after subsequent separation processes.

paper, rubber, electrolyte e.g. ethylene glycol (EG) or γ-butyrolactone (GBL). For motor starting, aluminium electrolytic capacitors with non-solid electrolyte seem to be most frequently used.

With the increased use of variable speed drives and permanent magnet motors, the need for motor starting capacitors is decreasing.

Other, smaller, capacitors can be on the printed circuit boards and will be processed together with them.

There is no need for additional recyclability requirements for capacitors from fridges.

Displays

The reference refrigerator-freezer has a relatively simple user interface, which appears on the BoM as a UI-board of 22 x 3 cm (66 cm2), a UI-cable, and two plastic parts in ABS and PC. Other fridge models may have (much) larger user-interface displays, possibly touch-screen type. Modern fridges will use LED or OLED displays.

The WEEE directive (section 1.5.6) prescribes that liquid crystal displays (together with their casing where appropriate) of a surface greater than 100 cm2 shall be removed before shredding.

Printed circuit boards are among the components in Ecodesign regulation 2019/2019 for which manufacturers shall make spare parts and replacement instructions available to professional repairers (see earlier remarks on PCBs). Displays are not explicitly mentioned, while they can contain materials interesting for recycling, such as Indium, Tin, Phosphorous and Arsenic.

The existing requirements in the WEEE directive and CR 2019/2019 seem sufficient.

6.3.4.8 Other components

For the reference refrigerator-freezer (section 5.3), 0.7% of the mass (0.42 kg) is in other components. Of this, 0.23 kg are adhesives used in the fridge body and doors, 0.14 kg is lubrication oil from the compressor, and 0.05 kg is refrigerant for the cooling circuit.

In addition, the reference refrigerator-freezer contains 0.28 kg of foam blowing agent, but this mass is counted, together with isocyanate and polyol, as part of the PUR foam mass, under plastics.

The WEEE directive (section 1.5.6) prescribes that equipment containing gases that are ozone depleting or have a global warming potential (GWP) above 15, such as those contained in foams and refrigeration circuits must be properly extracted and properly treated. Ozone-depleting gases must be treated in accordance with Regulation (EC) No 1005/2009.

The WEEE directive also prescribes that hydrocarbons (such as lubrication oil) shall be removed before shredding.

Refrigerant

Modern fridges use isobutane R600A as refrigerant, with GWP < 15 and low ODP [374]. Older fridges arriving at recyclers may still contain refrigerants with CFC (F-gases). Recyclers empty the cooling circuit before shredding and collect the refrigerant. Refrigerants can be pre-

[374] The EcoReportTool uses 2.3 kgCO2eq/kg R600A for climate change and 1.8E-10 kgCFC11eq/kg R600A for ozone depletion.

processed by the fridge recycler and then sent to a specialist recycler, which can use them e.g. in acid production.

Recyclers do not have time to check which type of refrigerant is in a fridge: all types are collected together. A small share of the fridges arrives to recyclers with an empty cooling circuit, e.g. due to damage during collection and transportation. This share could not be quantified.

Ammonia [375] [376] from absorption fridges (e.g. low-noise models) requires dedicated recycling facilities with additional protective measures, but it is being recovered.

Although the analyses use a recycling output rate R2 of zero, near 100% of all collected refrigerant is being recovered from fridges, but it does not seem to be re-used as refrigerant. A part of the refrigerant may end up incinerated with heat recovery.

It could be considered to require a label indicating the type of refrigerant being used in the fridge, clearly visible from a distance during the recycling process. This would open the possibility to separately collect and re-use isobutane R600A in future. Considering the low refrigerant mass per fridge, it would have to be verified if this is economically viable.

Lubrication oil

Lubrication oil (containing hydrocarbons) is removed from the hermetic compressor.

Although the analyses use a recycling output rate R2 of zero, nearly 100% of all collected lubrication oil is being recovered from fridges. As oils degrade during use (compare motor oils that are regularly substituted), direct re-use does not seem feasible. The oils are processed by specialized recyclers. A part of the oils may end up incinerated with heat recovery.

No recyclability requirements are recommended for lubrication oil.

Foam blowing agent

PUR foam from recent fridges contains blowing agent cyclopentane. APPLiA reported that approximately 20% of the old appliances coming back as WEEE today still contain CFCs at the end of life [377]. The blowing agents are recovered during shredding (all types together), as prescribed by the WEEE directive for ozone depleting gases.

No recyclability requirements are recommended for foam blowing agents.

[375] The EcoReportTool uses 2.1 kgCO2eq/kg NH3 for climate change and 3.2E-10 kgCFC11eq/kg NH3 for ozone depletion.

[376] Ammonia is not used in the reference refrigerator-freezer

[377] APPLiA input to priority products under ED study on ReCo and CRM, 2024-09-13, Refrigerators, Q6: Where are we with research on the recycling of polyurethane? Processes, costs, feasibility, already in practice? Can polyurethane insulation be separated during dismantling?

6.3.5 Additives and fillers in plastics

Almost all plastics contain additives and fillers for functional reasons. Examples include [378] [379] [380]:

- Stabilizers (heat stabilizers, antioxidants, anti-aging, UV absorbers [381])
- Processing aids (plasticizers, lubricants, hardeners)
- Fillers [382]
- Coupling agents (improve interfacial properties between filler and polymer material).
- Cross-linking agents (mainly used in rubber and thermosetting resins)
- Foaming agents (such as for the PUR foam of fridges)
- Nucleating Agents (accelerate the crystallization rate, increase the density of crystallization, and promote finer crystal grain size)
- Colorants (Inorganic or organic pigments)
- Antimicrobials
- Flame retardant [383]
- Anti-static agents (avoid the accumulation of static electricity caused by friction)
- Anti-stick (anti-block, anti-clumping, anti-caking, slippery additives) [384]
- Optical: transparency, anti-fog, bleaching
- Biodegradability [385]
- Additives to increase porosity
- Deodorants / Odor-removing additives

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[378] Plastic Additives Complete Guide(2025), https://www.immould.com/plastic-additives/

[379] https://sunrisecolour.com/what-are-plastic-additives-l-en?l=en

[380] https://europlas.com.vn/en-US/blog-1/recycled-abs-plastic-recycling-code-process-advantages-and-disadvantages

[381] E.g. Hindering Amine Light Stabilizer (HALS). They do not absorb UV but work by reacting with free radicals (which cause polymer breakdown)

[382] Common fillers include inorganic materials like graphite, calcium carbonate, and aluminates, as well as natural organic fillers like wood flour, coconut shell powder, and cotton.

[383] The additives that slow down the burning performance of plastics are called flame retardants, and most of the plastics containing flame retardants are self-extinguishing or have the effect of slowing down the burning rate.

The principle of flame retardant used in plastics can be roughly divided into three kinds:

• Reactive type flame retardant can react with oxygen to form an inert gas, shrouded in the burning material around, reducing the oxygen content of the burning material, in order to achieve the purpose of terminating combustion. Where the combustion can produce CO, CO2, NH3 and halogen compounds, such as PVC, PU foam, polyester or epoxy resin are selected for this method.

• Non-reactive type of flame retardant is containing halogen, phosphorus, nitrogen or boron compounds. When combustion occurs, it can decompose a kind of inert material, phi cover in the surface of the plastic combustion material, forming a layer of obstacles to isolate the outside world of oxygen, to achieve the purpose of flame retardant.

Water-containing oxides such as alumina flame retardant encountered when burning, can release water, absorb the heat of the combustion process. So that the temperature around the burning material to inhibit the spread of flame, to prevent the formation of smoke.

[384] E.g. Diatomaceous earth, Talc, Calcium carbonate (CaCO3), Synthesis of silicas and silicates

[385] The complete decomposition of plastic will take a long time, which is an alarming environmental problem today. A decomposition additive controls the breakdown and turns the plastic at the end of the cycle into a material with a completely different molecular structure. This structure is capable of breaking down into simple molecules such as: CO2, H2O, CH4, inorganic compounds or biomass. E.g. Reverte additives

- Desiccants
- Fiber reinforcements

Fossil fuels are the raw material that makes plastic, and more than 13,000 chemicals are added to change durability, flexibility, color, UV-protection and more. Roughly 3,200 of those chemicals are considered a concern for human health, and an additional 6,000 have never been screened, according to a report from the United Nations Environment Program [386]. It is estimated that by 2050, 2 billion tons of chemical additives will have been used in plastic [387].

Plastic additives and fillers in fridges

A fridge manufacturer and a fridge recycler communicated to the study team that [388]:

- Flame retardants are found in fridges near high voltage parts, near or in the compressor, in the power supply cable and its plug. Some are still allowed; some have been banned. Brominated flame retardants may pollute material in the quantity banned by RoHS - thinking of future restrictions that may get stricter and stricter, they might contaminate plastics recycling [389].
- Some plastic parts contain glass fibre reinforcement [390].
- Talcum or calcium carbonate are used as fillers in polypropylene.
- Pigments and colorants use mainly titanium dioxide (for parts in white)
- Zinc stearate is used as releasing agent.
- During HIPS recycling (section 4.2.1), an impact modifier is added to replace part of the rubber phase that has been deteriorated. This additive is to reach the proper resistance to impact and to chemicals and does not hinder recycling.

  High-impact PS (HIPS) and general-purpose PS (GPPS) must be separated at the source (different qualities), or an impact modifier additive has to be added to re-create HIPS characteristics. For use in fridges, the impact modifier for PS is food contact approved [391].
- Fibers and fillers may have a negative impact on the future recycling. E.g. PP is recyclable if it is unfilled or with maximum 10% chalk, talcum, or fibre glass filler.
- During extrusion, melt filters are used to separate polymers with different melting points. Fast and high-pressure extrusion like for virgin plastics will degrade the polymers while recycling. This must be compensated by adding additives.

[386] Environmental Health News, Recycling plastics “extremely problematic” due to toxic chemical additives: Report, https://www.ehn.org/plastic-recycling-2660739413.html

[387] Chemicals of concern in plastics, https://www.dcceew.gov.au/environment/protection/chemicals-management/chemicals-of-concern-plastics

[388] Personal communications of Electrolux and CoolRec to the study team.

[389] In its 2025-04-04 answers, APPLiA stated: Each plastic around the compressor compartment which is in contact with PU foam must include flame retardants (IEC standard requirement), also PCB (printed circuit board) material includes flame retardants. Fiber reinforcements are rarely used. Talcum and chalk are added to PP, used for drawers. Glass fibre is often present in electronic board structures. It may also be used as core material in vacuum insulation panels and may then end up in PUR after shredding and separation. Titanium dioxide is used in pigments / colorants / masterbatch. Other additives: UV stabilisers for external plastic parts. Releasing agents. APPLiA does not see any consequences for recycling.

[390] It was not specified to which parts this applies.

[391] Recycled PS: Coolstar Plus has no additives and is suitable for injection moulding, extrusion and 3D filament. Coolstar Master is modified for higher impact strength and is also suitable for thin wall sheet extrusion.

Impact of additives and fillers on plastic recycling

Various sources signal the large quantity of chemicals added to plastics, and their potential harms to human health and to the environment [392]. This study cannot address the thousands of chemicals potentially present in plastics and assess their impact on recyclability. It is assumed that RoHS and REACH regulations already address the most dangerous substances and that these will no longer be present in currently manufactured fridges.

In addition, most of the plastics in fridges have to meet food contact material regulations (section 1.5.7), which have detailed limits for the migration of substances to food for a large number of additives and impurities.

Except for the presence of brominated flame retardants [393], and for the maximum 10% chalk, talcum, or fibre glass filler in polypropylene, fridge manufacturers and recyclers have not signalled recycling problems due to additives and fillers.

The WEEE directive already specifies that plastic containing brominated flame retardants have to be removed from any separately collected WEEE. Question remains how recyclers can recognize these parts and if they have time to identify and remove them. If not already addressed in other EU regulation, the review of the Ecodesign regulation on fridges could consider forbidding the use of halogenated flame retardants, and require a marking for plastics containing flame retardants, like the regulation for electronic displays [394] [395]. However, considering the limited number of parts to which this would apply, and their low mass, this might not be worthwhile for fridges.

In comments following the 4th SH meeting of 1 July 2025, chemical organizations have indicated that:

- According to the latest information available, sorting techniques are available for BFRs. In line with the new findings [396], over 95% of BFRs (including HFRs) can already be eliminated in WEEE plastics. Coupled with continued advancement in technologies and alternative to mechanical recycling processes, this shows solid improvements in the efficiency of BFRs extraction. It should also be noted that a shift away from HFRs would mean a shift to new plastics, whereas literature suggests that these new types of plastics are less stable in mechanical recycling streams.
- Forbidding the use of halogenated flame retardants and requiring a marking for plastics containing flame retardants should not be done without going through the mandated ESPR impact assessment, taking into account the latest data from recyclers, and what has been learned from the practical application of Ecodesign for electronic displays.

[392] See e.g. Hahladakis, J., et al. (2017). "An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling." Journal of Hazardous Materials, 344:179-199. https://foodpackagingforum.org/news/plastics-additives-and-recycling

[393] Brominated flame retardants (BFRs) are mixtures of man-made chemicals that are added to a wide variety of products, including for industrial use, to make them less flammable. They are used commonly in plastics, textiles and electrical/electronic equipment. In the European Union the use of certain BFRs is banned or restricted. Research and additional regulation development is ongoing, see e.g. https://www.efsa.europa.eu/en/topics/topic/brominated-flame-retardants#milestones

[394] The Ecodesign regulation 2019/2021 on electronic displays in Annex II.D.4 forbids the use of halogenated flame retardants in the enclosure and stand of electronic displays.

[395] The Ecodesign regulation 2019/2021 on electronic displays requires a marking. Annex II.D.2(a) requires plastic components heavier than 50 g to be marked by specifying the type of polymer. Point (b) requires that: Components containing flame retardants shall additionally be marked with the abbreviated term of the polymer followed by hyphen, then the symbol 'FR' followed by the code number of the flame retardant in parentheses. The marking on the enclosure and stand components shall be clearly visible and readable.

[396] https://www.consultdss.com/content-hub/bfr-impact-weee-plastics-recycling-report/

- While the ESPR is key to identify substances of concern that prevent recycling, any potential substance restrictions should be considered under EU Chemical Legislation (REACH, CLP, POPs, WFD/SCIP, WEEE, RoHS) to avoid unnecessary multiplication of regulatory initiatives.

Setting requirements on the amount and type of fillers or reinforcement fibres in fridge plastics (or specifically for PP) would need further study.

In comments on the 3rd stakeholder meeting, a recycler suggested to require a density higher than 1.2 g/cm3 (or 1.12 g/cm3?) for plastic parts containing fillers or additives that cause recycling problems. Such a density would facilitate their separation after shredding.

For coated plastics, see section 4.2.5 on recycling of coated ABS.

Plastic additives can have both positive and negative effects on recycling. Some additives can enhance the recyclability of plastics by improving their stability, compatibility, or processability. Additives can e.g. enhance the quality of recycled plastics, improve the compatibility between different types of plastic, or facilitate recycling of hard-to-recycle plastics [397].

There are several ways to reduce the impact of plastic additives on recycling, such as [397]:

- Designing for recycling: Choose plastic materials and additives compatible with each other and the recycling process. Use biodegradable or compostable additives [398], non-halogenated flame retardants, or easily removable pigments.
- Improving sorting and separation: Develop more efficient and accurate methods to separate different types of plastics and additives from each other and other contaminants. Use near-infrared spectroscopy, magnetic density separation, or enzymatic degradation.
- Enhancing recycling technologies: Develop more advanced and innovative techniques to process recycled plastics and additives without compromising their quality or performance. Use supercritical fluids, microwave heating, or nanocomposites.

Researchers of the Imperial College of London [399] recommend reducing the number of permissible additives for use in plastics. Simplifying and standardising the range of plastic additives would simplify and standardise the range of circulating plastic formulations, enabling a more circular economy for plastics. Representatives from academia and waste management companies have already indicated that this would enable more effective and efficient post-consumer processing and a closed-loop recycling system. These changes should focus in the first instance on those plastics used in the greatest bulk. These are polyethylene (PE) and polypropylene (PP), mostly from food packaging, and polyester (PET) from clothes.

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[397] Further details in https://phoenixplastics.com/plastic-additives-recycling/

[398] The Association of Plastic Recyclers does not agree with this: Plastic items, packages or film that contain Degradable Additives, Nutrients, and Supplements are not recyclable. A package containing degradable additives cannot be detected using commercially available technologies and will affect both the quality and yield of post-consumer recycled resin (PCR) when they perform as designed. Based on APR’s definition, Degradable Additives, Nutrients, and Supplements are now in the “RENDERS THE PACKAGE NON-RECYCLABLE” category in the APR Design® Guide. An item, package or film that contains ANY design feature that is considered non-recyclable renders the entire item, package or film Not Recyclable. The design guide gives detailed indications for packaging in PET, HDPE, PE and PP. https://plasticsrecycling.org/wp-content/uploads/2024/08/APR-Position-Degradable-Additives.pdf

[399] Imperial College London, Institute for Molecular Science and Engineering, Briefing Topic No 10 , November 2023, Addressing plastic additives – policy recommendations, Jason Hallett, Agi Brandt-Talbot, and Isabella von Holstein, doi.org/10.25561/105699, https://dspace.library.uu.nl/bitstream/handle/1874/436969/10_Addressing_plastic_additives_Nov_2023_policy_recommendations_URLs.pdf?sequence=2

6.3.6 Recyclability index

In the context of the Ecodesign preparatory study on photovoltaic panels and inverters, a recyclability index is being developed. The interim report of September 2024 presents a literature summary of various methods being used or proposed [400]. Some of the parameters that are being considered for a recyclability index are shown in Figure 32.

The ESPR [401] mentions the following design-for-recycling parameters:

- use of easily recyclable materials.
- safe, easy and non-destructive access to recyclable components and materials or components and materials containing hazardous substances.
- material composition and homogeneity.
- possibility for high-purity sorting.
- number of materials and components used.
- use of standard components.
- use of component and material coding standards for the identification of components and materials.
- number and complexity of processes and tools needed.
- ease of non-destructive disassembly and re-assembly.
- conditions for access to product data.
- conditions for access to or use of hardware and software needed.

Type	#	Parameter
Service-related Parameters	1	Information on presence (or absence) of substances of concern
	2	Dismantling information and condition for access
	3	Information on composition
	4	Information on CRMs and SRMs
Dismantling Related Parameters	5	# of steps for dismantling of priority parts (dismantling depth)
	6	Type of tools needed to dismantle priority parts
Material based parameters	7	Level of concentration of hazardous substances and other substances affecting the recycling process
	8	Selection of materials based on recyclability complexity
	9	Combination of materials used / homogeneity

Figure 32: Parameters considered for a recyclability index for photovoltaic panels and inverters

Reflecting on the applicability of these recyclability parameters to fridges, considering the recycler practices and fridge components' recyclability discussed in previous sections:

- Fridge collectors, (pre-)sorters and recyclers do not have the time to consult product information. They are sceptic on the usefulness (for them) of the Digital Product

[400] Interim Report, Technical support for the development of a recyclability index for photovoltaic products, September 2024, Viegand Maagøe, in collaboration with Universidad de Murcia and Centro Nacional de Energias Renovables (CENER), for the European Climate, Infrastructure and Environment Executive Agency (CINEA), https://www.pv-recyclability-index.eu/ .

[401] Ecodesign for Sustainable Products Regulation (Regulation (EU) 2024/178), see also section 1.5.4, Annex A (d)

Passport introduced by the ESPR. In the current fridge recycling practice, it is difficult to see how product information provision could increase recyclability.

- In the current fridge recycling practice, components are removed before shredding because legislation requires it, because components can potentially damage the recycling equipment, or because it is economically advantageous for the recycler (time necessary to remove a component versus its value). Recyclers prefer using shears, saws or axes, rather than screwdrivers. Dismantling is not a reverse assembly.

  20% of the fridge mass is in shelves, drawers, baskets and accessories which can easily be taken out of the fridge without any tools, but recyclers tend to just shred them together with the rest of the fridge (except for the glass).

  55% of the fridge mass is in the main structure (body and doors), and in practically all refrigerators and freezers this a non-dismantlable sandwich structure that is shredded as a whole.

  Shredding followed by separation techniques seems to work quite well, with high recycling rates for metals, PS, ABS and PP. For fridges, this raises doubts on how much recyclability could be increased by ease of dismantling.

- For printed circuit boards, light sources, user-interface displays and related electronics, ease of access and removability could make (some) difference.
- As regards the selection of materials for the ease of recycling, the main concerns are the rigid polyurethane foam, the use of glass fibres (e.g. in the core of vacuum insulation panels), which are currently not recyclable, and maybe the soft-PVC used for the door gaskets (in the reference COLD7 appliance).
- Combination of materials in a single component can be an issue for shelves, drawers, baskets and accessories, spacers in thermal insulating glazing, frames for transparent doors.

Altogether, the usefulness of a recyclability index for fridges seems limited but anyway deserves further reflection in the review study on fridge regulations, and discussion with stakeholders.

In comments following the 4th SH meeting of 1 July 2025, a major non-ferrous metal (CRM and precious metals) recycler suggested considering a compulsory dismantling manual, explaining amongst others where the parts containing CRMs are located and identified (which CRMs in which part) and that they are easily removable. The Digital Product Passport could be a tool to share this information.

6.4. Design options for CRMs

Critical and strategic raw materials present in fridges are listed in section 4.1.3.

Copper and aluminium are used mainly in the cooling circuit. They are shredded together with the rest of the fridge structure, separated and recycled. Increasing the amount of recycled Cu and Al depends mainly on fridge collection rates. Copper from power cables is also being recycled. See section 6.2.2 for remarks on recycled content requirements for copper.

Steel, cast iron, copper and aluminium parts of fridges can contain CRMs and SRMs as alloying elements, often in small quantities. These alloying elements remain in the recycled metal, as useful contribution to the metal properties, or as tolerated impurities. They are not separately recovered (except during copper recycling).

RF manufacturers indicated that variable speed compressors with permanent ferrite magnet motors are increasingly being used in fridges.

The small fan motors (1-4 W), for internal air circulation and/or assisting external heat dissipation, also use permanent ferrite magnet motors, or rubber compound magnets with ferrite powders.

For cooling generators, and for electric motors with permanent magnets, article 28 of the CRM Act (see section 1.5.5) already requires a labelling indicating whether those products incorporate one or more permanent magnets, and if so, whether those permanent magnets belong to any of the following types:

(i) neodymium-iron-boron;
(ii) samarium-cobalt;
(iii) aluminium-nickel-cobalt;
(iv) ferrite.

In future, there will also be a data carrier providing access to information on the weight, location and chemical composition of all individual permanent magnets included in the product, and on the presence and type of magnet coatings, glues and any additives used, and to information enabling access and safe removal of all permanent magnets incorporated in the product, at least including the sequence of all removal steps, tools or technologies required for the access and removal of the permanent magnet.

For the rest, CRMs and SRMs are found mainly in the electronic components of fridges: printed circuit boards, LED light sources, user-interface displays. In fridges, the economic value of these components is relatively low and consequently they are not always being removed before shredding. However, they are separated after shredding and delivered to companies specializing in their recycling. Ease of access and removability would probably not make much difference from a recycling point of view but could be important for recyclers to avoid potential damage to their equipment (see section 6.3.4.7).

Recyclers have stated that before setting recycled content requirements on CRMs, the economics of their recycling should be addressed [402]. For CRMs, distinguishing between pre-consumer and post-consumer recycled material could not be feasible [403].

A recycler noted to the study team that also Fluorspar is on the list of CRMs. Some recyclers send their refrigerants and blowing agents to the cracker of Daikin Refrigerants, where these

[402] In comments following the 4th SH meeting of 1 July 2025, a major non-ferrous metal recycler clarified that: In a complex mixture of several CRMs and precious metals, the recycling costs will be allocated mainly to the precious metals. The only costs that are allocated to the CRMs are the costs for refining of the intermediates containing those CRMs. If there are no precious metals in the waste stream, and all costs must be borne by the CRMs, it could be not economically viable. Therefore, it is a political decision which CRMs must be recycled. E.g. in the batteries regulation, the regulator has decided that Li, Co, Ni and Cu must be recycled, independently from their economic value. This is important for recyclers: given the price volatility of many CRMs, if recycling would only happen if the prices were high, the recycling industry will not emerge. And an emerging recycling industry for CRMs is needed because scale leverage effects will lower the recycling costs.

[403] For reasons of economy of scale, both types of input are processed together, while concentrating and refining processes typically involve several different companies. See also section 2.2.6.

gases are transformed into hydrochloric and hydrofluoric acid. As such, the mining of Fluorspar is being avoided [404].

In comments following the 4th SH meeting of 1 July 2025, a major non-ferrous metal (CRM and precious metals) recycler noted that [405]:

- Recycled content (RC) targets may lead to several unintended consequences:
    - In a rapidly evolving technological landscape, setting fixed targets is virtually impossible. Targets risk being either overly ambitious - due to insufficient availability of recyclable materials - or becoming obsolete if the targeted material is substituted by alternative technologies.
    - Unrealistic targets could undermine efforts to extend product lifespans.
    - They may incentivize production in regions without domestic RC obligations, giving non-EU producers a competitive advantage (they can allocate all recycled materials in products for the EU market).
    - If RC targets are not universally applied across all applications and all economic regions, recycled content may simply be reallocated from unregulated to regulated uses, without increasing overall recycling volumes.
- The metallurgical recycling processes (concentration and refining) usually combine primary (virgin) and secondary materials (recyclables). Because recycled and primary atoms are chemically identical, physical verification of recycled content is impossible. Therefore, a documented chain of custody (CoC) is essential to verify RC.
    - Segregated processing would be the easiest to verify but is impractical due to scale and quality consistency requirements. It would result in economic and environmental inefficiencies. Moreover, verifying targets on the ground is extremely difficult, especially across complex global value chains.
    - A mass balance approach is more feasible but must be carefully designed to avoid disincentivizing recycling efforts. For example, a rolling average system could allow all downstream users to claim the same RC percentage, regardless of their contribution to recycling. This could result in no incentive for OEMs to design for recycling or to use high-quality recyclers and equal RC claims by users who do not contribute to recycling (e.g., lithium in pharmaceuticals or cobalt in tires).
    - Ultimately, the value in circularity lies in effective collection and high-quality recycling—not in the use of recycled materials. RC targets, as currently conceived, risk rewarding passive rather than proactive manufacturers.
- In a context where all recycled materials can easily be sold (as for CRMs and precious metals), the bottleneck for circular economy is collection and recycling; in a market where recycled materials are not easily sold (for instance because of inferior quality, e.g. plastics), market stimulation measures can be recommended.
- Consider a compulsory dismantling manual, explaining amongst others where the parts containing CRMs are located and identified (which CRMs in which part) and that they are easily removable. The Digital Product Passport could be a tool to share this information.

For the moment no recycled content requirements for CRMs and SRMs are proposed. For copper and aluminium such requirements are not of benefit. For other materials, the types and quantities used in fridges are uncertain (lack of information), but likely very low (estimated less

[404] This seems to apply only to the legacy CFC-containing refrigerants and blowing agents. The iso-butane refrigerant and cyclopentane blowing agent predominantly used now, do not contain chlorine or fluor.

[405] Umicore feedback on the Ecodesign preparatory study, July 2025.

than 0.4 g per fridge, see section 6.2.4), so that recycled content requirements are not worth the effort. In addition, as indicated in stakeholder comments, the target RC levels are difficult to establish, while setting recycled content requirements for CRMs may not have the desired effects.

Recyclability requirements for CRMs and SRMs need further discussion. Increasing the amount of CRMs and SRMs recycled from fridges mainly depends on fridge collection rates (which are beyond the scope of this study), and on the recycling rate of printed circuit boards and other electronic components. Fridge recyclers have stated that the latter is already high, but other stakeholders believe that more CRMs can be captured during recycling by separating CRM-containing parts before shredding. Recyclability requirements could include design-for recyclability criteria, development of high-quality recycling standards, and ensuring ease of access and removability for CRM-containing parts.

Considering the lack of information on the types and quantities of CRMs and SRMs used in fridges, setting information requirements could be relevant. Considering the expected small quantities, and the considerable traceability effort for fridge manufacturers and other supply chain actors, it should be evaluated if this is worthwhile. In comments following the 4th SH meeting, some stakeholders stressed that the small quantities should not be a reason not to require separation of CRM-containing parts during disassembly, suggesting a compulsory dismantling manual.

7. MEErP Task 7, Scenarios

7.1. Potential requirements overview

Table 36 provides a survey of all potential requirements on recycled content, recyclability and CRMs for fridges that have been identified in the previous chapters. For each requirement the reference section where more information can be found is indicated. The recommendations are preliminary, for discussion with stakeholders, and to be further assessed in the review study on regulations 2019/2019 and 2019/2016 that started in December 2024.

Recycled content (RC) requirements are recommended only for plastics and glass, not for metals, electronics, CRMs and other materials. Two tiers are proposed, in 2030 and 2033 (see section 6.1). The intention is to apply the minimum requirements to post-consumer recycled material.

The RC requirement for plastics can be set either on the entire plastics mass in the fridge (1.2 in the table), or on the sum of masses of PS, PP and ABS (1.3), or on the separate masses of these plastic types (1.4). In the latter option it is proposed to evaluate latest by 2030 if a minimum requirement for PUR should be added. This depends, e.g. on the economic viability of chemical PUR recycling and on the development of the use of vacuum insulation panels.

For glass, the requirement would be limited to flat glass, excluding glass fibre.

The amount of recycled material from fridges can be increased mainly by increasing the separate collection rate, which is beyond the scope of this study. Recycling rates for fridge materials are already high (section 6.3.3) and the current practice of shredding many materials together and applying post-shredder separation processes seems to work satisfactorily (section 6.3.2). Considering in addition that 50% of the fridge mass is in the sandwich construction of body and the doors for which dismantlability is undesirable, another 20% is in internal components that are already easily removable, and 10% is in the hermetic compressor, which is already being removed by recyclers before shredding, the impacts of potential requirements on the ease of separation before shredding are limited. In any case, recyclers would only apply separation before shredding if this is economically worthwhile or necessary to protect their equipment. In those cases, they prefer using shears, saws or axes rather than time-consuming screwdrivers.

For this reason, a recyclability index for fridges has not been developed yet. Some potential requirements to facilitate separation before shredding have been identified (see the table), but several need further study and discussion. Setting these requirements does not automatically imply that recyclers will also apply pre-shredding separation.

As regards critical and strategic raw materials, copper and aluminium are present in relevant quantities in fridges, but their recycling rates are already high, and their recycled content in fridges depends on the general market situation. In previous consultations, most stakeholders were not in favour of setting RC requirements on metals (section 6.2.2).

For other CRMs and SRMs, the types and quantities used in fridges are uncertain, but (very) low (sections 4.1.3 and 6.4). Considering the lack of information, information requirements could be set, but this seems hardly worthwhile.

Table 36: Survey of potential requirements on fridges

	Potential requirement	reference	recommendation
1	**Recycled content requirements**		
1.1	Minimum recycled content for entire fridge. > 25% in 2030, > 45% in 2033	6.2.1.4, option 1	no
1.2	Minimum recycled content for entire plastics fridge mass. > 10% in 2030, > 30% in 2033	6.2.1.4, option 2	YES
1.3	Minimum recycled content for sum of PS, PP, ABS mass in fridge. > 20% in 2030, > 40% in 2033	6.2.1.4, option 3	Alternative to 1.2
1.4.1	Minimum recycled content per type of plastic in a fridge. PS > 30% in 2030, > 50% in 2033 PP > 20% in 2030, > 40% in 2033 ABS > 20% in 2030, > 40% in 2033	6.2.1.4, option 4	Alternative to 1.2
1.4.2	Minimum recycled content per type of plastic in a fridge PUR > X% in 2033	6.2.1.4, option 4	To be decided in 2030.
1.5	Minimum recycled content per (plastic) fridge component. Body inner liner > 30% in 2030, > 50% in 2033 Door inner liner > 30% in 2030, > 50% in 2033 Shelves, drawers, etc. > 30% in 2030, > 50% in 2033	6.2.1.4, option 5	no
1.6	Minimum recycled content for ferrous metals in fridges	6.2.2	no
1.7	Minimum recycled content for aluminium in fridges	6.2.2	no
1.8	Minimum recycled content for copper in fridges	6.2.2	no
1.9	Minimum recycled content for flat glass in fridges > 15% in 2030, > 35% in 2033	6.2.3	YES
1.10	Minimum recycled content for electronics in fridges	6.2.4	no
1.11	Minimum recycled content for other fridge materials	6.2.5	no
2	**Recyclability requirements**		
2.1	Main structure: marking for the presence or not of vacuum insulation panels, and of the type of core material used	6.3.4.1	YES
2.2	Transparent doors: design for ease of separation of glass from other door materials (e.g. spacers, frames)	6.3.4.2	YES, but needs further study
2.3	Shelves, drawers, etc.: require a marking on the shelves, drawers, baskets and accessories that indicates the type of plastic, like what is done for packaging.	6.3.4.3	YES
2.4	Shelves, drawers, etc.: design for ease of separation of different material types used in a single component.		YES, but needs further study
2.4	Hermetic compressor: require separation before shredding and separate processing by specialists	6.3.4.4	no
2.5	Cooling system: no potential requirements identified	6.3.4.5	void
2.6	Internal air flow: require spare parts availability for fans, fan motors, and controls	6.3.4.6	YES, but needs further study
2.7.1	Electronics: boards larger than 10 cm² and boards containing batteries or wet capacitors should be easily removable for recyclers, without the use of screwdrivers	6.3.4.7	YES, but needs further study
2.7.2	Electronics: position all printed circuit boards in a box on top of the fridge, or if that is not possible use a standardized marking, recognizable from 2-meter distance, to indicate the location of the box	6.3.4.7	YES, but needs further study
2.7.3	Electronics, for printed circuit boards in fridges, use any of the four types of plastics that are recycled from fridges today (GPPS, HIPS, PP, ABS), as bare board material	6.3.4.7	no
2.8	Other components: require a label indicating the type of refrigerant being used in the fridge, clearly visible from a distance during the recycling process	6.3.4.8	no
2.9.1	Additives and fillers: forbid the use of halogenated flame retardants, and require a marking for plastics containing flame retardants, like the regulation for electronic displays	0	Needs further study
2.9.2	Additives and fillers: set a maximum 10% mass content for chalk, talcum, or fibre glass filler in polypropylene	0	maybe
2.9.3	Plastics with additives or fillers giving recycling problems: require density 1.2 g/cm3 or higher to facilitate separation	0	maybe
2.10	Recyclability index: develop a recyclability index for fridges	6.3.6	Needs further study

	Potential requirement	reference	recommendation
3	**Requirements for CRMs**		
3.1	Recycled content requirements	6.4	no
3.2	Recyclability requirements	6.4	Needs further study
3.3	Information requirements	6.4	Needs further study

7.2. Analysis of recycled content requirements

For plastics, there are three alternative formulations for recycled content requirements (1.2, 1.3, 1.4.1 in Table 36). The recommended requirement is 1.2, i.e. a minimum percentage of post-consumer recycled plastic content compared to the entire fridge plastics mass, because this leaves more freedom for manufacturers. However, in practice the effects of the three alternatives are expected to be similar, because a large share of the fridge plastics mass is GPPS and HIPS, so the use of recycled PS seems an obligated choice. For the analysis, alternative 1.4.1 has been chosen because this formulation has clear limits per type of plastic. The results for 1.4.1 are assumed to be indicative also for the alternatives 1.2 and 1.3.

In addition, the recycled content requirement for flat glass (1.9 in Table 36) has been included in the analysis.

Summarizing, the analysis has been performed for the following minimum post-consumer recycled contents (RC):

PS > 30% in 2030, > 50% in 2033

PP > 20% in 2030, > 40% in 2033

ABS > 20% in 2030, > 40% in 2033

Flat glass > 15% in 2030, > 35% in 2033

In section 5.7, impact reductions due to recycled content requirements have been calculated for a unit product, for an RC increase of 10% compared to the baseline. As explained there, all other things being equal, these impact reductions increase linearly with the percentage RC. The data of section 5.7 have been scaled to compute the impact reductions for the above RC percentages.

7.2.1 Impact reduction due to tier 1 in 2030

Table 37 shows the impact reductions for PP, HIPS, GPPS, ABS and Glass when applying the proposed minimum recycled content percentages of tier 1 (2030). Impacts in this table are per unit product, for the reference refrigerator-freezer of Table 15. Like earlier tables, it is divided in two parts, showing data for different impact categories. For reference, the top four rows show the baseline materials and end-of-life impacts, for plastics only, for glass only, and for all fridge materials, and the latter when adding impacts from use phase electricity consumption over the product lifetime [406]. The bottom four rows show the impact reduction shares versus the baseline impacts.

The mass reduction of virgin material compared to the baseline is 19% for plastics, 11% for glass, and 10% over all fridge materials.

[406] impacts from electricity use over the lifetime of the fridge-freezer combi (for 235 kWh/year, 15.7 years lifetime, electricity grid mix dataset 243)

For 'ozone depletion', 'ionising radiation' and 'eutrophication, freshwater', the impact reduction is negative, indicating that the recycled content creates additional impacts. This is due to the datasets used for HIPS and GPPS, see remarks in sections 5.6 and 5.7.

For other environmental impact categories, the reduction due to plastics recycled content compared to the baseline impacts for plastics varies from 1.1% for 'land use' to 13.6% for 'human toxicity, non-cancer'. Other high reduction shares are found for 'eco toxicity, freshwater' (13.0%), 'human toxicity, cancer' (10.3%) and 'resource use, fossils' (10.3%).

The impact reduction due to glass recycled content compared to the baseline impacts for glass varies from 0.1% for 'acidification' to 3.2% for 'eco toxicity, freshwater'. Other high reduction shares are found for 'particulate matter' (3.1%), 'ionising radiation' (3.0%), 'ozone depletion' (2.9%) and 'eutrophication, freshwater' (2.9%).

The impact reduction due to plastics and glass recycled content compared to the baseline impacts for all fridge materials varies from 0.0% for 'land use' and 0.1% for 'resource use, minerals and metals' to 6.8% for 'resource use, fossils' and 7.6% for 'eco-toxicity, freshwater'. The percentage impact reduction depends on the baseline impacts from plastics and glass compared to those from other materials (Figure 24), and on the baseline impacts of PS, PP and ABS compared to those from other plastics, e.g. PUR foam (Figure 26).

Compared to the baseline impacts including those from lifetime electricity use, the largest impact reductions occur for 'human toxicity, non-cancer (1.2%) and 'ecotoxicity, freshwater' (1.1%).

Table 37: Reduction of material and end-of-life environmental impacts compared to the baseline, per unit product, when using 2030 minimum proposed recycled content percentages for PS, PP, ABS and flat glass, for base case COLD 7 (combi).

Unit product, Tier 1, 2030	Virgin Mass in input [g]	Climate change, total [kg CO2 eq]	Ozone depletion [kg CFC-11 eq]	Human toxicity, cancer [CTUh]	Human toxicity, non-cancer [CTUh]	Particulate matter [disease incidence]	Ionising radiation, human health [kBq U235 eq]	Photo-chemical ozone formation, human health [kg NMVOC eq]	Acidifi-cation [mol H+ eq]
Baseline impact Material & EoL									
Plastics only	24548	50	1.0E-06	2.3E-08	6.4E-07	1.5E-06	2.2	0.12	0.13
Glass only	5506	6	1.5E-10	8.7E-10	8.1E-09	3.6E-06	0.2	0.02	0.04
All materials	51196	113	1.1E-06	5.2E-08	2.0E-06	8.9E-06	7.4	0.264	0.38
All materials & Electricity use		1659	1.7E-06	3.1E-07	7.2E-06	5.8E-05	664	2.79	5.09
Impact reduction									
PP (R1=20%)	497	0.52	5.0E-09	3.7E-10	4.5E-09	6.0E-08	8.2E-03	3.0E-03	4.0E-03
HIPS (R1=30%)	2485	1.94	-8.7E-08	1.2E-09	4.8E-08	7.7E-10	-2.2E-02	2.8E-03	7.2E-04
GPPS (R1=30%)	1727	1.35	-6.1E-08	8.1E-10	3.3E-08	5.3E-10	-1.5E-02	1.9E-03	5.0E-04
ABS (R1=20%)	68	0.09	9.6E-13	3.4E-11	1.4E-09	1.2E-09	1.7E-03	1.9E-04	1.9E-04
Glass (R1=15%)	580	0.08	4.4E-12	-1.9E-11	7.2E-11	1.1E-07	6.1E-03	9.8E-05	2.8E-05
Sum reduction	**5355**	**3.98**	**-1.4E-07**	**2.4E-09**	**8.8E-08**	**1.7E-07**	**-2.1E-02**	**8.1E-03**	**5.4E-03**
Share reduction vs. baseline									
Plastics only	19%	7.8%	-14.1%	10.3%	13.6%	4.1%	-1.3%	6.7%	4.0%
Glass only	11%	1.3%	2.9%	-2.1%	0.9%	3.1%	3.0%	0.5%	0.1%
All materials	10%	3.5%	-12.5%	4.6%	4.3%	2.0%	-0.3%	3.1%	1.4%
All materials & Electricity use		0.2%	-8.3%	0.8%	1.2%	0.3%	0.0%	0.3%	0.1%

Unit product, Tier 1, 2030	Eutrophi-cation, terrestrial [mol N eq]	Eutrophi-cation, freshwater [kg P eq]	Eutrophi-cation, marine [kg N eq]	Ecotoxicity, freshwater [CTUe]	Land use [pt]	Water use [m3 water eq. of deprived water]	Resource use, minerals and metals [kg Sb eq]]	Resource use, fossils [MJ]
Baseline impact Material & EoL								
Plastics only	0.4	6.2E-04	0.04	689	98	14	5.5E-05	1464
Glass only	0.1	2.3E-06	0.01	106	5	0	3.7E-07	69
All materials	0.9	9.5E-04	0.08	1227	4743	27	3.2E-03	2211
All materials & Electricity use	10.3	4.1E-03	0.98	8265	11398	554	3.6E-03	29092
Impact reduction								
PP (R1=20%)	1.0E-02	4.1E-05	1.1E-03	10.8	-0.30	0.42	3.3E-06	15.6
HIPS (R1=30%)	4.9E-03	-2.6E-05	5.3E-04	45.7	0.71	0.21	5.7E-07	78.1
GPPS (R1=30%)	3.4E-03	-1.8E-05	3.7E-04	31.8	0.49	0.15	3.9E-07	54.3
ABS (R1=20%)	7.0E-04	2.1E-07	6.7E-05	1.3	0.14	-0.08	1.5E-08	2.6
Glass (R1=15%)	5.7E-04	6.7E-08	3.2E-05	3.4	0.03	4.7E-03	9.5E-09	0.4
Sum reduction	2.0E-02	-2.1E-06	2.1E-03	93.0	1.07	0.70	4.3E-06	151.0
Share reduction vs. baseline								
Plastics only	5.3%	-0.4%	5.9%	13.0%	1.1%	5.0%	7.9%	10.3%
Glass only	0.5%	2.9%	0.3%	3.2%	0.6%	0.9%	2.5%	0.6%
All materials	2.3%	-0.2%	2.5%	7.6%	0.0%	2.6%	0.1%	6.8%
All materials & Electricity use	0.2%	-0.1%	0.2%	1.1%	0.0%	0.1%	0.1%	0.5%

Table 38 shows the same data as Table 37 but multiplied by the 17.2 million projected unit sales of all refrigerator and freezer types in 2030 (section 2.1.3). This uses the BoM for refrigerator-freezer combis of Table 14 for all RF types, which is a rough proxy of reality, but it gives the order of magnitude of proposed tier 1 impact reductions. Note that metrics used in Table 38 often differ from those in Table 37 (red metrics in the top row).

As baseline impacts and impact reductions have both been multiplied by the same sales quantity, the shares at the bottom of Table 38 are the same as in Table 37. For 'climate change', 'water use', and 'resource use, fossils' a comparison has also been made with the EU27 total impacts in 2020 [407]. For these parameters, the tier 1 (2030) recycled content requirements decrease the impacts by 0.002% to 0.008%.

As regards the reduction in use of virgin materials in input to fridge production, compared to EU27 total plastic consumption and recycling capacity of section 2.2.3:

- The 97 kton reduction is 0.15% of the 53.3 Mton total consumed plastics in EU27 in 2022, and 2.1% of the 4.0 Mton plastics used in EEE.
- The 72.5 kton reduction for HIPS and GPPS is 2.7% of the 2.7 Mton total PS consumed in EU27 in 2022, and 27% of the EU27 recycling capacity for PS of 264 kton.
- The 8.6 kton reduction for PP is 0.10% of the 8.8 Mton total PP consumed in EU27 in 2022, and 0.5% of the EU27 recycling capacity for PP of 1.7 Mton.
- The 1.2 kton reduction for ABS is 0.15% of the 0.8 Mton total ABS consumed in EU27 in 2022.

Between 2022 and 2030, the plastics recycling capacity in the EU27 is expected to further increase. However, for use in fridges the recycled PS needs to be food-contact-approved and

[407] Source: EIA 2024 Materials and Environmental impacts report, VHK October 2024, Table 50. See further references there. The EU27 total value for 'resource use, fossils' is for 'primary energy', but for the calculation of the shares this does not make any difference.

cannot be bought just anywhere on the recycled PS market. Current use of recycled PS in fridges relies on specially developed fridge-to-fridge collection and recycling processes (sections 4.2.1 and 4.2.2).

Table 38: Reduction of material and end-of-life environmental impacts compared to the baseline, for fridges projected to be sold in 2030, when using 2030 minimum proposed recycled content percentages for PS, PP, ABS and flat glass, for base case COLD 7 (combi). Metrics in red differ from those in the previous table.

RF sales in 2030 Tier 1, 2030	Virgin Mass in input [kton]	Climate change, total [kton CO2 eq]	Ozone depletion [kg CFC-11 eq]	Human toxicity, cancer [CTUh]	Human toxicity, non-cancer [CTUh]	Particulate matter [disease incidence]	Ionising radiation, human health [ton Bq U235 eq]	Photo-chemical ozone formation, human health [ton NMVOC eq]	Acidifi-cation [k mol H+ eq]
Baseline impact Material & EoL									
Plastics only	423	860	17.5	0.4	11.1	27	37651	2045	2309
Glass only	95	108	0.003	0.015	0.1	62	3508	365	621
All materials	882	1947	19.7	0.9	35.2	154	127207	4543	6629
All materials & Electricity use		28568	29.6	5.3	124.3	1003	11439378	48140	87635
EU27 total 2020		3311000							
Impact reduction									
PP (R1=20%)	8.6	9.0	8.6E-02	6.3E-03	7.7E-02	1.0E+00	141	52.4	69.0
HIPS (R1=30%)	42.8	33.4	-1.5E+00	2.0E-02	8.3E-01	1.3E-02	-378	48.1	12.4
GPPS (R1=30%)	29.7	23.2	-1.0E+00	1.4E-02	5.8E-01	9.2E-03	-263	33.4	8.6
ABS (R1=20%)	1.2	1.6	1.7E-05	5.8E-04	2.4E-02	2.1E-02	29	3.2	3.2
Glass (R1=15%)	10.0	1.4	7.6E-05	-3.2E-04	1.2E-03	1.9E+00	105	1.7	0.5
Sum reduction	**92**	68.6	-2.5	0.04	1.5	3.0	-366	138.9	93.7
Share reduction vs. baseline									
Plastics only	19%	7.8%	-14.1%	10.3%	13.6%	4.1%	-1.3%	6.7%	4.0%
Glass only	11%	1.3%	2.9%	-2.1%	0.9%	3.1%	3.0%	0.5%	0.1%
All materials	10%	3.5%	-12.5%	4.6%	4.3%	2.0%	-0.3%	3.1%	1.4%
All materials & Electricity use		0.2%	-8.3%	0.8%	1.2%	0.3%	0.0%	0.3%	0.1%
Share EU27 total 2020		0.002%							

RF sales in 2030 Tier 1, 2030	Eutrophi-cation, terrestrial [k mol N eq]	Eutrophi-cation, freshwater [kg P eq]	Eutrophi-cation, marine [ton N eq]	Ecotoxicity, freshwater [k CTUe]	Land use [k pt]	Water use [Mm3 water eq. of deprived water]	Resource use, minerals and metals [kg Sb eq]]	Resource use, fossils [TJ]
Baseline impact Material & EoL								
Plastics only	6292	10710	603	11873	1682	239	941	25217
Glass only	1852	40	158	1823	85	8	6	1185
All materials	15219	16303	1432	21140	81702	460	55832	38089
All materials & Electricity use	178097	70568	16796	142363	196335	9549	62613	501094
EU27 total 2020						158640		(51749000)
Impact reduction								
PP (R1=20%)	180	713	19.1	186	-5.2	7.27	57.4	268
HIPS (R1=30%)	84	-445	9.1	788	12.2	3.61	9.8	1345
GPPS (R1=30%)	58	-309	6.3	548	8.5	2.51	6.8	935
ABS (R1=20%)	12	3.6	1.1	22	2.4	-1.45	0.3	45
Glass (R1=15%)	10	1.1	0.5	58	0.5	0.08	0.2	7
Sum savings	**344**	**-36.9**	**36.2**	**1602**	**18.5**	**12.0**	**74.3**	**2600**

Share reduction vs. baseline								
Plastics only	5.3%	-0.4%	5.9%	13.0%	1.1%	5.0%	7.9%	10.3%
Glass only	0.5%	2.9%	0.3%	3.2%	0.6%	0.9%	2.5%	0.6%
All materials	2.3%	-0.2%	2.5%	7.6%	0.0%	2.6%	0.1%	6.8%
All materials & Electricity use	0.2%	-0.1%	0.2%	1.1%	0.0%	0.1%	0.1%	0.5%
Share EU27 total 2020						0.008%		(0.005%)

7.2.2 Impact reduction due to tier 2 in 2033

Table 39 shows the impact reductions for PP, HIPS, GPPS, ABS and Glass when applying the proposed minimum recycled content percentages of tier 2 (2033). Impacts in this table are per unit product, for the reference refrigerator-freezer of Table 15. Like earlier tables, it is divided in two parts, showing data for different impact categories. For reference, the top four rows show the baseline materials and end-of-life impacts, for plastics only, for glass only, and for all fridge materials, and the latter when adding impacts from use phase electricity consumption over the product lifetime [408]. The bottom four rows show the impact reduction shares versus the baseline impacts.

The mass reduction of virgin material compared to the baseline is 33% for plastics, 32% for glass, and 19% over all fridge materials.

For 'ozone depletion' and 'ionising radiation', the impact reduction is negative, indicating that the recycled content creates additional impacts. This is due to the datasets used for HIPS and GPPS, see remarks in sections 5.6 and 5.7.

For other environmental impact categories, the reduction due to plastics recycled content compared to the baseline impacts for plastics varies from 1.6% for 'eutrophication, freshwater' to 23.0% for 'human toxicity, non-cancer'. Other high reduction shares are found for 'eco toxicity, freshwater' (22.3%), 'human toxicity, cancer' (17.7%) and 'resource use, fossils' (17.6%).

The impact reduction due to glass recycled content compared to the baseline impacts for glass varies from 0.2% for 'acidification' to 7.5% for 'eco toxicity, freshwater'. Other high reduction shares are found for 'particulate matter' (7.2%), 'ionising radiation' (7.0%), 'ozone depletion' (6.9%) and 'eutrophication, freshwater' (6.8%).

The impact reduction due to plastics and glass recycled content compared to the baseline impacts for all fridge materials varies from 0.0% for 'land use' and 0.3% for 'resource use, minerals and metals' to 11.7% for 'resource use, fossils' and 13.1% for 'eco-toxicity, freshwater'. The percentage impact reduction depends on the baseline impacts from plastics and glass compared to those from other materials (Figure 24), and on the baseline impacts of PS, PP and ABS compared to those from other plastics, e.g. PUR foam (Figure 26).

Compared to the baseline impacts including those from lifetime electricity use, the largest impact reductions occur for 'human toxicity, non-cancer (2.1%) and 'ecotoxicity, freshwater' (2.0%).

[408] impacts from electricity use over the lifetime of the fridge-freezer combi (for 235 kWh/year, 15.7 years lifetime, electricity grid mix dataset 243)

Table 39: Reduction of material and end-of-life environmental impacts compared to the baseline, per unit product, when using 2033 minimum proposed recycled content percentages for PS, PP, ABS and flat glass, for base case COLD 7 (combi).

Unit product, Tier 2, 2033	Virgin Mass in input [g]	Climate change, total [kg CO2 eq]	Ozone depletion [kg CFC-11 eq]	Human toxicity, cancer [CTUh]	Human toxicity, non-cancer [CTUh]	Particulate matter [disease incidence]	Ionising radiation, human health [kBq U235 eq]	Photo-chemical ozone formation, human health [kg NMVOC eq]	Acidifi-cation [mol H+ eq]
Baseline impact Material & EoL									
Plastics only	24548	49.9	1.0E-06	2.3E-08	6.4E-07	1.5E-06	2.2	0.12	0.13
Glass only	5506	6.3	1.5E-10	8.7E-10	8.1E-09	3.6E-06	0.2	0.021	0.036
All materials	51196	113.0	1.1E-06	5.2E-08	2.0E-06	8.9E-06	7.4	0.264	0.38
All materials & Electricity use		1659	1.7E-06	3.1E-07	7.2E-06	5.8E-05	664	2.79	5.09
Impact reduction									
PP (R1=40%)	994	1.04	1.0E-08	7.4E-10	8.9E-09	1.2E-07	1.6E-02	6.1E-03	8.0E-03
HIPS (R1=50%)	4141	3.23	-1.5E-07	2.0E-09	8.0E-08	1.3E-09	-3.7E-02	4.7E-03	1.2E-03
GPPS (R1=50%)	2878	2.25	-1.0E-07	1.4E-09	5.6E-08	8.9E-10	-2.5E-02	3.2E-03	8.3E-04
ABS (R1=40%)	135	0.18	1.9E-12	6.7E-11	2.8E-09	2.5E-09	3.4E-03	3.8E-04	3.8E-04
Glass (R1=35%)	1739	0.19	1.0E-11	-4.3E-11	1.7E-10	2.6E-07	1.4E-02	2.3E-04	6.4E-05
Sum reduction	**9887**	**6.90**	**-2.4E-07**	**4.1E-09**	**1.5E-07**	**3.9E-07**	**-2.8E-02**	**1.5E-02**	**1.0E-02**
Share reduction vs. baseline									
Plastics only	33%	13.4%	-23.3%	17.7%	23.0%	8.1%	-1.9%	12.1%	7.8%
Glass only	32%	3.0%	6.9%	-5.0%	2.1%	7.2%	7.0%	1.1%	0.2%
All materials	19%	6.1%	-20.7%	7.8%	7.2%	4.3%	-0.4%	5.5%	2.7%
All materials & Electricity use		0.4%	-13.8%	1.3%	2.1%	0.7%	0.0%	0.5%	0.2%

Unit product, Tier 2, 2033	Eutrophi-cation, terrestrial [mol N eq]	Eutrophi-cation, freshwater [kg P eq]	Eutrophi-cation, marine [kg N eq]	Ecotoxicity, freshwater [CTUe]	Land use [pt]	Water use [m3 water eq. of deprived water]	Resource use, minerals and metals [kg Sb eq]]	Resource use, fossils [MJ]
Baseline impact Material & EoL								
Plastics only	3.7E-01	6.2E-04	3.5E-02	689	98	13.9	5.5E-05	1464
Glass only	1.1E-01	2.3E-06	9.2E-03	106	5	0.5	3.7E-07	69
All materials	0.9	9.5E-04	0.08	1227	4743	27	3.2E-03	2211
All materials & Electricity use	10.3	4.1E-03	0.98	8265	11398	554	3.6E-03	29092
Impact reduction								
PP (R1=40%)	2.1E-02	8.3E-05	2.2E-03	21.7	-0.60	0.84	6.7E-06	31.1
HIPS (R1=50%)	8.1E-03	-4.3E-05	8.8E-04	76.2	1.18	0.35	9.4E-07	130.2
GPPS (R1=50%)	5.6E-03	-3.0E-05	6.1E-04	53.0	0.82	0.24	6.6E-07	90.5
ABS (R1=40%)	1.4E-03	4.1E-07	1.3E-04	2.5	0.28	-0.17	3.0E-08	5.2
Glass (R1=35%)	1.3E-03	1.6E-07	7.4E-05	7.9	0.07	1.1E-02	2.2E-08	1.0
Sum reduction	**3.7E-02**	**1.0E-05**	**3.9E-03**	**161**	**1.75**	**1.28**	**8.3E-06**	**258**
Share reduction vs. baseline								
Plastics only	9.9%	1.6%	11.0%	22.3%	1.7%	9.1%	15.2%	17.6%
Glass only	1.2%	6.8%	0.8%	7.5%	1.4%	2.2%	5.9%	1.5%
All materials	4.2%	1.1%	4.7%	13.1%	0.0%	4.8%	0.3%	11.7%
All materials & Electricity use	0.4%	0.3%	0.4%	2.0%	0.0%	0.2%	0.2%	0.9%

Table 40 shows the same data as Table 39 but multiplied by the 17.4 million projected unit sales of all refrigerator and freezer types in 2033 (section 2.1.3). This uses the BoM for refrigerator-freezer combis of Table 14 for all RF types, which is a rough proxy of reality, but it gives the order of magnitude of proposed tier 2 impact reductions. Note that metrics used in Table 40 often differ from those in Table 39 (red metrics in the top row).

As baseline impacts and impact reductions have both been multiplied by the same sales quantity, the shares at the bottom of Table 40 are the same as in Table 39. For 'climate change', 'water use', and 'resource use, fossils' a comparison has also been made with the EU27 total impacts in 2020 [409]. For these parameters, the tier 2 (2033) recycled content requirements decrease the impacts by 0.004% to 0.014%.

As regards the reduction in use of virgin materials in input to fridge production, compared to EU27 total plastic consumption and recycling capacity of section 2.2.3:

- The 177 kton reduction is 0.27% of the 53.3 Mton total consumed plastics in EU27 in 2022, and 3.5% of the 4.0 Mton plastics used in EEE.
- The 122 kton reduction for HIPS and GPPS is 4.5% of the 2.7 Mton total PS consumed in EU27 in 2022, and 46% of the EU27 recycling capacity for PS of 264 kton.
- The 17.3 kton reduction for PP is 0.20% of the 8.8 Mton total PP consumed in EU27 in 2022, and 1.0% of the EU27 recycling capacity for PP of 1.7 Mton.
- The 2.3 kton reduction for ABS is 0.31% of the 0.8 Mton total ABS consumed in EU27 in 2022.

Between 2022 and 2033, the plastics recycling capacity in the EU27 is expected to further increase. However, for use in fridges the recycled PS needs to be food-contact-approved and cannot be bought just anywhere on the recycled PS market. Current use of recycled PS in fridges relies on specially developed fridge-to-fridge collection and recycling processes (sections 4.2.1 and 4.2.2).

Table 40: Reduction of material and end-of-life environmental impacts compared to the baseline, for fridges projected to be sold in 2033, when using 2033 minimum proposed recycled content percentages for PS, PP, ABS and flat glass, for base case COLD 7 (combi). Metrics in red differ from those in the previous table.

RF sales in 2033 Tier 2, 2033	Virgin Mass in input [kton]	Climate change, total [kton CO2 eq]	Ozone depletion [kg CFC-11 eq]	Human toxicity, cancer [CTUh]	Human toxicity, non-cancer [CTUh]	Particulate matter [disease incidence]	Ionising radiation, human health [ton Bq U235 eq]	Photo-chemical ozone formation, human health [ton NMVOC eq]	Acidifi-cation [k mol H+ eq]
Baseline impact Material & EoL									
Plastics only	427	868	17.6	0.4	11.2	26.9	37985	2063	2330
Glass only	96	109	0.0	0.0	0.1	62.9	3539	368	627
All materials	890	1964	19.9	0.9	35.5	155.3	128335	4583	6688
All materials & Electricity use		28821	29.8	5.4	125.4	1011.6	11540810	48567	88412
EU27 total 2020		3311000							
Impact reduction									
PP (R1=40%)	17.3	18.1	1.7E-01	1.3E-02	1.6E-01	2.1E+00	285	105.8	139.3
HIPS (R1=50%)	72.0	56.2	-2.5E+00	3.4E-02	1.4E+00	2.2E-02	-636	80.9	20.8

[409] Source: EIA 2024 Materials and Environmental impacts report, VHK October 2024, Table 50. See further references there. The EU27 total value for 'resource use, fossils' is for 'primary energy', but for the calculation of the shares this does not make any difference.

GPPS (R1=50%)	50.0	39.1	-1.8E+00	2.4E-02	9.7E-01	1.5E-02	-442	56.2	14.5
ABS (R1=40%)	2.3	3.2	3.3E-05	1.2E-03	4.9E-02	4.3E-02	59	6.5	6.5
Glass (R1=35%)	30.2	3.2	1.8E-04	-7.5E-04	2.9E-03	4.5E+00	248	4.0	1.1
Sum reduction	**172**	**119.8**	**-4.1**	**0.1**	**2.6**	**6.7**	**-487**	**253**	**182**
Share reduction vs. baseline									
Plastics only	33%	13.4%	-23.3%	17.7%	23.0%	8.1%	-1.9%	12.1%	7.8%
Glass only	32%	3.0%	6.9%	-5.0%	2.1%	7.2%	7.0%	1.1%	0.2%
All materials	19%	6.1%	-20.7%	7.8%	7.2%	4.3%	-0.4%	5.5%	2.7%
All materials & Electricity use		0.4%	-13.8%	1.3%	2.1%	0.7%	0.0%	0.5%	0.2%
Share EU27 total 2020		0.004%							

RF sales in 2033 Tier 2, 2033	Eutrophi-cation, terrestrial [k mol N eq]	Eutrophi-cation, freshwater [kg P eq]	Eutrophi-cation, marine [ton N eq]	Ecotoxicity, freshwater [k CTUe]	Land use [k pt]	Water use [Mm3 water eq. of deprived water]	Resource use, minerals and metals [kg Sb eq]]	Resource use, fossils [TJ]
Baseline impact Material & EoL								
Plastics only	6348	10.8	609	11978	1696	241	949	25440
Glass only	1868	0.04	160	1839	86	9	6	1196
All materials	15354	16.4	1445	21327	82427	464	56327	38427
All materials & Electricity use	179676	71.2	16945	143625	198076	9633	63168	505537
EU27 total 2020						158640		(51749000)
Impact reduction								
PP (R1=40%)	364	1.4	38.5	376	-10.5	14.7	115.8	540
HIPS (R1=50%)	141	-0.7	15.3	1325	20.6	6.1	16.4	2262
GPPS (R1=50%)	98	-0.5	10.6	921	14.3	4.2	11.4	1572
ABS (R1=40%)	24	0.0	2.3	44	4.9	-2.9	0.5	91
Glass (R1=35%)	23	0.0	1.3	138	1.2	0.2	0.4	17
Sum reduction	**650**	**0.2**	**68.1**	**2803**	**30.4**	**22.2**	**144**	**4483**
Share reduction vs. baseline								
Plastics only	9.9%	1.6%	11.0%	22.3%	1.7%	9.1%	15.2%	17.6%
Glass only	1.2%	6.8%	0.8%	7.5%	1.4%	2.2%	5.9%	1.5%
All materials	4.2%	1.1%	4.7%	13.1%	0.0%	4.8%	0.3%	11.7%
All materials & Electricity use	0.4%	0.3%	0.4%	2.0%	0.0%	0.2%	0.2%	0.9%
Share EU27 total 2020						0.014%		(0.009%)

7.3. Stakeholder comments

Stakeholder comments received during and following the 4th stakeholder meeting of 1 July 2025 have been considered throughout the report. This section summarizes comments that more specifically regard the potential requirements presented in section 7.1.

a. Organisations of home appliance manufacturers are not in favour of setting minimum recycled plastic content requirements for refrigerating appliances, judging them as premature. The reasons include:

- Uncertainty in the supply of recycled plastics in the quality required by fridges.
- Economic impacts.
- Information sharing schemes are not fully established yet.

- Lack of a verification method for recycled content in fridges.
- The analyses show small environmental impact reductions which do not justify setting minimum recycled plastic content requirements.

If recycled plastic content requirements are anyway going to be set, the manufacturer organisations ask to:

- Consider more product base cases in the impact analyses.
- Extend the consultation to more manufacturers and recyclers.
- Consider the interaction between different sectors [410]
- Provide more time between publication of the regulation (assumed in 2028) and the first tier with 10% recycled plastic content (proposed in 2030).
- Provide more time between tier 1 (10% RC in 2030) and tier 2 (30% RC in 2033).
- Exclude components produced through injection moulding and expected to come into contact with food [411].
- Exclude transparent plastic types (e.g. GPPS) [412]

If any requirement is to be introduced, the manufacturer organisations find it more appropriate to begin with mandatory disclosure of recycled content levels. This would provide information to the consumer, could eventually drive competition, and, if it works and if recycled material is available in sufficient quantities, one could consider introducing minimum requirements in a next step.

b. As regards setting minimum recycled flat glass requirements, organisations of home appliance manufacturers have the same position as for plastic above, but they see more possibilities:

- Recycled flat glass content rates >15% are reachable, but >35% would require a big step from the flat glass producing industry.
- An increase of 20%-points in 3 years is too important.
- Manufacturers of cooling and freezing appliances have little to no influence on the recycled content of the glass they use.
- As for plastics, prefer information requirements on recycled flat-glass content.
- Consider recycled content measures under an ESPR DA for glass products.

c. Chemical industry associations are in favour of setting minimum recycled content requirements for polyurethane by 2030. Ongoing (chemical recycling) research is expected to be scalable and economically viable by then. The increased use of vacuum insulation panels will complicate the PU recycling.

Organisations of home appliance manufacturers warn that using recycled polyurethane can have an influence on the insulation performance and they stress that energy efficiency should be prioritized.

d. Waste treatment and recyclers' organisations and environmental NGOs are generally in favour of setting minimum recycled content requirements on plastics and flat glass. They stress that only post-consumer recyclates should contribute to meeting recycled content requirements.

In addition, environmental NGOs ask:

[410] Avoid that recycled content requirements lead to a shift in recycled material use from non-regulated to regulated products, without overall increasing the amount of recycled material.

[411] The manufacturer organisations find the findings of the PRIMUS project (section 4.2.2) optimistic: recycled plastic certified for food contact applications in fridges is not available and would have prohibitive costs. Parts produced by injection moulding cannot use the virgin barrier layer (as applied by Electrolux for the inner liner, section 4.2.1).

[412] At the moment, no recycled plastics are available that are truly transparent: a 'milky effect' is stated to remain.

- A horizontal approach to recycled content, not product by product
- Addition of RC requirements for ferrous metals, copper and aluminium
- Count only closed-loop recycled material, from EEE to EEE
- Do not count recyclates from pyrolysis and gasification (chemical recovery)
- Do not count biobased materials
- For verification, do not allow mass balance method with flexible / non-proportional allocation and credit methods.

e. Chemical industry associations oppose a ban on halogenated flame retardants:

- Since the electronics display regulation of 2018, the situation has evolved: 95% of BFRs (including HFRs) can already be eliminated from WEEE plastics.
- Measures should not be taken without going through the mandated ESPR impact assessment, taking into account the latest data from recyclers, and what has been learned from the practical application of Ecodesign for electronic displays.
- While the ESPR is key to identify substances of concern that prevent recycling, any potential substance restrictions should be considered under EU Chemical Legislation (REACH, CLP, POPs, WFD/SCIP, WEEE, RoHS) to avoid unnecessary multiplication of regulatory initiatives.

Organisations of home appliance manufacturers state that alignment with new requirements on flammability is needed (EN 60335-2-24). It is not always possible to use alternative flame retardants. If manufacturers want to use alternatives, they possibly need to increase the amount of material to be compliant to the EN Standard.

f. As regards the potential requirements 2.7.1 and 2.7.2 on electronic boards, metal industry organisations and recyclers (especially CRM recyclers) are (strongly) in favour of measures that facilitate the removal of the boards (and of other CRM-containing parts) prior to shredding. Some stakeholders would like to see ALL boards removed. Low amounts of CRM and precious metals must not be a reason not to require separation of CRM containing parts during disassembly.

   Organisations of home appliance manufacturers state that potential requirement 2.7.2 is a possibly good option, but it requires demanding design changes, and the current recycling processes do not recover the PCB. Further studies on the feasibility for recyclers and the effort for manufacturers should be assessed before recommending this policy option.

g. Stakeholders generally agree with the proposal not to consider recycled content requirements for CRMs and SRMs. However, following detailed comments from a CRM recycler, the recommendation for recyclability and information requirements for CRMs has been changed to 'needs further discussion', to consider e.g.:

- Developing design-for-recycling criteria to facilitate the recovery of CRMs,
- Setting ambitious collection targets,
- Establishing high-quality recycling standards.

h. An industry stakeholder is sceptical about the usefulness of a recyclability index for fridges. Requirements on repairability that are already in Ecodesign regulations need not be repeated for dismantling at end-of-life. A clear recyclability rate based on IEC TR 62635 and EN 45555 seems more practical.

   Some other stakeholders seem in favour of the recyclability index, but without providing detailed comments.

i. Some stakeholders observed that more transparency is required regarding databases and methodologies used in LCA, as these have a direct impact on the outcome of the LCA. A free accessible database built on harmonised methodological standards, considering relevant data for LCAs, will ensure comparability and reliability in LCA results.

References

[1] COMMISSION REGULATION (EU) 2019/2019 of 1 October 2019 laying down ecodesign requirements for refrigerating appliances pursuant to Directive 2009/125/EC of the European Parliament and of the Council and repealing Commission Regulation (EC) No 643/2009, OJ L 315/187, 5.12.2019

[2] COMMISSION DELEGATED REGULATION (EU) 2019/2016 of 11 March 2019 supplementing Regulation (EU) 2017/1369 of the European Parliament and of the Council with regard to energy labelling of refrigerating appliances and repealing Commission Delegated Regulation (EU) No 1060/2010, OJ L 315/102, 5.12.2019

[3] EPREL - European Product Registry for Energy Labelling, https://eprel.ec.europa.eu/screen/home

[4] Preparatory/review study, Commission Regulation (EC) No. 643/2009 with regard to ecodesign requirements for household refrigeration appliances and Commission Delegated Regulation (EU) No.1060/2010 with regard to energy labelling of household refrigeration appliances, FINAL REPORT, VHK and ARMINES in collaboration with Viegand & Maagøe and Wuppertal Institute, contract co-ordination VITO, 4 March 2016

[5] SWD(2019) 341 final, Brussels 1.10.2019, COMMISSION STAFF WORKING DOCUMENT IMPACT ASSESSMENT Accompanying the document COMMISSION REGULATION (EU) .../... laying down ecodesign requirements for refrigerating appliances pursuant to Directive 2009/125/EC of the European Parliament and of the Council and repealing Commission Regulation (EC) No 643/2009 and COMMISSION DELEGATED REGULATION (EU) .../... supplementing Regulation (EU) 2017/1369 of the European Parliament and of the Council with regard to energy labelling of refrigerating appliances and repealing Commission Delegated Regulation (EU) No 1060/2010

[6] DIRECTIVE 2009/125/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (recast) (OJ L 285, 31.10.2009, p. 10), consolidated version with amendments of Directive 2012/27/EU

[7] REGULATION (EU) 2024/1781 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/EC, OJ L 28.6.2024

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[9] WEEE Directive: Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE), consolidated text of 19.3.2024, (OJ L 197 24.7.2012, p. 38) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02012L0019-20240408

[10] DIRECTIVE 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 November 2008 on waste and repealing certain Directives (OJ L 312, 22.11.2008, p. 3), consolidated version of 17.4.2024

[11] Regulation (EC) No 1935/2004 of the European Parliament and of the Council of 27 October 2004 on materials and articles intended to come into contact with food and repealing Directives 80/590/EEC and 89/109/EEC (OJ L 338, 13.11.2004, pp. 4–17): https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02004R1935-20090807 as amended by Regulation (EC) No. 596/2009

[12] COMMISSION REGULATION (EC) No 2023/2006 of 22 December 2006 on good manufacturing practice for materials and articles intended to come into contact with food (OJ L 384, 29.12.2006, p. 75), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02006R2023-20080417 , as amended by Commission Regulation (EC) No 282/2008

[13] COMMISSION REGULATION (EU) No 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food (OJ L 12, 15.1.2011, p.1): https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02011R0010-20230831, consolidated text with amendments up to CR (EU) 2023/1627 of 10 August 2023.

[14] COMMISSION REGULATION (EU) 2022/1616 of 15 September 2022 on recycled plastic materials and articles intended to come into contact with foods, and repealing Regulation (EC) No 282/2008 (OJ L 243 20.9.2022, p. 3):

https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02022R1616-20220920 consolidated text with corrigendum Food Contact Materials

[15] APPLiA annual statistics reports (https://www.applia-europe.eu/publications/statistical-report and https://www.statreport2021applia-europe.eu/ . APPLiA (formerly CECED) is a Brussels-based trade association that provides a single, consensual voice for the home appliance industry in Europe.

[16] REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC, Brussels, 4 December 2024, PE-CONS 73/24

(other references in footnotes throughout the text)

ANNEXES

Annex A, Data from the Ecodesign Impact Accounting

Introduction

The Ecodesign Impact Accounting (EIA) collects data for all products regulated by Ecodesign and Energy Labelling regulations. This Annex shows the EIA2024 data for refrigerating appliances (household refrigerators and freezers, RF)[413]. They are based on EU27 data from the 2019 Impact Assessment [414] and the underlying Excel file and review study. This implies that data until approximately 2018 can be considered 'historical', while data for later years are projections made at the time of the last study.

Unfortunately, EIA data are not detailed per type of refrigerating appliance: a single base case with average characteristics is intended to be representative for all models.

Generic parameters

Table 41: Generic parameters used in the EIA2024.

	unit	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Number of households	mln	152	159	166	174	182	191	196	200	201	201	202	201	200
Efficiency of electricity generation CC	-	40%	40%	40%	40%	40%	40%	40%	53%	53%	53%	53%	53%	53%
Efficiency of electricity generation PEF	-	2.5	2.5	2.5	2.5	2.5	2.5	2.5	1.9	1.9	1.9	1.9	1.9	1.9
GHG-intensity factors for electricity	kgCO2eq/kWh	0.500	0.449	0.399	0.389	0.349	0.335	0.235	0.176	0.103	0.032	0.001	0.000	0.000
Residential sector, electricity rate	euro / kWh	0.196	0.189	0.172	0.152	0.178	0.186	0.203	0.265	0.256	0.237	0.238	0.237	0.233
Industry sector, electricity rate	euro / kWh	0.118	0.103	0.085	0.083	0.101	0.098	0.096	0.105	0.102	0.100	0.105	0.109	0.111
Tertiary/Services, electricity rate	euro / kWh	0.175	0.163	0.145	0.132	0.156	0.167	0.187	0.234	0.227	0.210	0.211	0.212	0.210

[413] The EIA2024 data are the same as the EIA2023 data, which are available on CIRCABC: ecodesign - Library

[414] SWD(2019) 341 final, Brussels 1.10.2019, COMMISSION STAFF WORKING DOCUMENT IMPACT ASSESSMENT Accompanying the document COMMISSION REGULATION (EU) .../... laying down ecodesign requirements for refrigerating appliances pursuant to Directive 2009/125/EC of the European Parliament and of the Council and repealing Commission Regulation (EC) No 643/2009 and COMMISSION DELEGATED REGULATION (EU) .../... supplementing Regulation (EU) 2017/1369 of the European Parliament and of the Council with regard to energy labelling of refrigerating appliances and repealing Commission Delegated Regulation (EU) No 1060/2010

Agriculture / other sector, electricity rate	euro / kWh	0.136	0.127	0.113	0.103	0.121	0.135	0.147	0.153	0.160	0.158	0.159	0.158	0.160

Sales and Stock

Table 42: Sales and Stock for (household) Refrigerating Appliances (RF) in the EIA2024.

	unit		1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Sales	000 units		14323	14705	15117	15357	15991	16355	16732	16987	17242	17497	17751	18006	18261
Average lifetime	years	16													
Stock (EIA traditional)	000 units		219351	225638	232154	238171	244578	251180	258072	264525	269539	273831	277908	281985	286062
Stock per EU27 household	units		1.33	1.31	1.28	1.26	1.23	1.21	1.21	1.22	1.23	1.25	1.27	1.29	1.32
Shape factor for Weibull distribution	-		2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28
Scale factor for Weibull distribution	-		17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7
Delay factor for Weibull distribution	-		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stock (Weibull lifetime distribution)	000 units		218118	225231	232070	238269	244640	251493	258345	264485	269854	274621	279016	283229	287371
Share residential sector of RF		92%													
Share services sector of RF		6%													
Share industry sector of RF		1%													
Share other sectors of RF		1%													

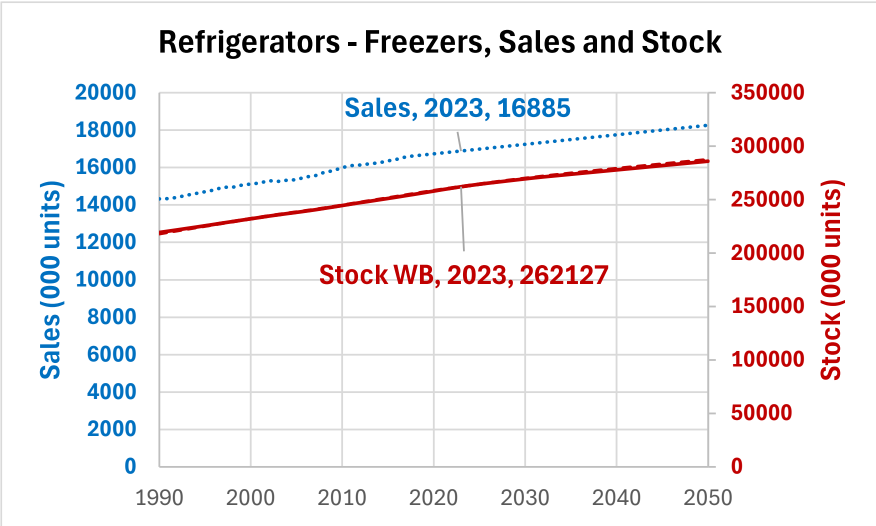

Figure 33: Sales and Stock for (household) Refrigerating Appliances in the EIA2024

Cooled volumes

Table 43: Cooled volumes for (household) Refrigerating Appliances in the EIA2024.

	unit	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Unit Net volume Vnet (CECED 2013)	ltr/unit	203	216	230	251	259	278	297	316	337	358	380	401	422
Unit Estimated equivalent volume Veq	ltr/unit	274	292	311	340	350	377	401	428	456	485	514	542	571
SAEc (EEI=100, CR 643/2009)	kWh/a/unit	468	482	496	516	526	545	563	582	602	623	644	664	685
EU27 freezer net volume	M m³ @ -18C°	9.8	10.7	11.7	13.2	13.9	15.4	16.8	18.4	20.0	21.6	23.2	24.9	26.6
EU27 refrigerator net volume	M m³ @ 5C°	34.7	38.0	41.7	46.6	49.4	54.5	59.7	65.2	70.8	76.5	82.3	88.2	94.2
Unit freezer net volume	dm3/unit	45	47	51	55	57	61	65	70	74	79	83	88	93
Unit refrigerator net volume	dm3/unit	158	168	179	196	202	217	231	247	263	279	296	313	329
Share freezer volume in total net volume	%	22%	22%	22%	22%	22%	22%	22%	22%	22%	22%	22%	22%	22%

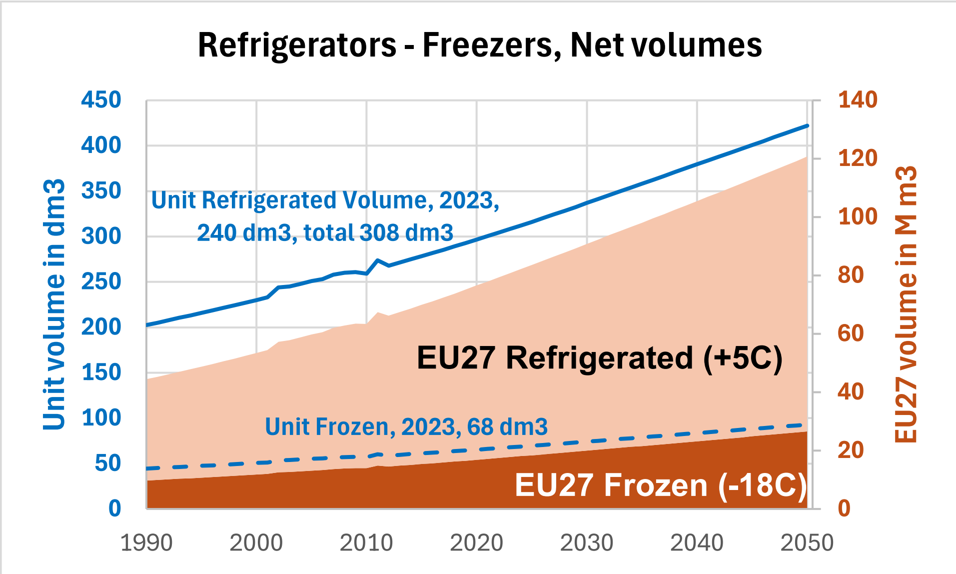

Figure 34: Cooled volumes for (household) Refrigerating Appliances in the EIA2024

Efficiency, Electricity consumption and GHG-emissions

Table 44: Efficiency, Electricity consumption and use-phase GHG-emissions for (household) Refrigerating Appliances in the EIA2024.

	unit	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Sales-average Efficiency AEC	kWh/a	477	452	357	285	253	201	181	113	114	101	93	86	78
Sales-average Efficiency EEI, CR 643/2009	EEI	102	94	72	55	48	37	32	19	19	16	14	13	11
Stock-average Efficiency AEC	kWh/a	490	479	449	397	333	271	227	183	148	121	106	98	89
Stock-average Efficiency per m3	kWh/m3/a	2525	2320	2043	1674	1342	1021	802	611	466	356	294	256	223
Stock-average Efficiency EEI, CR 643/2009	EEI	109	104	95	81	66	52	42	33	26	20	17	15	14
EU27 electricity consumption	TWh/a	**112**	**113**	**109**	**100**	**85**	**71**	**61**	**51**	**42**	**35**	**31**	**29**	**27**
EU27 GHG-emissions, use-phase	MtCO2eq/a	**56**	**51**	**44**	**39**	**30**	**24**	**14**	**9**	**4**	**1**	**0**	**0**	**0**

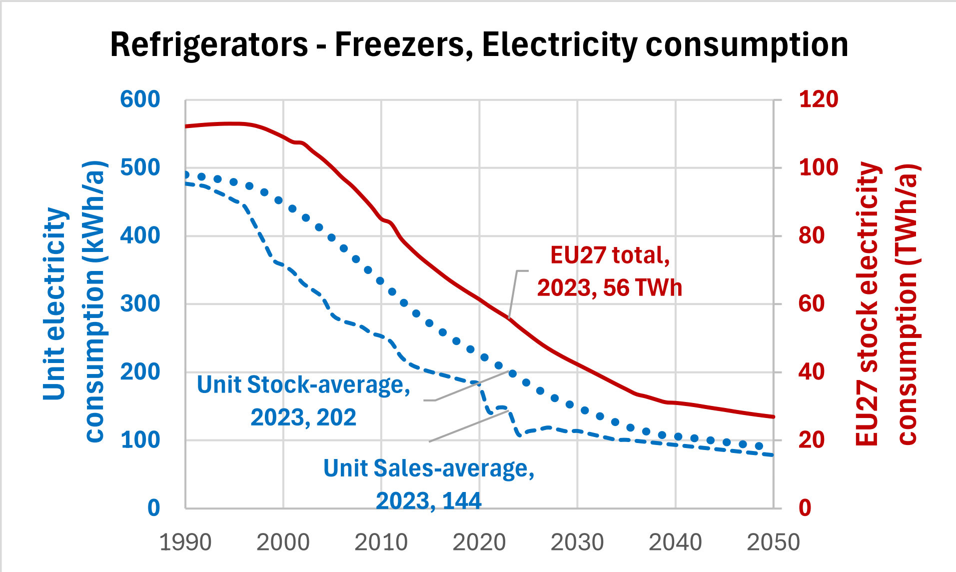

Figure 35: Efficiency and Electricity consumption for (household) Refrigerating Appliances in the EIA2024

Prices and costs

Table 45: Prices and costs for (household) Refrigerating Appliances in the EIA2024.

Monetary amounts in 2020 euros	**unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
unit product price excl. VAT	euro / unit	404	404	429	453	464	495	508	571	540	583	592	599	604
unit installation costs excl. VAT	euro / unit	0	0	0	0	0	0	0	0	0	0	0	0	0
unit repair and maintenance costs excl. VAT	euro/unit/a	0	0	0	0	0	0	0	0	0	0	0	0	0
VAT for residential sector	%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
EU27 acquisition costs (incl. install & VAT)	bn euros	6.9	7.0	7.7	8.2	8.8	9.6	10.1	11.5	11.0	12.1	12.4	12.8	13.1
EU27 energy costs	bn euros	21.7	21.0	18.4	15.0	14.9	13.1	12.3	13.3	10.7	8.1	7.3	6.8	6.2
EU27 repair and maintenance costs	bn euros	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EU27 consumable costs	bn euros	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EU27 total user expense	bn euros	**28.6**	**28.0**	**26.1**	**23.3**	**23.7**	**22.7**	**22.3**	**24.8**	**21.7**	**20.2**	**19.7**	**19.5**	**19.2**
EU27 total user expense residential	bn euros	26.7	26.2	24.4	21.7	22.1	21.2	20.8	23.2	20.3	18.9	18.4	18.2	17.9
EU27 total user expense per household	euros/a	176	165	147	125	121	111	106	116	101	94	91	91	90

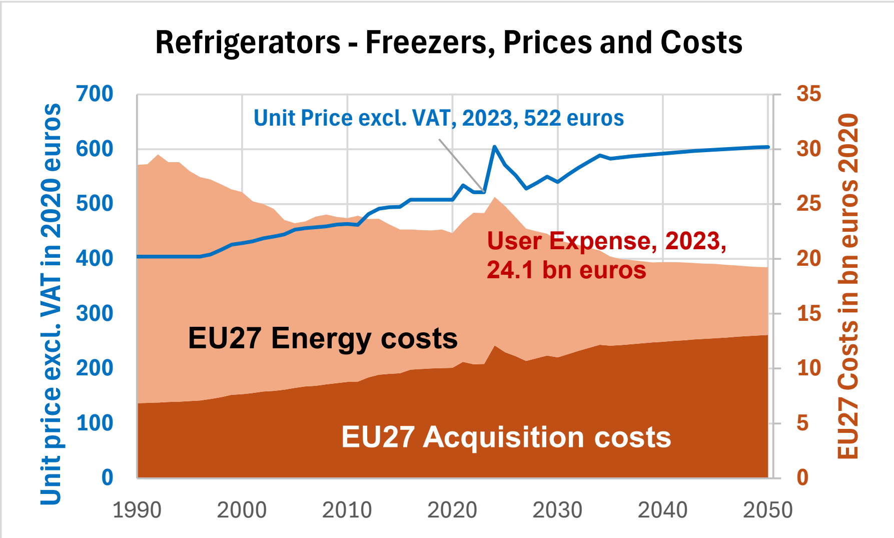

Figure 36: Prices and costs for (household) Refrigerating Appliances in the EIA2024

Business revenues and jobs

Table 46: Business revenues and jobs for (household) Refrigerating Appliances in the EIA2024.

Monetary amounts in 2020 euros	**unit**		**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
share industry of product price	-	49%													
share wholesale of product price	-	4%													
share retail of product price	-	47%													
industry revenue	mln euros		2842	2918	3182	3417	3642	3971	4172	4762	4572	5007	5160	5296	5416
wholesale revenue	mln euros		206	211	230	247	264	287	302	345	331	362	373	383	392
retail revenue	mln euros		2742	2815	3070	3296	3513	3831	4025	4594	4411	4830	4979	5110	5225
installers revenue	mln euros		0	0	0	0	0	0	0	0	0	0	0	0	0
repair and maintenance revenue	mln euros		0	0	0	0	0	0	0	0	0	0	0	0	0
total business revenue	**bn euros**		**5.8**	**5.9**	**6.5**	**7.0**	**7.4**	**8.1**	**8.5**	**9.7**	**9.3**	**10.2**	**10.5**	**10.8**	**11.0**
Manufacturer's 'wages'	mln revenue/employee	0.057													
Wholesale 'wages'	mln revenue/employee	0.286													
Retail 'wages'	mln revenue/employee	0.069													
Installation 'wages'	mln revenue/employee	0.114													
Maintenance 'wages'	mln revenue/employee	0.114													
industry jobs	000 jobs		50	51	56	60	64	70	73	83	80	88	90	93	95
wholesale jobs	000 jobs		1	1	1	1	1	1	1	1	1	1	1	1	1
retail jobs	000 jobs		40	41	45	48	51	56	59	67	64	70	73	75	76
installers jobs	000 jobs		0	0	0	0	0	0	0	0	0	0	0	0	0
repair and maintenance jobs	000 jobs		0	0	0	0	0	0	0	0	0	0	0	0	0
total business jobs	**000 jobs**		**91**	**93**	**101**	**109**	**116**	**126**	**133**	**152**	**146**	**159**	**164**	**169**	**172**

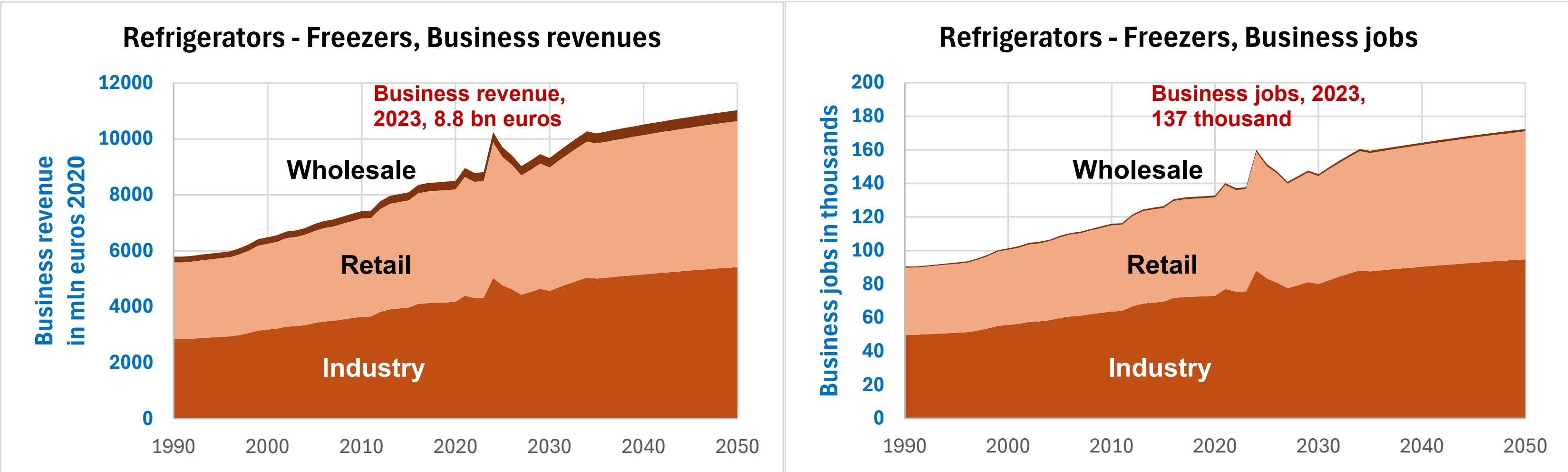

Figure 37: Business revenues and jobs for (household) Refrigerating Appliances in the EIA2024

Sales per RF category

EIA data are not detailed per type of refrigerating appliance: a single base case with average characteristics is intended to be representative for all fridge and freezer models. Based on information in the 2016 review study [4], the 2019 impact assessment [5] and the 2024 EPREL database (Annex B), the annual total EIA sales have been subdivided in the five RF categories introduced in section 1.2, plus minibars.

The sales shares per type in 1999 and 2015 have been taken from the 2016 review study [4] [415]. The sales shares per type in 2024 have been derived from the distribution of the number of models in the EPREL database (see Annex B). Before 1999 and after 2024 the shares have been assumed to remain constant. Linear interpolation has been used in intermediate years. Sales totals are those from the EIA2024, except for the period before year 2000, where they have been reduced to avoid that the stock per EU27 household in 1990 would be larger than in 2024.

Table 47: Sales for (household) Refrigerating Appliances split per type (source: VHK elaboration of EIA2024 and EPREL data)

	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Sales shares													
COLD 0 minibars	4.0%	4.0%	4.1%	4.4%	4.7%	5.0%	6.1%	6.9%	6.9%	6.9%	6.9%	6.9%	6.9%
COLD 1 refrigerators	15.1%	15.1%	15.0%	14.5%	14.0%	13.5%	13.3%	13.2%	13.2%	13.2%	13.2%	13.2%	13.2%
COLD 2 wine storage	1.1%	1.1%	1.1%	1.3%	1.4%	1.5%	5.2%	8.1%	8.1%	8.1%	8.1%	8.1%	8.1%
COLD 7 combis	53.0%	53.0%	53.4%	55.4%	57.5%	59.5%	56.1%	53.4%	53.4%	53.4%	53.4%	53.4%	53.4%

[415] For minibars the 1999 and 2015 shares were estimated and subtracted from the original shares of refrigerators.

COLD 8 upright freezers	13.1%	13.1%	12.7%	10.9%	9.0%	7.2%	7.4%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
COLD 9 chest freezers	13.7%	13.7%	13.6%	13.5%	13.4%	13.3%	11.9%	10.8%	10.8%	10.8%	10.8%	10.8%	10.8%
Sales in (000 units)													
COLD 0 minibars	573	588	614	672	750	818	1013	1172	1190	1207	1225	1242	1260
COLD 1 refrigerators	1629	1948	2271	2227	2236	2202	2228	2242	2276	2310	2343	2377	2410
COLD 2 wine storage	157	161	169	193	224	252	867	1376	1397	1417	1438	1459	1479
COLD 7 combis	5708	6828	8074	8513	9189	9729	9388	9071	9207	9343	9479	9615	9751
COLD 8 upright freezers	1412	1689	1927	1672	1445	1174	1231	1274	1293	1312	1331	1350	1370
COLD 9 chest freezers	1471	1760	2062	2079	2148	2181	1995	1835	1862	1890	1917	1945	1972
Sum all RF types	**10950**	**12974**	**15117**	**15357**	**15991**	**16355**	**16723**	**16970**	**17225**	**17479**	**17734**	**17988**	**18243**

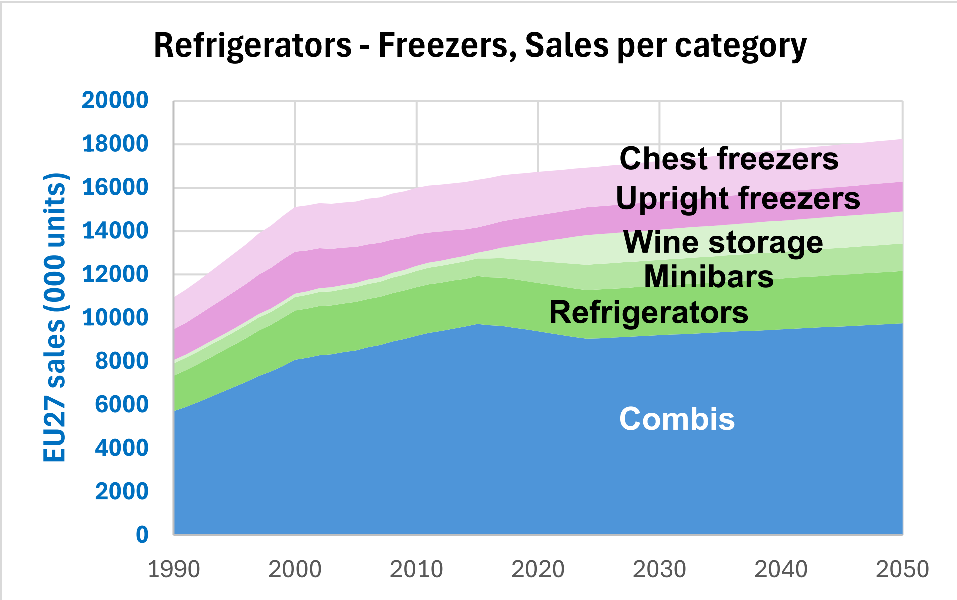

Figure 38: Sales for (household) Refrigerating Appliances split per type

Stock per RF category

The stock per RF type has been determined from the sales per RF type using a Weibull lifetime distribution with shape factor 2.28 [416], scale factor 17.7 [417] and delay factor 0.0 (the same for all RF types). See the EIA2023 annual report for details on stock calculations with the Weibull distribution. Using these factors, the mean lifetime is 15.7 years and the median lifetime 15.0 years (the EIA and underlying studies used 16 years).

Table 48: Stock for (household) Refrigerating Appliances split per type (source: VHK elaboration of EIA2024 and EPREL data)

Stock in (000 units)	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
COLD 0 minibars	8725	9009	9292	9729	10403	11292	12689	14699	16542	17904	18811	19390	19786
COLD 1 refrigerators	24806	26430	29348	32173	34109	35164	35656	35893	36134	36477	36915	37413	37940
COLD 2 wine storage	2384	2462	2540	2693	2949	3297	5450	10303	15169	18809	21128	22426	23132
COLD 7 combis	86928	92621	102961	115193	127134	138396	146078	148625	149119	149427	150245	151697	153586
COLD 8 upright freezers	21508	22917	25404	27003	26799	24955	22839	21479	20860	20766	20952	21239	21550
COLD 9 chest freezers	22404	23871	26517	29292	31532	33207	33723	32838	31734	30991	30704	30788	31092
Sum all RF types	**166754**	**177310**	**196062**	**216084**	**232926**	**246311**	**256435**	**263836**	**269557**	**274375**	**278756**	**282953**	**287086**

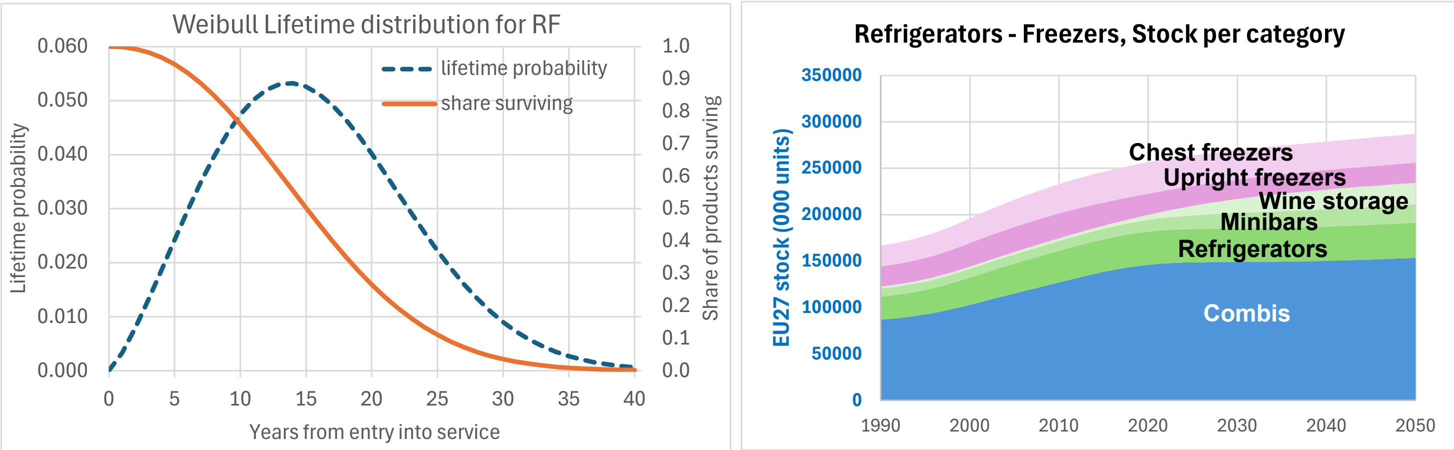

Figure 39: Weibull lifetime distribution (shape 2.28, scale 17.7, delay 0.0) and Stock for (household) Refrigerating Appliances split per type

[416] Source: C.P. Balde, R. Kuehr, K. Blumenthal, S. Fondeur Gill, M. Kern, P. Micheli, E. Magpantay, J. Huisman (2015), E-waste statistics: Guidelines on classifications, reporting and indicators. United Nations University, IAS - SCYCLE, Bonn, Germany, 2015. Annex 2: Lifespan profiles of various EEE in the Netherlands, France and Belgium, referred to in MEErP revision: Review of the MEErP - Methodology for Ecodesign of Energy-related Products, JRC Technical Report 2021, https://susproc.jrc.ec.europa.eu/product-bureau/product-groups/521/home . Details on the Weibull distribution are in Annex III, and Forti V., Baldé C.P., Kuehr R. (2018). E-waste Statistics: Guidelines on Classifications, Reporting and Indicators, second edition. United Nations University, ViE – SCYCLE, Bonn, Germany (newer version of the former). UNU-key 0108 for Fridges (shape 2.2 in NL, BE, FR, 2.36 in IT) has been used.

[417] The scale factor has been determined in the EIA2023, such that the stock calculated with the Weibull lifetime distribution approximates the stock from the 2016 review study [4] and the 2019 impact assessment [5].

Annex B, Data from EPREL

Introduction

The European Product Registry for Energy Labelling (EPREL)[418], in the category 'Household, hotel and wine refrigerators' contains all product data that must be supplied according to Energy Labelling regulation 2019/2016 for refrigerating appliances (RFs) [2].

On request of the study team, the Commission supplied an extract from the EPREL database for RFs on 9 December 2024, later integrated with additional data on 20 December 2024, in four Excel files. These data were elaborated by the study team, to gain insight in the subdivision of the currently marketed models over the various RF types, their energy classes, average electricity consumption, average cooled volumes, etc. This Annex reports the methodology and the results.

Limitations

The presented data are based on the EPREL database and are thus an elaboration of data supplied by manufacturers and suppliers of RFs. Although the study team performed some consistency checks and excluded some entries from the analyses (see below), not all EPREL data could be verified. It is likely that there are still errors in the basic data, which will reflect in the elaborated data, but the impression is that these errors regard a minority of models.

The presented totals, averages and distributions regard the number of models in the EPREL database, not the sold quantities or the stock quantities. However, in first approximation it is assumed that the model averages and distributions are indicative for those of the sales in 2024.

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Methodology and Elaboration

The study team elaborated the EPREL data as follows:

1. The four Excel files supplied by the Commission were united to a single large Excel file and columns were reordered, for clarity and ease of use.

[418] https://eprel.ec.europa.eu/screen/product/refrigeratingappliances2019

2. The database entries differ in quantity of compartments (from 1 to 11), while compartment types and associated volumes are presented in different orders. That was difficult to work with, so compartment volume information has been reordered, obtaining one Excel column per compartment type.

   Compartment volumes for the types pantry, wine storage, cellar, fresh-food and chill have been summed to total refrigerated volume.

   Compartment volumes for the types 0-star, 1-star, 2-star, 2-star section, 3-star, 4-star and variable temperature have been summed to total frozen volume.

   For several entries, the sum of compartment volumes did not match the declared total net refrigerated or frozen volume, often because the first or the latter was zero or absent. As far as feasible, the non-zero volume information from the first of the latter has been used. Where this was not possible, the entry was excluded from the analyses (see point 6).

3. Based on the external dimensions declared in EPREL (width, depth, height), the following parameters have been computed:

   a. External volume (litres)

   b. Ratio external to internal net volume

   c. Ratio height to maximum of width and depth.

   For hundreds of entries, the ratio external to internal volume had an anomalous value. In many cases this was clearly due to (some of the) external dimensions being expressed in cm instead of mm. These values have been corrected where possible. Entries with remaining anomalous ratio have been excluded (see point 6).

4. The EPREL extract contains two columns for the annual energy consumption, AEC and AECv2. For most entries, only one of the two columns is used. Where both columns are used, the values are usually the same. For the analysis, the maximum of both columns was used.

   In addition, a specific AEC in kWh/a/litre has been computed, dividing the declared AEC (in kWh/a) by the total net volume.

5. In EPREL, suppliers must declare separately if the RF is a wine storage appliance. Hence there is a dedicated column indicating this status [419].

   There is no such indication for minibars, but following the definition in the regulation, all entries with total net volume below 60 litres (and not classified as wine storage) have been classified for the analyses as minibars.

   All entries with a single refrigerated compartment (and not classified as wine-storage or minibar) have been classified as 1-comp-refrig.

   All entries with a single frozen compartment (and not classified as wine-storage or minibar) have been classified as 1-comp-freeze. EPREL does not distinguish between chest freezers and upright freezers, but it has been assumed for the analyses that one-compartment freezers with ratio height / width > 1.0 are upright freezers, and the others chest freezers.

   All entries that have more than one compartment (and not classified as wine-storage or minibar) have been classified as combis.

6. The database contains entries for 48256 models, of which 9227 have been excluded from the analysis by the study team, as specified below:

[419] There are 57 models not declared as wine storage, but that have a single compartment of type wine storage. These have not been counted as wine-storage, but under 1-compartment refrigerators.

a. Many entries in the database have a marketing end date. The 7921 models with an end date before 01/01/2025 have been excluded from the analysis, so that presented data refer only to models still on the market.

b. Considering the scope of regulation 2019/2016, the 167 database entries with volume below 10 litres or above 1500 litres have been excluded from the analyses.

c. Entries with an external / internal volume ratio < 1 or > 5 have been excluded from the analyses, in total 657 models.

d. Entries with a declared EEI not consistent with the declared energy label class have been excluded, total 845.

e. Entries with a specific annual energy consumption (kWh/a/litre) below 0.1 or above 20 have been excluded, total 92.

f. Three entries have been excluded for inconsistencies in compartment types or volumes.

Note that entries may have been excluded for more than one reason.

The entries considered for analysis are 39029.

Distribution of models and volumes over the energy label classes, per design type and cooling type

In December 2024, 48256 Refrigerator-Freezer (RF) models were registered in EPREL, of which 39029 have been considered for analyses (see exclusions at point 6 above). All presented results refer to the 39029 non-excluded models still on the market at 1/1/2025. Table 49 and Figure 40 show the distribution of the model counts over the energy label classes, split in free-standing and built-in, and the distribution of the model volumes over the energy label classes, split in refrigerated and frozen volume.

82% of the models is free-standing, and 18% is intended for built in.

65% of the model volumes is refrigerated, 35% frozen.

47.5% of the models, representing 49.8% of the cooled volume, is in energy label class E.

Ecodesign regulation 2019/2019, from 1 March 2024, requires most refrigerating appliances to have an Energy Efficiency Index (EEI) not above 100. This means that RF in classes F (29.4% of models) and G (7.5%) cannot be placed on the market anymore. An exception are wine storage appliances and low-noise models, which are still allowed in classes F and G.

Most models in class G are wine storage appliances, see next section.

Table 49: Distribution of RF models per design type (count) and volumes per cooling type (litres) over the energy label classes (VHK elaboration of EPREL December 2024 data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Number of models, all	170	308	1574	4036	18534	11472	2935	**39029**
Number of models, free-standing	166	277	1410	3275	15068	9893	2000	**32089**
Number of models, built-in	4	31	164	761	3466	1579	935	**6940**
Share of models, all	0.4%	0.8%	4.0%	10.3%	47.5%	29.4%	7.5%	**100.0%**
Share of models, free-standing	0.4%	0.7%	3.6%	8.4%	38.6%	25.3%	5.1%	**82.2%**
Share of models, built-in	0.0%	0.1%	0.4%	1.9%	8.9%	4.0%	2.4%	**17.8%**
Sum of model volumes, all (litres)	63116	83338	476077	1143022	4943496	2702876	519493	**9931418**
Sum of model volumes, freeze	21076	25106	158923	379054	1786254	1069872	16729	**3457014**
Sum of model volumes, refrigerated	42040	58232	317154	763967	3157243	1633004	502764	**6474404**
Share of volume, all	0.6%	0.8%	4.8%	11.5%	49.8%	27.2%	5.2%	**100.0%**
Share of volume, freeze	0.2%	0.3%	1.6%	3.8%	18.0%	10.8%	0.2%	**34.8%**
Share of volume, refrigerated	0.4%	0.6%	3.2%	7.7%	31.8%	16.4%	5.1%	**65.2%**
Average total unit volume (litres)	371	271	302	283	267	236	177	**254**
Average freeze unit volume	124	82	101	94	96	93	6	**89**
Average refrigerated unit volume	247	189	201	189	170	142	171	**166**

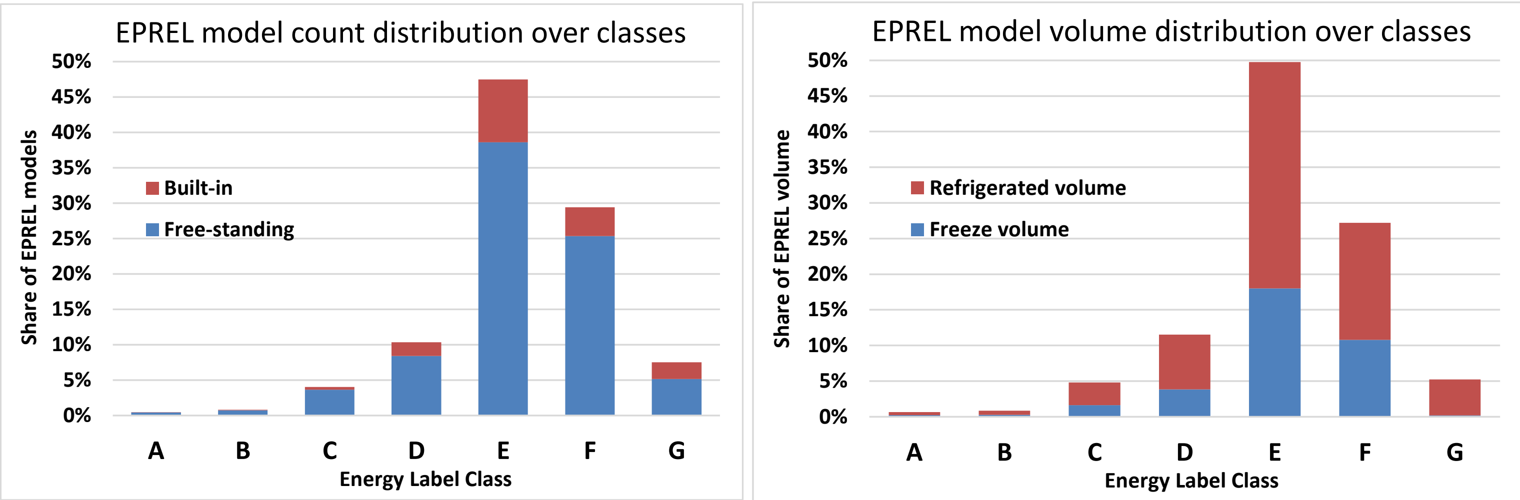

Figure 40: Distribution of RF models per design type (left) and volumes per cooling type (right) over the energy label classes (VHK elaboration of EPREL December 2024 data)

Distribution of models and volumes over the energy label classes, per type of appliance

Of the 39029 EPREL models, 45.6% are combis with a fresh-food and a 4-star freezer compartment (Table 50, last column), and 7.8% are combis with other compartment types, so 53.4% of the models are combis. Wine storage appliances are 8.1% of the models, and minibars 6.9%. The remaining 31.6% are 1-compartment models: 12.1% fresh-food, 17.0% 4-star freezers, and 2.5% other single compartment models.

Energy label class G contains 2935 models, 7.5% of the total. Of these, 2469 (84%) are wine storage appliances. Of the total 3173 wine storage appliances, 78% is in class G and 19% in class F.

Of the 9931 thousand litres total net volume of the EPREL models, 55.4% is used by combis with a fresh-food and a 4-star freezer compartment (Table 51, last column), while other combis cover 10.6% of the total volume, so 66.0% of the cooled volume is in combis. Wine storage appliances cover 5.8% of the volume, and minibars 1.0%. The remaining 27.2% of the cooled volume is in 1-compartment models: 10.7% fresh-food, 14.4% 4-star freezers, and 2.0% other single compartment models.

The average RF unit has a net volume of 254 litres (Table 51, last column). Combis are larger than average, above 300 litres, while single compartment models are smaller (200-225 litres). Wine storage appliances have an average volume of 182 litres, and minibars 37 litres.

Table 50: Distribution of RF models (count) per appliance type over the energy label classes (VHK elaboration of EPREL December 2024 data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Number of models								
all	170	308	1574	4036	18534	11472	2935	**39029**
wine store	0	1	0	13	76	614	2469	**3173**
minibar	7	70	126	256	1099	850	290	**2698**
1-compartment, fresh-food	1	11	103	488	2531	1563	18	**4715**
1-compartment, 4-star	10	13	172	572	3292	2543	14	**6616**
1-compartment, other	5	9	26	66	527	295	52	**980**
Combi, fresh-food + 4-star	37	91	713	2042	9822	5014	76	**17795**
Combi, other	110	113	434	599	1187	593	16	3052
Share of models								
all	0.4%	0.8%	4.0%	10.3%	47.5%	29.4%	7.5%	**100.0%**
wine store	0.0%	0.0%	0.0%	0.0%	0.2%	1.6%	6.3%	**8.1%**
minibar	0.0%	0.2%	0.3%	0.7%	2.8%	2.2%	0.7%	**6.9%**
1-compartment, fresh-food	0.0%	0.0%	0.3%	1.3%	6.5%	4.0%	0.0%	**12.1%**
1-compartment, 4-star	0.0%	0.0%	0.4%	1.5%	8.4%	6.5%	0.0%	**17.0%**
1-compartment, other	0.0%	0.0%	0.1%	0.2%	1.4%	0.8%	0.1%	**2.5%**
Combi, fresh-food + 4-star	0.1%	0.2%	1.8%	5.2%	25.2%	12.8%	0.2%	**45.6%**
Combi, other	0.3%	0.3%	1.1%	1.5%	3.0%	1.5%	0.0%	**7.8%**

Table 51: Distribution of RF total net volumes (litres) per appliance type over the energy label classes (VHK elaboration of EPREL December 2024 data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Sum of model volumes (litres)								
all	63116	83338	476077	1143022	4943496	2702876	519493	**9931418**
wine store	0	21	0	3033	16138	105008	453453	**577654**
minibar	176	2412	4641	9390	41490	33637	9254	**101000**
1-compartment, fresh-food	189	2171	27500	121122	603495	300706	4468	**1059650**
1-compartment, 4-star	2521	2559	33808	126209	706313	555497	3434	**1430341**
1-compartment, other	717	1983	8014	19531	108371	51590	8362	**198567**
Combi, fresh-food + 4-star	14764	31958	238163	643640	3043085	1497747	36526	**5505883**
Combi, other	44750	42235	163951	219575	424249	158365	3449	**1056575**
Share of total volume								
all	0.6%	0.8%	4.8%	11.5%	49.8%	27.2%	5.2%	**100.0%**
wine store	0.0%	0.0%	0.0%	0.0%	0.2%	1.1%	4.6%	**5.8%**
minibar	0.0%	0.0%	0.0%	0.1%	0.4%	0.3%	0.1%	**1.0%**
1-compartment, fresh-food	0.0%	0.0%	0.3%	1.2%	6.1%	3.0%	0.0%	**10.7%**
1-compartment, 4-star	0.0%	0.0%	0.3%	1.3%	7.1%	5.6%	0.0%	**14.4%**
1-compartment, other	0.0%	0.0%	0.1%	0.2%	1.1%	0.5%	0.1%	**2.0%**
Combi, fresh-food + 4-star	0.1%	0.3%	2.4%	6.5%	30.6%	15.1%	0.4%	**55.4%**
Combi, other	0.5%	0.4%	1.7%	2.2%	4.3%	1.6%	0.0%	**10.6%**
Average unit volumes (litres)								
all	371	271	302	283	267	236	177	**254**
wine store	-	21	-	233	212	171	184	**182**
minibar	25	34	37	37	38	40	32	**37**
1-compartment, fresh-food	189	197	267	248	238	192	248	**225**
1-compartment, 4-star	252	197	197	221	215	218	245	**216**
1-compartment, other	143	220	308	296	206	175	161	**203**
Combi, fresh-food + 4-star	399	351	334	315	310	299	481	**309**
Combi, other	407	374	378	367	357	267	216	**346**

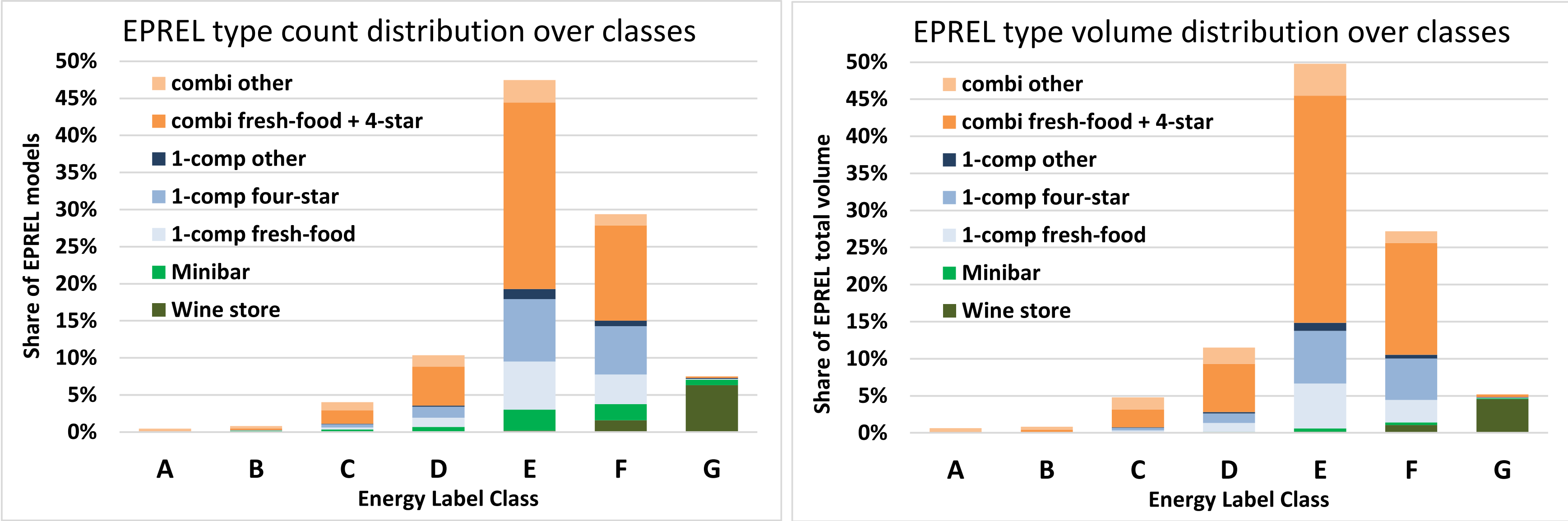

Figure 41: Distribution of RF models per type (left) and volumes per type (right) over the energy label classes (VHK elaboration of EPREL December 2024 data)

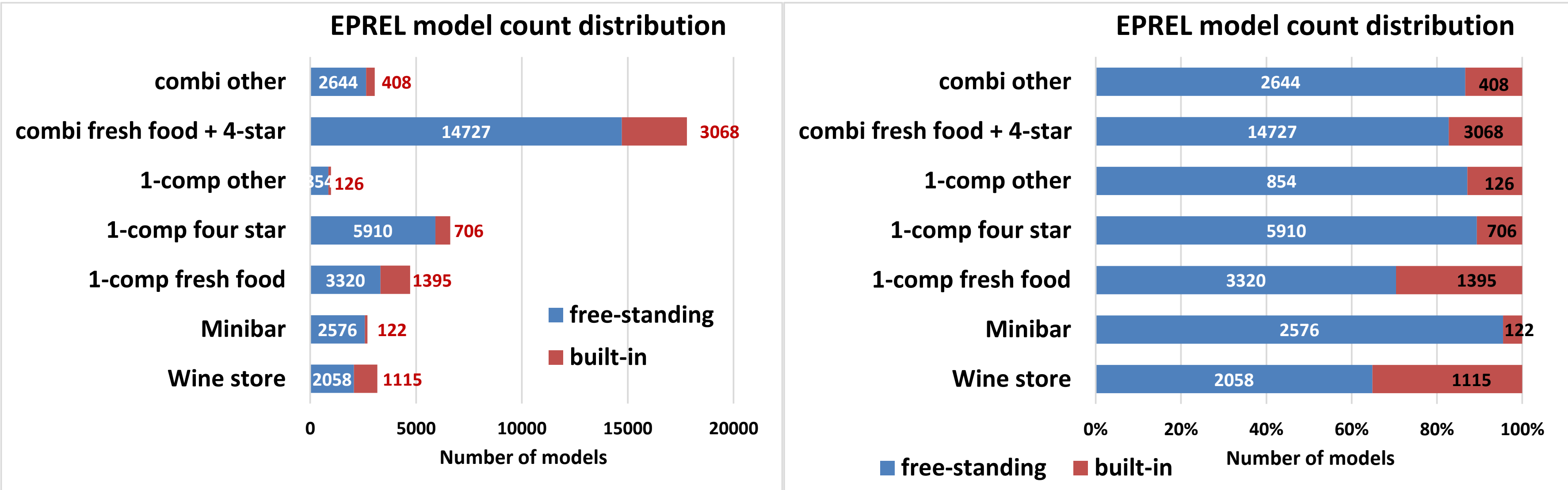

Figure 42: Distribution of RF models over the appliance types, split in free-standing and built-in (VHK elaboration of EPREL December 2024 data)

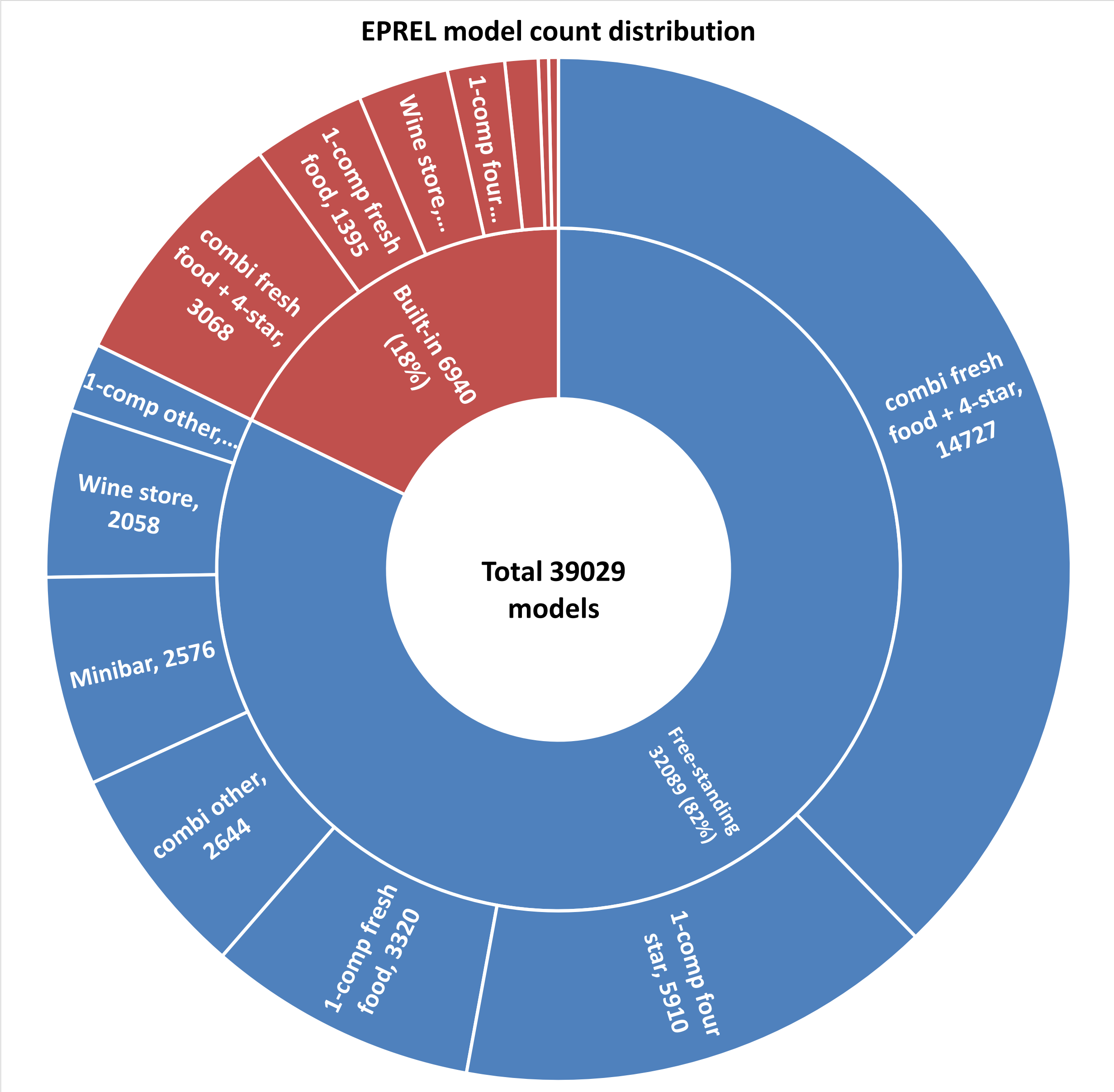

Figure 43: Distribution of RF models over the appliance types, split in free-standing and built-in, pie-chart (VHK elaboration of EPREL December 2024 data)

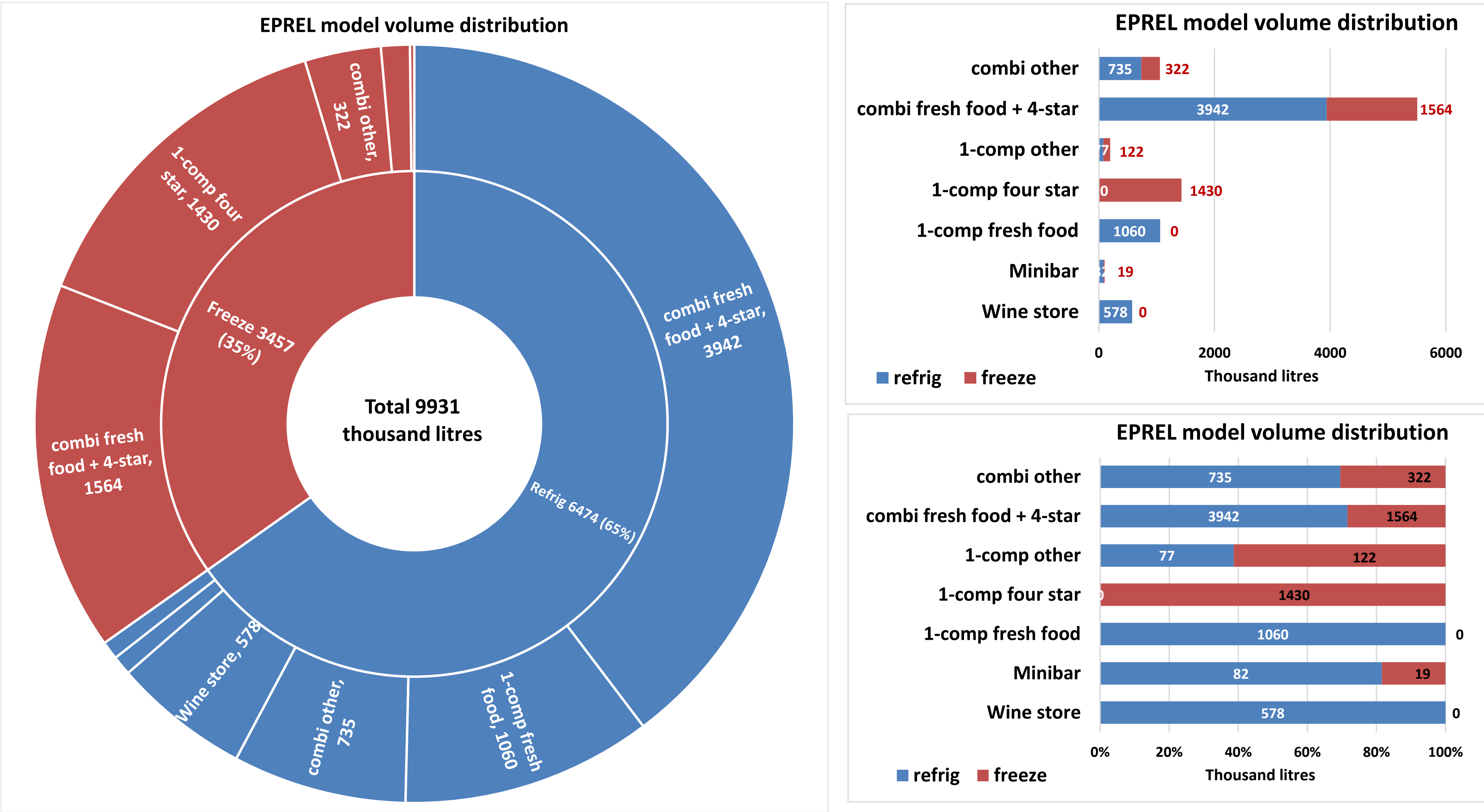

Figure 44: Distribution of RF volumes over the appliance types, split in refrigerated and frozen (VHK elaboration of EPREL December 2024 data)

Table 52: Average net refrigerated, frozen and total volumes per appliance type and per design type (VHK elaboration of EPREL December 2024 data).

	refrigerated				**frozen**				**total**		
	free	built-in	all	share	free	built-in	all	share	free	built-in	all
Wine store	207	137	**182**	100%				0%	207	137	**182**
Minibar	30	32	**31**	82%	7	0	**7**	18%	38	32	**37**
1-comp fresh food	219	239	**225**	100%				0%	219	239	**225**
1-comp 4-star chest				0%	204	100	**197**	100%	204	100	**197**
1-comp 4-star upright				0%	239	265	**243**	100%	239	265	**243**
1-comp other	67	155	**78**	39%	132	69	**124**	61%	199	224	**203**
combi fresh food + 4-star	228	192	**222**	72%	94	59	**88**	28%	322	251	**309**
combi other	247	199	**241**	70%	113	58	**106**	30%	360	257	**346**
weighted average	**165**	**170**	**166**	**65%**	**97**	**52**	**89**	**35%**	**262**	**221**	**254**

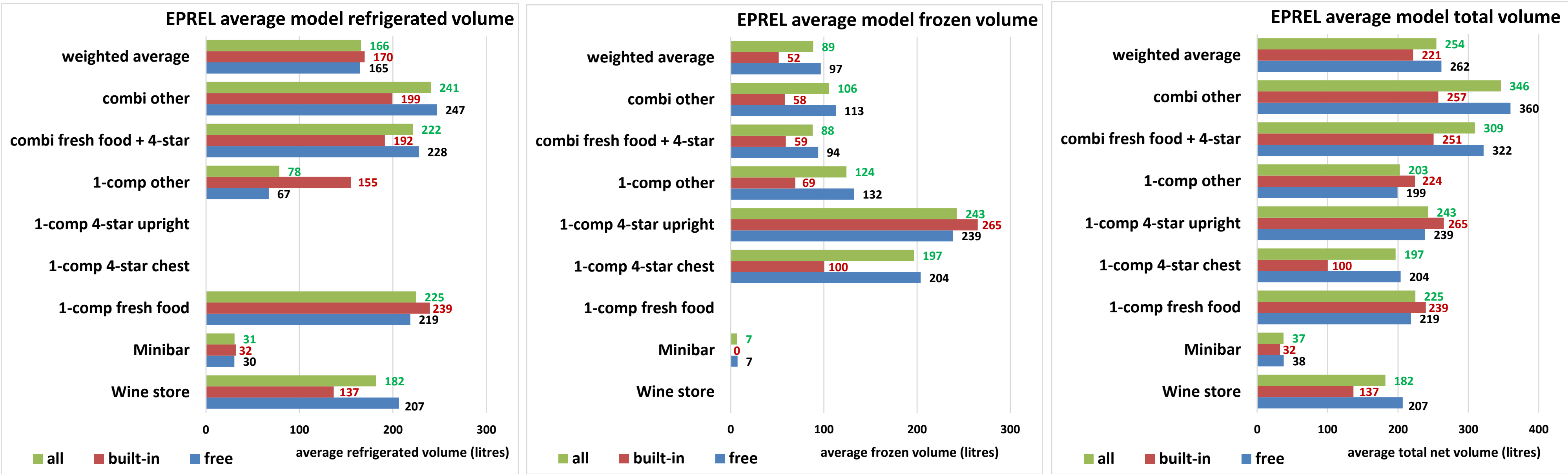

Figure 45: Average net refrigerated, frozen and total volumes per appliance type and per design type (VHK elaboration of EPREL December 2024 data).

Distribution of electricity consumption over the appliance types

The 39029 RF models in EPREL consume a total of 7858 MWh of electricity per year: on average 201 kWh/a/unit (Table 53). The average annual consumption is lower for minibars (107 kWh/a/unit) and wine storage appliances (140 kWh/a/unit), and higher for 1-compartment 4-star freezers (228 kWh/a/unit) and combis (223-235 kWh/a/unit).

The average kWh/a/unit depend on the efficiency and on the volume of the appliances. Dividing the declared kWh/a/unit by the net cooled volume gives the specific annual electricity consumption in kWh/a/litre (Table 53), which is more indicative for the energy efficiency. Small volume minibars have the highest annual electricity consumption per litre (3.15 kWh/a/litre), followed by wine storage appliances (1.36 kWh/a/litre) and 1-compartment 4-star freezers (1.26 kWh/a/litre). The lowest specific consumptions are for combis (0.64-0.76 kWh/a/litre) and 1-compartment fresh-food (0.66 kWh/a/litre). The average over all EPREL models is 1.09 kWh/a/litre.

For most appliance types and energy label classes, the average energy efficiency index is close to the largest value that still falls in the class (Table 53 near the bottom). E.g. for class E, with EEI between 80 and 100, the average EEIs vary from 96 to 100. The average over all EPREL models is EEI 109.

Table 53: Distribution of RF electricity consumption (kWh/a) per appliance type over the energy label classes (VHK elaboration of EPREL December 2024 data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Sum of model electricity (kWh/a)								
all	18649	33446	229188	699714	3737866	2642573	497068	**7858502**
wine store	0	100	0	1151	6974	65838	369266	**443329**
minibar	628	2678	6292	16778	107772	95849	58101	**288097**
1-compartment, fresh-food	66	838	9740	55334	285807	209252	2934	**563970**
1-compartment, 4-star	916	2004	23156	100616	703677	666633	8873	**1505876**
1-compartment, other	319	514	2644	22103	105216	58894	13023	**202713**
Combi, fresh-food + 4-star	4061	11667	112155	378172	2238271	1395832	34629	**4174787**
Combi, other	12659	15645	75200	125559	290148	150275	10243	**679729**
Share of total electricity								
all	0.2%	0.4%	2.9%	8.9%	47.6%	33.6%	6.3%	**100.0%**
wine store	0.0%	0.0%	0.0%	0.0%	0.1%	0.8%	4.7%	**5.6%**
minibar	0.0%	0.0%	0.1%	0.2%	1.4%	1.2%	0.7%	**3.7%**
1-compartment, fresh-food	0.0%	0.0%	0.1%	0.7%	3.6%	2.7%	0.0%	**7.2%**
1-compartment, 4-star	0.0%	0.0%	0.3%	1.3%	9.0%	8.5%	0.1%	**19.2%**
1-compartment, other	0.0%	0.0%	0.0%	0.3%	1.3%	0.7%	0.2%	**2.6%**
Combi, fresh-food + 4-star	0.1%	0.1%	1.4%	4.8%	28.5%	17.8%	0.4%	**53.1%**
Combi, other	0.2%	0.2%	1.0%	1.6%	3.7%	1.9%	0.1%	**8.6%**
Average unit electricity (kWh/a)								

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
all	110	109	146	173	202	230	169	**201**
wine store	-	100	-	89	92	107	150	**140**
minibar	90	38	50	66	98	113	200	**107**
1-compartment, fresh-food	66	76	95	113	113	134	163	**120**
1-compartment, 4-star	92	154	135	176	214	262	634	**228**
1-compartment, other	64	57	102	335	200	200	250	**207**
Combi, fresh-food + 4-star	110	128	157	185	228	278	456	**235**
Combi, other	115	138	173	210	244	253	640	**223**
<u>Average specific electricity (kWh/a/litre)</u>								
all	0.40	0.62	0.60	0.74	0.97	1.27	1.98	**1.09**
wine store	-	4.75	-	0.44	0.76	1.12	1.44	**1.36**
minibar	2.65	1.29	1.47	2.00	2.87	3.05	6.65	**3.15**
1-compartment, fresh-food	0.20	0.33	0.38	0.46	0.59	0.87	0.68	**0.66**
1-compartment, 4-star	0.37	0.82	0.83	0.93	1.18	1.45	4.52	**1.26**
1-compartment, other	0.45	0.26	0.33	1.13	0.97	1.14	1.56	**1.02**
Combi, fresh-food + 4-star	0.28	0.37	0.47	0.59	0.74	0.93	0.95	**0.76**
Combi, other	0.28	0.37	0.46	0.57	0.68	0.95	2.97	**0.64**
<u>Average EEI</u>								
all	40	50	64	80	99	124	182	**109**
wine store	-	42	-	77	96	122	169	**158**
minibar	35	47	60	76	98	121	272	**119**
1-compartment, fresh-food	40	51	64	80	99	124	152	**105**
1-compartment, 4-star	41	50	64	80	99	124	333	**107**
1-compartment, other	41	50	62	77	98	124	228	**110**
Combi, fresh-food + 4-star	40	51	64	80	100	124	158	**103**
Combi, other	41	51	64	80	99	124	348	**92**

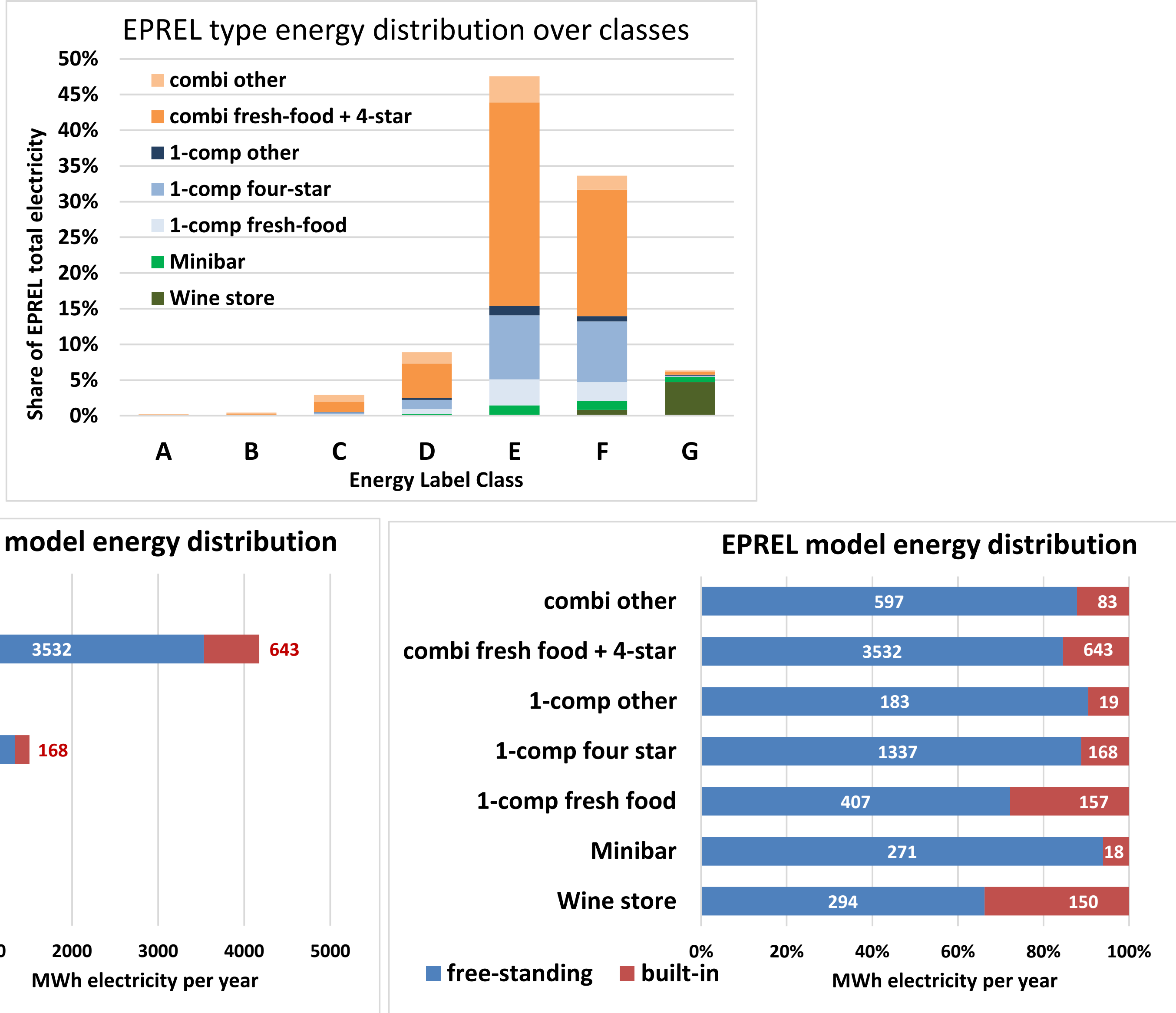

Figure 46: Distribution of RF models' annual electricity consumption over the appliance types, split in free-standing and built-in (VHK elaboration of EPREL December 2024 data)

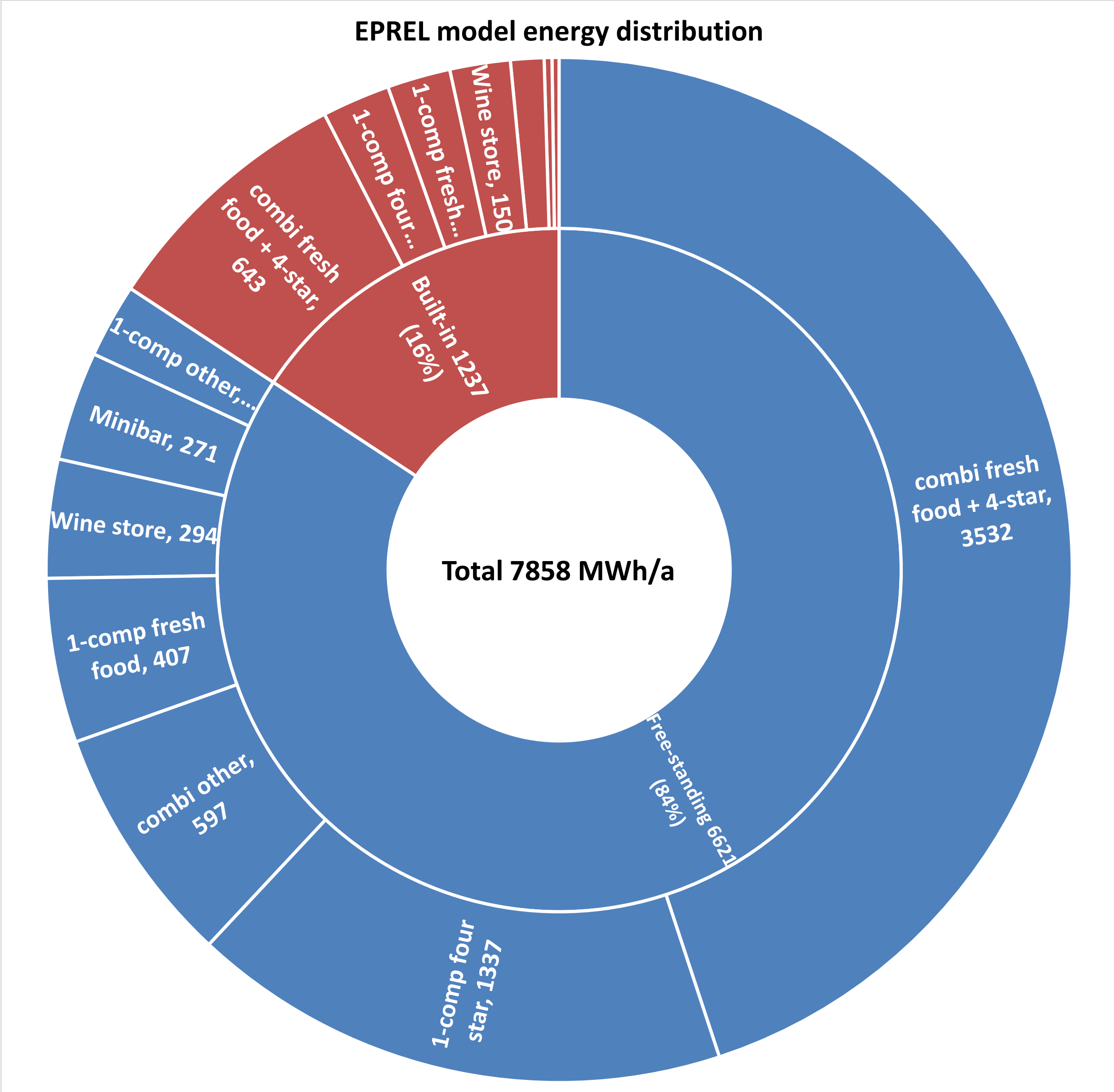

Figure 47: Distribution of RF models' annual electricity consumption over the appliance types, split in free-standing and built-in, pie-chart (VHK elaboration of EPREL December 2024 data)

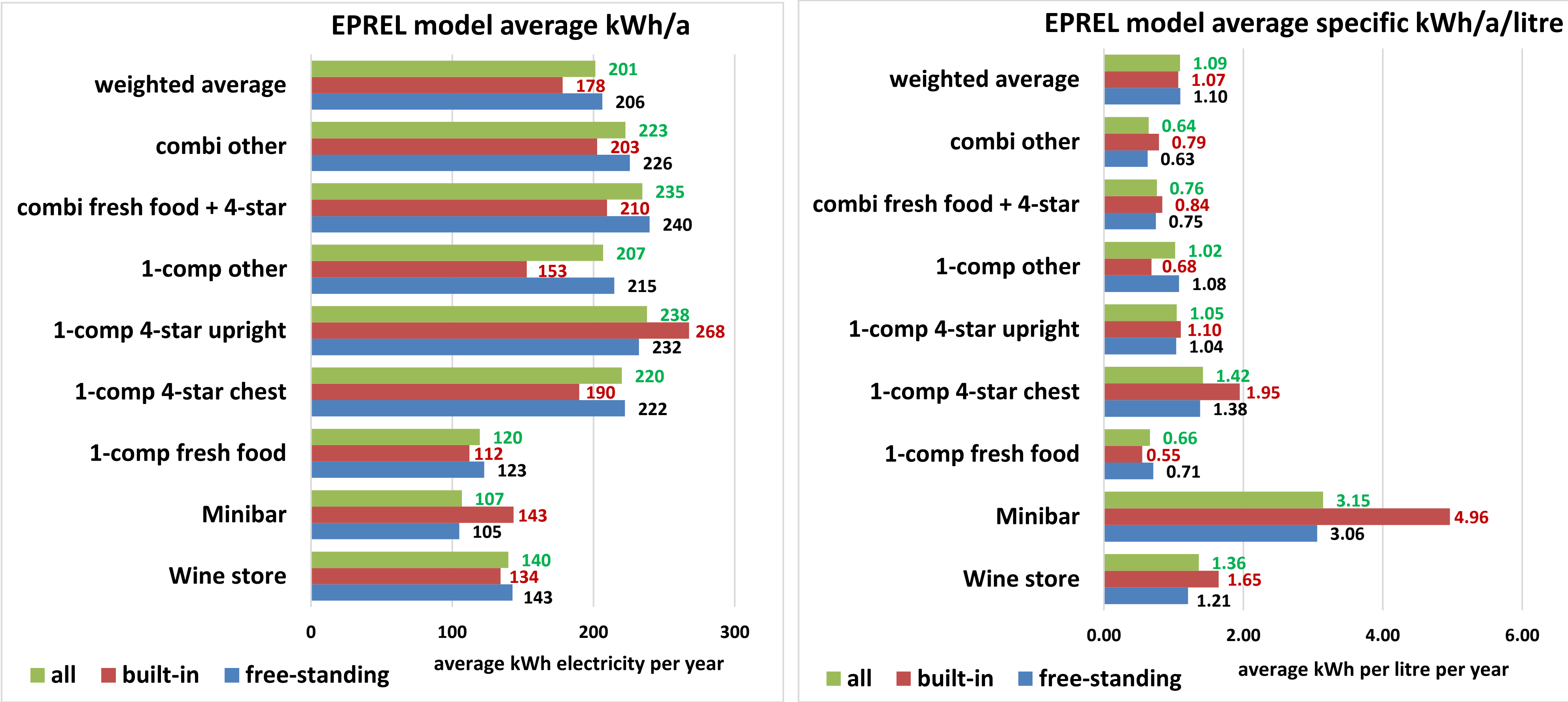

Figure 48: Average annual electricity consumption (kWh/a/unit) and specific consumption (kWh/a/litre) for EPREL models, per appliance type, split in free-standing and built-in (VHK elaboration of EPREL December 2024 data)

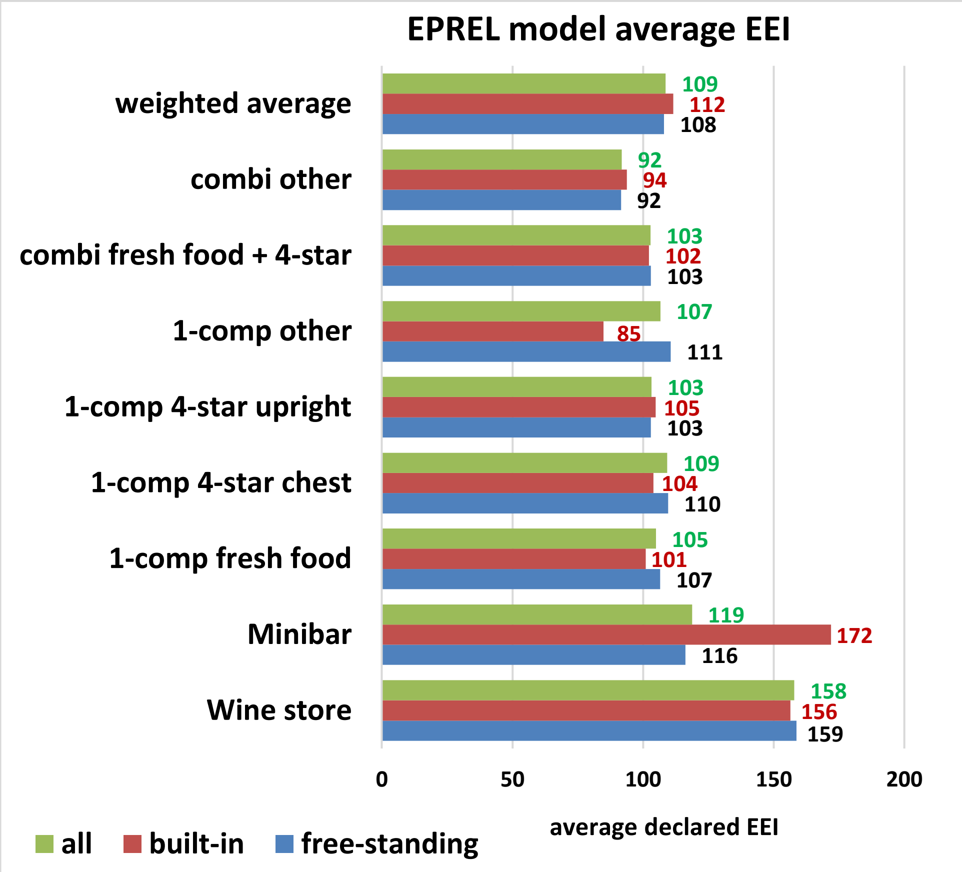

Figure 49: Average declared energy efficiency index (EEI) for EPREL models, per appliance type, split in free-standing and built-in (VHK elaboration of EPREL December 2024 data)

External to internal volume ratios

Based on the external dimensions declared in EPREL (width, depth, height), the external volumes (litres) and the ratios of external to internal net volume have been computed.

On average, over all EPREL models, the external volume is 2.26 times the net internal volume (Table 54). For free-standing models this is slightly higher (2.28) and for built-in models smaller (2.17). However, the situation differs per appliance type (Figure 50).

Free-standing models in energy label classes B, C and D have a higher average volume ratio than in the other classes. This seems to indicate that thermal insulation thickness has been increased to improve energy efficiency. For models in class A, the volume ratio is on average smaller, which could be due to application of vacuum insulation panels (same thermal insulation with smaller wall thickness).

For minibars, the volume ratio (2.80) is higher than for other types. This is probably also due to the small internal volumes: at parity of wall thickness, the volume ratio increases with decreasing internal volume.

For combis (2.10-2.13) and non-freezer 1-compartment appliances (2.02-2.13), the average volume ratio is smaller than the overall average (2.26).

For 1-compartment 4-star freezers the average volume ratio is 2.55, but it is higher for upright models (2.66) and lower for chest freezers (2.47).

Table 54: Average ratio between external and internal volume, per RF model type and per energy label class (VHK elaboration of EPREL December 2024 data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Average volume ratio								
All	2.25	2.41	2.32	2.31	2.24	2.25	2.29	**2.26**
All, free-standing	2.24	2.43	2.34	2.36	2.27	2.26	2.20	**2.28**
All, built-in	2.92	2.24	2.17	2.10	2.10	2.19	2.48	**2.17**
wine store	-	2.70	-	2.29	2.29	2.32	2.21	**2.23**
minibar	3.42	3.04	2.94	3.07	2.74	2.67	3.00	**2.80**
1-compartment, fresh-food	2.32	1.93	2.12	2.03	2.01	2.03	1.91	**2.02**
1-compartment, 4-star, all	2.75	2.92	2.94	2.74	2.59	2.43	2.88	**2.55**
1-compartment, 4-star, chest	2.68	2.97	3.05	2.79	2.51	2.36	2.74	**2.47**
1-compartment, 4-star, upright	2.91	2.86	2.82	2.70	2.66	2.62	2.99	**2.66**
1-compartment, other	2.53	1.56	1.58	2.00	2.21	2.11	2.08	**2.13**
Combi, fresh-food + 4-star	2.11	2.21	2.17	2.17	2.12	2.13	2.14	**2.13**
Combi, other	2.11	2.15	2.13	2.14	2.04	2.16	2.37	**2.10**

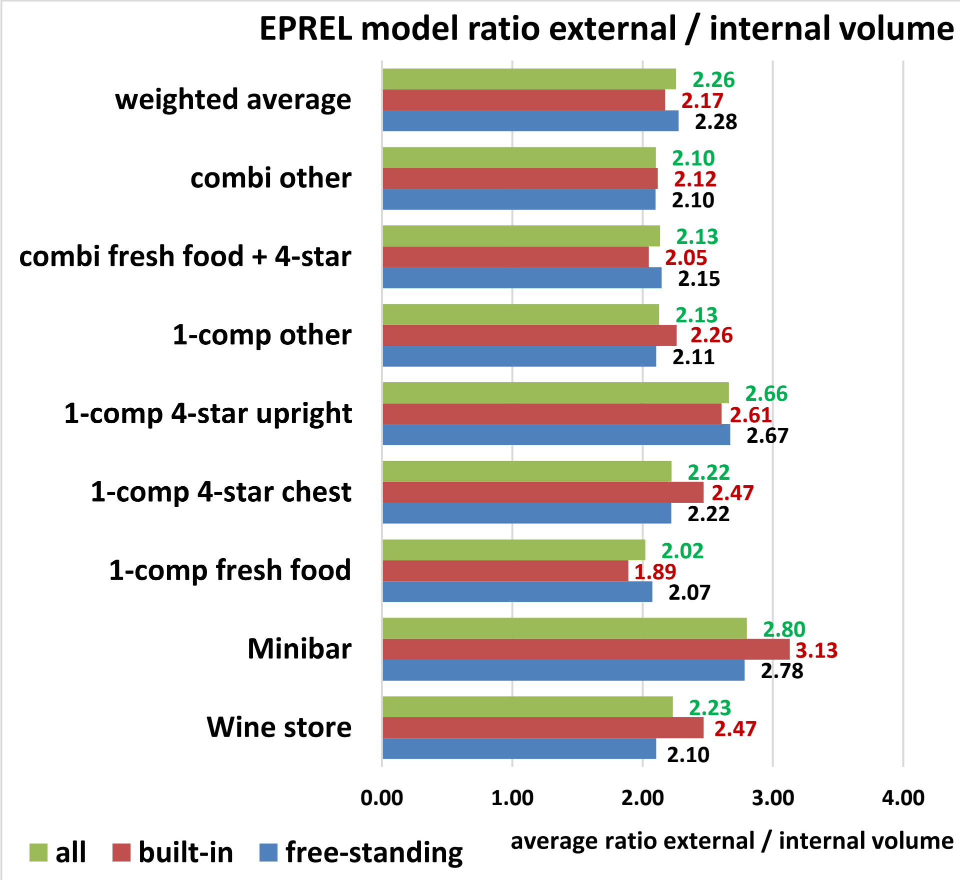

Figure 50: Average ratio between external and internal volume, per RF model type, split in free-standing and built-in (VHK elaboration of EPREL December 2024 data)

Wine Storage Appliances, distribution over volume ranges

Table 55 summarizes the EPREL data for wine storage appliances [420], per energy label class.

Wine storage appliances are 8.1% of the RF models registered in EPREL, represent 5.8% of the cooled volume, and consume 5.6% of the electricity.

78% of the wine storage appliances is in energy label class G.

Table 55: Wine storage appliances per energy label class (VHK elaboration of EPREL December 2024 data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Model count	0	1	0	13	76	614	2469	**3173**
Share of Wine Storage	0.0%	0.0%	0.0%	0.4%	2.4%	19.4%	77.8%	**100.0%**
Share of all models	0.0%	0.0%	0.0%	0.0%	0.2%	1.6%	6.3%	**8.1%**
Model count, share free-standing	0.0%	0.0%	0.0%	0.3%	1.7%	11.8%	51.0%	**64.9%**
Model count, share built-in	0.0%	0.0%	0.0%	0.1%	0.7%	7.5%	26.8%	**35.1%**
Total volume (litres)	0	21	0	3033	16138	105008	453453	**577654**
Volume share of Wine Storage	0.0%	0.0%	0.0%	0.5%	2.8%	18.2%	78.5%	**100.0%**
Volume share of All non-excluded	0.0%	0.0%	0.0%	0.0%	0.2%	1.1%	4.6%	**5.8%**
Average volume (litres)	-	21	-	233	212	171	184	**182**
External volume (litres)	0	57	0	7398	34141	213698	910746	**1166040**
External Volume share of Wine Storage	0.0%	0.0%	0.0%	0.6%	2.9%	18.3%	78.1%	**100.0%**
Average external volume (litres)	-	57	-	569	449	348	369	**367**
Average external / internal volume ratio	-	2.70	-	2.29	2.29	2.32	2.21	**2.23**
Annual Energy Consumption (kWh/a)	0	100	0	1151	6974	65838	369266	**443329**
AEC share of Wine store	0.0%	0.0%	0.0%	0.3%	1.6%	14.9%	83.3%	**100.0%**
AEC share of All non-excluded	0.0%	0.0%	0.0%	0.0%	0.1%	0.8%	4.7%	5.6%
Average AEC (kWh/a)	-	100	-	89	92	107	150	**140**
Specific AEC (kWh/a/litre)	-	4.75	-	0.44	0.76	1.12	1.44	1.36
Average EEI	-	42	-	77	96	122	169	**158**

[420] There are 57 models in EPREL that are not explicitly declared as wine storage appliance, but that have a single compartment of type wine storage. These have not been counted as wine storage, but as 1-compartment refrigerated models. On the other hand, models with a volume below 60 liters, explicitly declared as wine storage appliance have been counted as such, and not as minibars.

Wine storage appliances have an average net volume of 182 litres. Figure 35 (left) shows the distribution of the models over the net volume ranges. There are many models with volumes up to 150 litres, with highest model counts in the ranges 50 to 70 and 110 to 130 litres. The models with volume larger than 150 litres are spread over many volume ranges, up to a maximum of 600-700 litres.

Figure 51 (right) shows the distribution of the sum of cooled volumes over the volume ranges. The median volume is around 320 litres, in the sense that half of the cooled volume is provided by models with net volume below 320 litres, and the other half by models with volume larger than 320 litres.

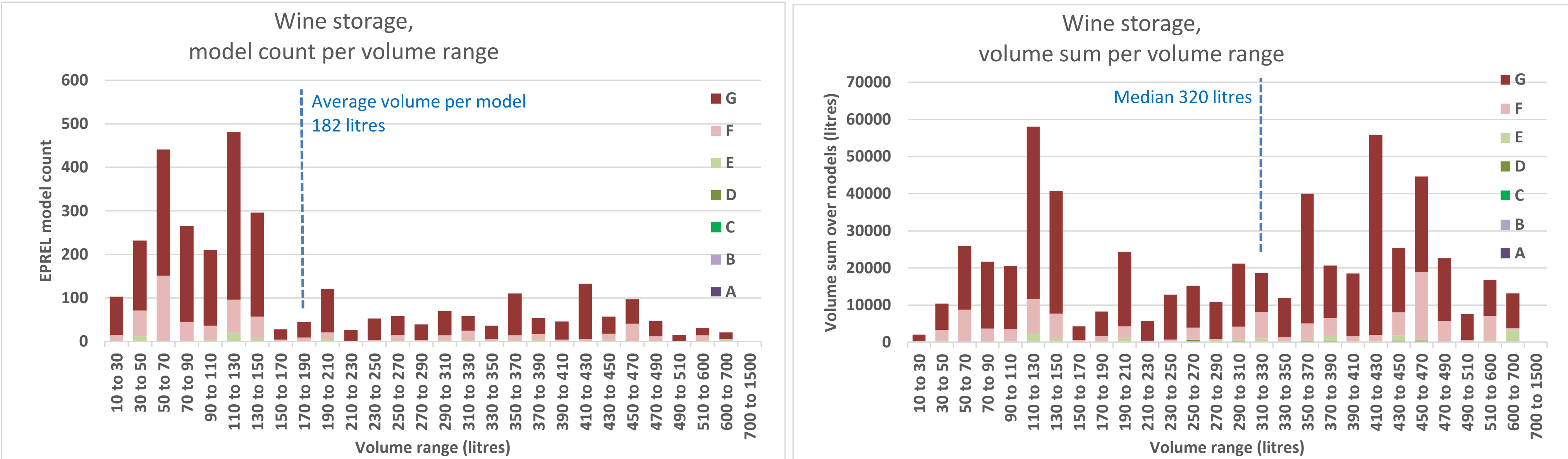

Figure 51: Wine storage appliances: number of models and sum of net internal volumes per volume range and energy label class (VHK elaboration of EPREL December 2024 data)

Minibars, distribution over volume ranges

Table 56 summarizes the EPREL data for minibars [421], per energy label class.

Minibars are 6.9% of the RF models registered in EPREL, represent 1.0% of the cooled volume, and consume 3.7% of the electricity.

42.2% of the minibars is in energy label class F or G [422].

Table 56: Minibars per energy label class (VHK elaboration of EPREL December 2024 data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Model count	7	70	126	256	1099	850	290	**2698**
Share of Minibars	0.3%	2.6%	4.7%	9.5%	40.7%	31.5%	10.7%	**100.0%**
Share of all models	0.0%	0.2%	0.3%	0.7%	2.8%	2.2%	0.7%	**6.9%**
Model count, share free-standing	0.2%	2.5%	4.4%	9.2%	39.8%	30.8%	8.5%	**95.5%**
Model count, share built-in	0.0%	0.1%	0.3%	0.3%	0.9%	0.7%	2.3%	**4.5%**
Total net volume (litres)	176	2412	4641	9390	41490	33637	9254	**101000**
Volume share of Minibars	0.2%	2.4%	4.6%	9.3%	41.1%	33.3%	9.2%	**100.0%**
Volume share of All non-excluded	0.0%	0.0%	0.0%	0.1%	0.4%	0.3%	0.1%	**1.0%**
Average total net volume (litres)	25	34	37	37	38	40	32	**37**
Average refrigerated volume	23	34	35	35	27	33	32	31
Average freeze volume	2	1	2	2	11	7	0	**7**
External volume (litres)	548	7100	13284	28268	113230	89090	27259	**278780**
External Volume share of Minibars	0.2%	2.5%	4.8%	10.1%	40.6%	32.0%	9.8%	**100.0%**
Average external volume (litres)	78	101	105	110	103	105	94	**103**
Average external / internal volume ratio	3.42	3.04	2.94	3.07	2.74	2.67	3.00	**2.80**
Annual Energy Consumption (kWh/a)	628	2678	6292	16778	107772	95849	58101	**288097**
AEC share of Minibars	0.2%	0.9%	2.2%	5.8%	37.4%	33.3%	20.2%	**100.0%**
AEC share of All non-excluded	0.0%	0.0%	0.1%	0.2%	1.4%	1.2%	0.7%	3.7%
Average AEC (kWh/a)	90	38	50	66	98	113	200	**107**
Specific AEC (kWh/a/litre)	2.65	1.29	1.47	2.00	2.87	3.05	6.65	3.15

[421] Models with a total net volume below 60 liters. Models explicitly declared as wine storage appliance have been counted as such, and not as minibars, even if their total net volume is below 60 liters.

[422] It has not verified if these models are low-noise (the supplied EPREL extract did not contain these data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Average EEI	35	47	60	76	98	121	272	**119**

Minibars have an average net volume of 37 litres. Figure 52 (left) shows the distribution of the models over the net volume ranges. Most models are in the ranges 30 to 35 and 40 to 45 litres.

Figure 52 (right) shows the distribution of the sum of cooled volumes over the volume ranges. The median volume is around 40 litres, in the sense that half of the cooled volume is provided by models with net volume below 40 litres, and the other half by models with volume larger than 40 litres.

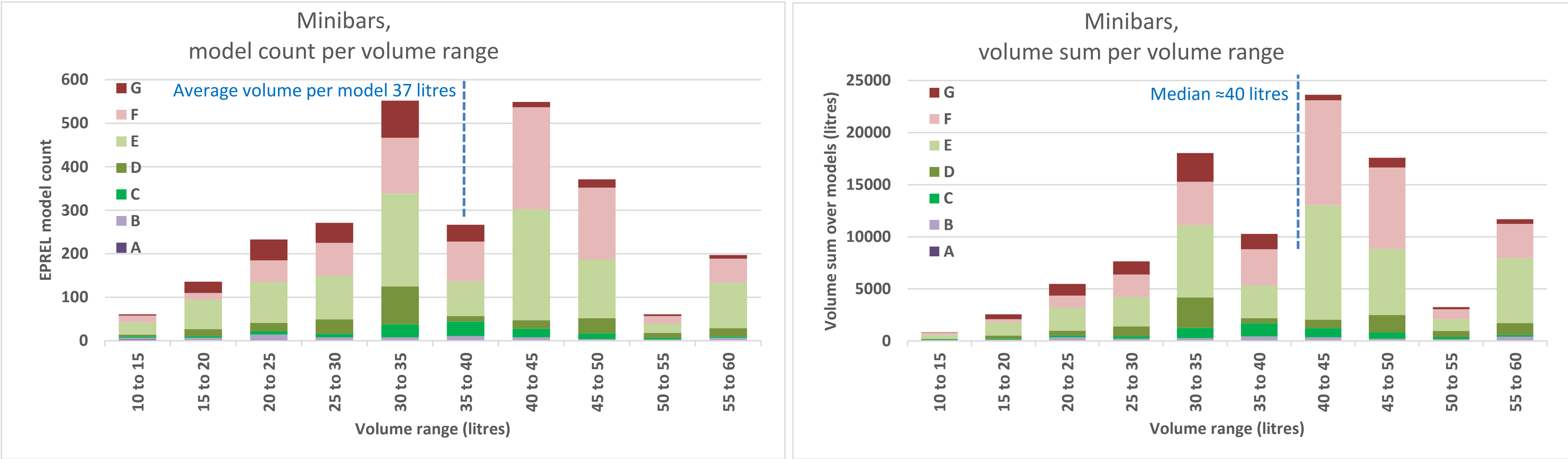

Figure 52: Minibars: number of models and sum of net internal volumes per volume range and energy label class (VHK elaboration of EPREL December 2024 data)

Single-compartment models, distribution over compartment types

Table 57 summarizes the EPREL data for 1-compartment RF models [423], per energy label class.

Single-compartment models are 31.5% of the RF models registered in EPREL, represent 27.1% of the cooled volume, and consume 28.9% of the electricity.

36.4% of the 1-compartment models is in energy label class F or G [424].

Table 57: Single-compartment models per energy label class (VHK elaboration of EPREL December 2024 data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Model count	16	33	301	1126	6350	4401	84	**12311**
Share of 1-Compartment	0.1%	0.3%	2.4%	9.1%	51.6%	35.7%	0.7%	**100.0%**
Share of all models	0.0%	0.1%	0.8%	2.9%	16.3%	11.3%	0.2%	**31.5%**
Model count, share free-standing	0.1%	0.2%	2.1%	6.7%	40.9%	31.4%	0.6%	**81.9%**
Model count, share built-in	0.0%	0.1%	0.4%	2.4%	10.7%	4.4%	0.1%	**18.1%**
Total net volume (litres)	**3427**	**6712**	**69322**	**266862**	**1418179**	**907793**	**16264**	**2688558**
Volume share of 1-Compartment	**0.1%**	**0.2%**	**2.6%**	**9.9%**	**52.7%**	**33.8%**	**0.6%**	**100.0%**
Volume share of All non-excluded	**0.0%**	**0.1%**	**0.7%**	**2.7%**	**14.3%**	**9.1%**	**0.2%**	**27.1%**
Average total net volume (litres)	214	203	230	237	223	206	194	218
Average refrigerated volume	57	112	110	121	100	72	148	92
Average freeze volume	158	92	121	116	123	135	46	126
External volume (litres)	9484	15236	171355	621618	3185226	2006257	34506	**6043681**
External Volume share of 1-Compartment	0.2%	0.3%	2.8%	10.3%	52.7%	33.2%	0.6%	**100.0%**
Average external volume (litres)	593	462	569	552	502	456	411	**491**
Average external / internal volume ratio	2.85	2.44	2.61	2.41	2.32	2.27	2.27	**2.32**
Annual Energy Consumption (kWh/a)	1301	3356	35540	178053	1094700	934780	24830	**2272559**
AEC share of 1-Compartment	0.1%	0.1%	1.6%	7.8%	48.2%	41.1%	1.1%	**100.0%**
AEC share of All non-excluded	0.0%	0.0%	0.5%	2.3%	13.9%	11.9%	0.3%	28.9%
Average AEC (kWh/a)	81	102	118	158	172	212	296	**185**
Specific AEC (kWh/a/litre)	0.43	0.56	0.65	0.74	0.94	1.23	2.12	1.02
Average EEI	41	51	64	80	99	124	229	**106**

[423] Except minibars and models declared to be for wine storage.

[424] It has not verified if these models are low-noise (the supplied EPREL extract did not contain these data).

Table 58 provides the model count breakdown per compartment type for 1-compartment RF models, per energy label class. Subtotals are provided for refrigerators (including chillers) and for freezers (including variable temperature compartments). The latter subtotal is also broken down in chest freezers (height smaller than 1000 mm) and upright freezers (height larger than 1000 mm) [425].

Table 59 gives the model count shares in all EPREL models. The single-compartment models are 31.5% of the total, and most are fresh-food refrigerated appliances (12.1% of total; 38.3% of 1-compartment) and four-star freezing appliances (17.0% of total, 53.7% of 1-compartment). All other compartment types represent 2.4% of the total (8.0% of 1-compartment).

Table 60 provides for each compartment type the model count shares over the label classes (sum of shares per type is 100%). Table 61 provides for each class the model count shares for the compartment types (sum of shares per class is 100%).

Further details for fresh-food refrigerators, chest freezers and upright freezers are presented in the next sections.

Table 58: Single-compartment model counts per compartment type and per energy label class (VHK elaboration of EPREL December 2024 data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Model count - all types	**16**	**33**	**301**	**1126**	**6350**	**4401**	**84**	**12311**
Model count - Pantry	0	5	5	9	77	12	14	**122**
Model count - Wine storage	0	0	0	0	6	7	30	**43**
Model count - Cellar	0	0	2	6	60	66	6	**140**
Model count - Fresh food	1	11	103	488	2531	1563	18	**4715**
Model count - Chill	5	3	9	37	67	30	0	**151**
Model count - Sum Refrigeration	**6**	**19**	**119**	**540**	**2741**	**1678**	**68**	**5171**
Model count - 0 star	0	0	0	1	2	5	0	**8**
Model count - 1 star	0	0	2	0	2	5	0	**9**
Model count - 2 star	0	0	0	0	11	3	2	**16**
Model count - 2 star section	0	0	0	0	0	1	0	**1**
Model count - 3 star	0	0	0	0	21	16	0	**37**
Model count - 4 star	10	13	172	572	3292	2543	14	**6616**
Model count - variable temperature	0	1	8	13	281	150	0	**453**
Model count - Sum Freezing	**10**	**14**	**182**	**586**	**3609**	**2723**	**16**	**7140**
Model count – Chest freezers	7	7	95	237	1901	1977	6	4230
Model count – Upright freezers	3	7	87	349	1708	746	10	2910

[425] Chest freezers have a lid that opens at the top; upright freezers a door that opens at the front, but this information is not available in EPREL. There are hardly any freezers with height below 800 mm, many with a height between 800 and 900 mm, few with a height between 900 and 1400 mm, and then many with height 1400 – 2200 mm. Considering the type of use, freezers with height above 1000 mm are almost certainly upright. Assumed that those with height < 1000 mm are chest type. This gives 59% chest type, which is compatible with earlier studies.

Table 59: Share in all non-excluded RF models - Single-compartment model counts per compartment type and per energy label class (VHK elaboration of EPREL December 2024 data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Shares in all models - all types	**0.0%**	**0.1%**	**0.8%**	**2.9%**	**16.3%**	**11.3%**	**0.2%**	**31.5%**
Shares in all models - Pantry	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.3%
Shares in all models - Wine storage	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%
Shares in all models - Cellar	0.0%	0.0%	0.0%	0.0%	0.2%	0.2%	0.0%	0.4%
Shares in all models - Fresh food	0.0%	0.0%	0.3%	1.3%	6.5%	4.0%	0.0%	12.1%
Shares in all models - Chill	0.0%	0.0%	0.0%	0.1%	0.2%	0.1%	0.0%	0.4%
Shares in all models - Sum Refrigeration	**0.0%**	**0.0%**	**0.3%**	**1.4%**	**7.0%**	**4.3%**	**0.2%**	**13.2%**
Shares in all models - 0 star	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Shares in all models - 1 star	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Shares in all models - 2 star	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Shares in all models - 2 star section	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Shares in all models - 3 star	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%
Shares in all models - 4 star	0.0%	0.0%	0.4%	1.5%	8.4%	6.5%	0.0%	17.0%
Shares in all models - variable temperature	0.0%	0.0%	0.0%	0.0%	0.7%	0.4%	0.0%	1.2%
Shares in all models - Sum Freezing	**0.0%**	**0.0%**	**0.5%**	**1.5%**	**9.2%**	**7.0%**	**0.0%**	**18.3%**
Shares in all models – Chest freezers	0.0%	0.0%	0.2%	0.6%	4.9%	5.1%	0.0%	10.8%
Shares in all models – Upright freezers	0.0%	0.0%	0.2%	0.9%	4.4%	1.9%	0.0%	7.5%

Table 60: Class shares per type - Single-compartment model counts per compartment type and per energy label class (VHK elaboration of EPREL December 2024 data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Class shares in type - all types	**0.1%**	**0.3%**	**2.4%**	**9.1%**	**51.6%**	**35.7%**	**0.7%**	**100.0%**
Class shares in type - Pantry	0.0%	4.1%	4.1%	7.4%	63.1%	9.8%	11.5%	100.0%
Class shares in type - Wine storage	0.0%	0.0%	0.0%	0.0%	14.0%	16.3%	69.8%	100.0%
Class shares in type - Cellar	0.0%	0.0%	1.4%	4.3%	42.9%	47.1%	4.3%	100.0%
Class shares in type - Fresh food	0.0%	0.2%	2.2%	10.3%	53.7%	33.1%	0.4%	100.0%
Class shares in type - Chill	3.3%	2.0%	6.0%	24.5%	44.4%	19.9%	0.0%	100.0%
Class shares in type - Sum Refrigeration	**0.1%**	**0.4%**	**2.3%**	**10.4%**	**53.0%**	**32.5%**	**1.3%**	**100.0%**
Class shares in type - 0 star	0.0%	0.0%	0.0%	12.5%	25.0%	62.5%	0.0%	100.0%
Class shares in type - 1 star	0.0%	0.0%	22.2%	0.0%	22.2%	55.6%	0.0%	100.0%
Class shares in type - 2 star	0.0%	0.0%	0.0%	0.0%	68.8%	18.8%	12.5%	100.0%
Class shares in type - 2 star section	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	100.0%

EEI **Class**	< 41 **A**	41-51 **B**	51-64 **C**	64-80 **D**	80-100 **E**	100-125 **F**	> 125 **G**	 **All**
Class shares in type - 3 star	0.0%	0.0%	0.0%	0.0%	56.8%	43.2%	0.0%	100.0%
Class shares in type - 4 star	0.2%	0.2%	2.6%	8.6%	49.8%	38.4%	0.2%	100.0%
Class shares in type - variable temperature	0.0%	0.2%	1.8%	2.9%	62.0%	33.1%	0.0%	100.0%
Class shares in type - Sum Freezing	**0.1%**	**0.2%**	**2.5%**	**8.2%**	**50.5%**	**38.1%**	**0.2%**	**100.0%**
Class shares in type – Chest freezers	0.2%	0.2%	2.2%	5.6%	44.9%	46.7%	0.1%	100.0%
Class shares in type – Upright freezers	0.1%	0.2%	3.0%	12.0%	58.7%	25.6%	0.3%	100.0%

Table 61: Type shares per class - Single-compartment model counts per compartment type and per energy label class (VHK elaboration of EPREL December 2024 data).

EEI **Class**	< 41 **A**	41-51 **B**	51-64 **C**	64-80 **D**	80-100 **E**	100-125 **F**	> 125 **G**	 **All**
Type shares in class - all types	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**
Type shares in class - Pantry	0.0%	15.2%	1.7%	0.8%	1.2%	0.3%	16.7%	1.0%
Type shares in class - Wine storage	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	35.7%	0.3%
Type shares in class - Cellar	0.0%	0.0%	0.7%	0.5%	0.9%	1.5%	7.1%	1.1%
Type shares in class - Fresh food	6.3%	33.3%	34.2%	43.3%	39.9%	35.5%	21.4%	38.3%
Type shares in class - Chill	31.3%	9.1%	3.0%	3.3%	1.1%	0.7%	0.0%	1.2%
Type shares in class - Sum Refrigeration	**37.5%**	**57.6%**	**39.5%**	**48.0%**	**43.2%**	**38.1%**	**81.0%**	**42.0%**
Type shares in class - 0 star	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%
Type shares in class - 1 star	0.0%	0.0%	0.7%	0.0%	0.0%	0.1%	0.0%	0.1%
Type shares in class - 2 star	0.0%	0.0%	0.0%	0.0%	0.2%	0.1%	2.4%	0.1%
Type shares in class - 2 star section	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Type shares in class - 3 star	0.0%	0.0%	0.0%	0.0%	0.3%	0.4%	0.0%	0.3%
Type shares in class - 4 star	62.5%	39.4%	57.1%	50.8%	51.8%	57.8%	16.7%	53.7%
Type shares in class - variable temperature	0.0%	3.0%	2.7%	1.2%	4.4%	3.4%	0.0%	3.7%
Type shares in class - Sum Freezing	**62.5%**	**42.4%**	**60.5%**	**52.0%**	**56.8%**	**61.9%**	**19.0%**	**58.0%**
Type shares in class – Chest freezers	43.8%	21.2%	31.6%	21.0%	29.9%	44.9%	7.1%	34.4%
Type shares in class – Upright freezers	18.8%	21.2%	28.9%	31.0%	26.9%	17.0%	11.9%	23.6%

Single-compartment fresh-food refrigerator models

Table 62 summarizes the EPREL data for 1-compartment fresh-food models, per energy label class.

Single-compartment fresh-food models are 12.1% of the RF models registered in EPREL, represent 10.7% of the cooled volume, and consume 7.2% of the electricity.

33.5% of the 1-compartment fresh-food models is in energy label class F or G [426].

Table 62: Single-compartment fresh-food refrigerator models per energy label class (VHK elaboration of EPREL December 2024 data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Model count	1	11	103	488	2531	1563	18	**4715**
Share of 1-Compartment fresh-food	0.0%	0.2%	2.2%	10.3%	53.7%	33.1%	0.4%	100.0%
Share of all models	0.0%	0.0%	0.3%	1.3%	6.5%	4.0%	0.0%	12.1%
Model count, share free-standing	0.0%	0.1%	1.6%	5.8%	36.2%	26.4%	0.3%	70.4%
Model count, share built-in	0.0%	0.2%	0.6%	4.5%	17.5%	6.8%	0.1%	29.6%
Total net volume (litres)	189	2171	27500	121122	603495	300706	4468	**1059650**
Volume share of 1-Compartment fresh-food	0.0%	0.2%	2.6%	11.4%	57.0%	28.4%	0.4%	100.0%
Volume share of All non-excluded	0.0%	0.0%	0.3%	1.2%	6.1%	3.0%	0.0%	10.7%
Average total net volume (litres)	189	197	267	248	238	192	248	**225**
External volume (litres)	767	5259	61384	245821	1191276	601768	8572	**2114846**
External Volume share of 1-Comp. fresh-food	0.0%	0.2%	2.9%	11.6%	56.3%	28.5%	0.4%	**100.0%**
Average external volume (litres)	767	478	596	504	471	385	476	**449**
Average external / internal volume ratio	2.32	1.93	2.12	2.03	2.01	2.03	1.91	**2.02**
Annual Energy Consumption (kWh/a)	66	838	9740	55334	285807	209252	2934	**563970**
AEC share of 1-Compartment fresh-food	0.0%	0.1%	1.7%	9.8%	50.7%	37.1%	0.5%	**100.0%**
AEC share of All non-excluded	0.0%	0.0%	0.1%	0.7%	3.6%	2.7%	0.0%	**7.2%**
Average AEC (kWh/a)	66	76	95	113	113	134	163	**120**
Specific AEC (kWh/a/litre)	0.20	0.33	0.38	0.46	0.59	0.87	0.68	0.66
Average EEI	40	51	64	80	99	124	152	**105**

[426] It has not verified if these models are low-noise (the supplied EPREL extract did not contain these data).

Single-compartment fresh-food models have an average net volume of 224 litres. Figure 53 (left) shows the distribution of the models over the net volume ranges. Most models are in the ranges 80 to 100 and 120 to 140 litres.

Figure 53 (right) shows the distribution of the sum of cooled volumes over the volume ranges. The median volume is around 300 litres, in the sense that half of the cooled volume is provided by models with net volume below 300 litres, and the other half by models with volume larger than 300 litres. The largest sum of volumes is found in the range 380 to 400 litres.

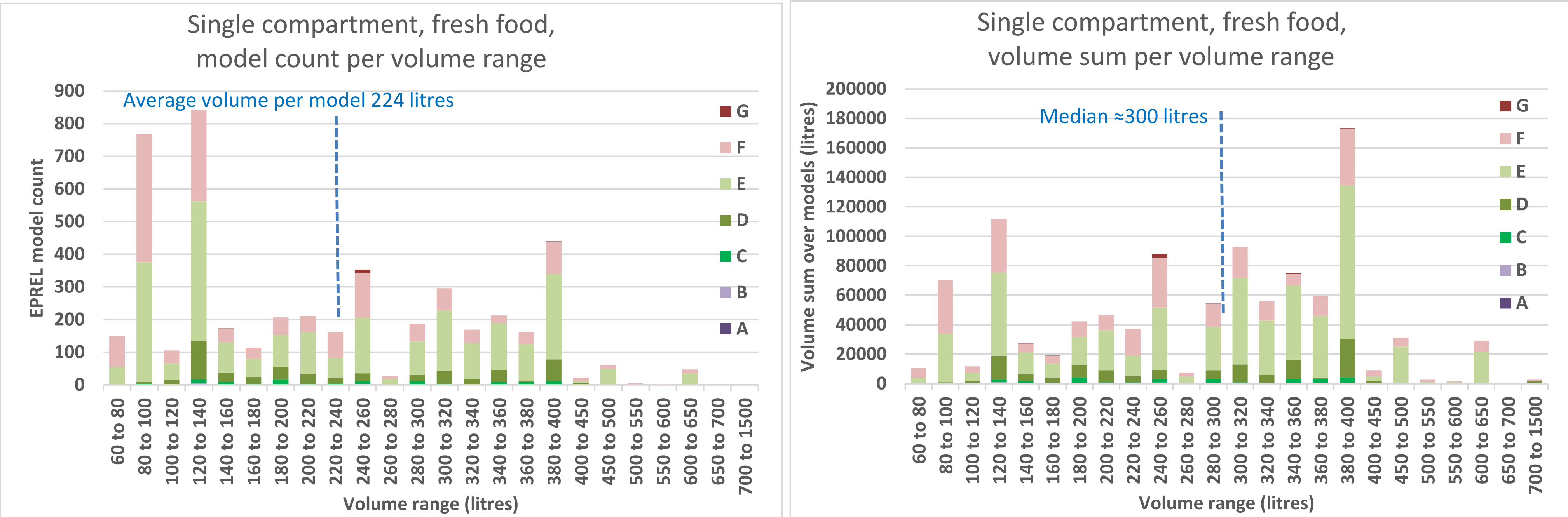

Figure 53: Single-compartment fresh-food: number of models and sum of net internal volumes per volume range and energy label class (VHK elaboration of EPREL December 2024 data)

Single-compartment 4-star chest freezer models

Table 63 summarizes the EPREL data for 1-compartment 4-star chest freezer models, per energy label class [427].

Single-compartment 4-star chest freezers are 9.8% of the RF models registered in EPREL, represent 7.6% of the cooled volume, and consume 10.7% of the electricity.

47.7% of the 1-compartment 4-star chest freezers is in energy label class F or G [428].

Table 63: Single-compartment chest freezer models per energy label class (VHK elaboration of EPREL December 2024 data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Model count	7	7	92	235	1658	1811	6	**3816**
Share of 1-Compartment 4-star chest	0.2%	0.2%	2.4%	6.2%	43.4%	47.5%	0.2%	100.0%
Share of all models	0.0%	0.0%	0.2%	0.6%	4.2%	4.6%	0.0%	9.8%
Model count, share free-standing	0.2%	0.1%	2.2%	5.7%	39.3%	45.4%	0.2%	93.1%
Model count, share built-in	0.0%	0.1%	0.2%	0.5%	4.2%	2.0%	0.0%	6.9%
Total net volume (litres)	1700	1283	12346	37863	308812	387635	1077	**750717**
Volume share of 1-Compartment 4-star chest	0.2%	0.2%	1.6%	5.0%	41.1%	51.6%	0.1%	100.0%
Volume share of All non-excluded	0.0%	0.0%	0.1%	0.4%	3.1%	3.9%	0.0%	7.6%
Average total net volume (litres)	243	183	134	161	186	214	180	**197**
External volume (litres)	4517	3257	36880	99542	719641	863903	2594	**1730334**
External Volume share of 1-Comp. 4-star chest	0.3%	0.2%	2.1%	5.8%	41.6%	49.9%	0.1%	**100.0%**
Average external volume (litres)	645	465	401	424	434	477	432	**453**
Average external / internal volume ratio	2.68	2.97	3.05	2.79	2.51	2.36	2.74	**2.47**
Annual Energy Consumption (kWh/a)	613	1312	10640	35541	325913	462491	3230	**839740**
AEC share of 1-Compartment 4-star chest	0.1%	0.2%	1.3%	4.2%	38.8%	55.1%	0.4%	**100.0%**
AEC share of All non-excluded	0.0%	0.0%	0.1%	0.5%	4.1%	5.9%	0.0%	10.7%
Average AEC (kWh/a)	88	187	116	151	197	255	538	**220**
Specific AEC (kWh/a/litre)	0.37	1.05	1.03	1.16	1.36	1.52	4.75	1.42

[427] In the overview of all 1-compartment models, chest freezer data referred to any type of freezer compartment. Here the data are only for the four-star compartments. This explains the small differences with data presented earlier.

[428] It has not verified if these models are low-noise (the supplied EPREL extract did not contain these data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Average EEI	41	50	64	79	99	124	306	**109**

Single-compartment 4-star chest freezers have an average net volume of 196 litres. Figure 54 (left) shows the distribution of the models over the net volume ranges. There is a model count peak in the range 80 to 100 litres.

Figure 54 (right) shows the distribution of the sum of cooled volumes over the volume ranges. The median volume is around 280 litres, in the sense that half of the cooled volume is provided by models with net volume below 280 litres, and the other half by models with volume larger than 280 litres. The largest sum of volumes is found in the ranges 80 to 100, 180 to 200, and 280 to 300 litres.

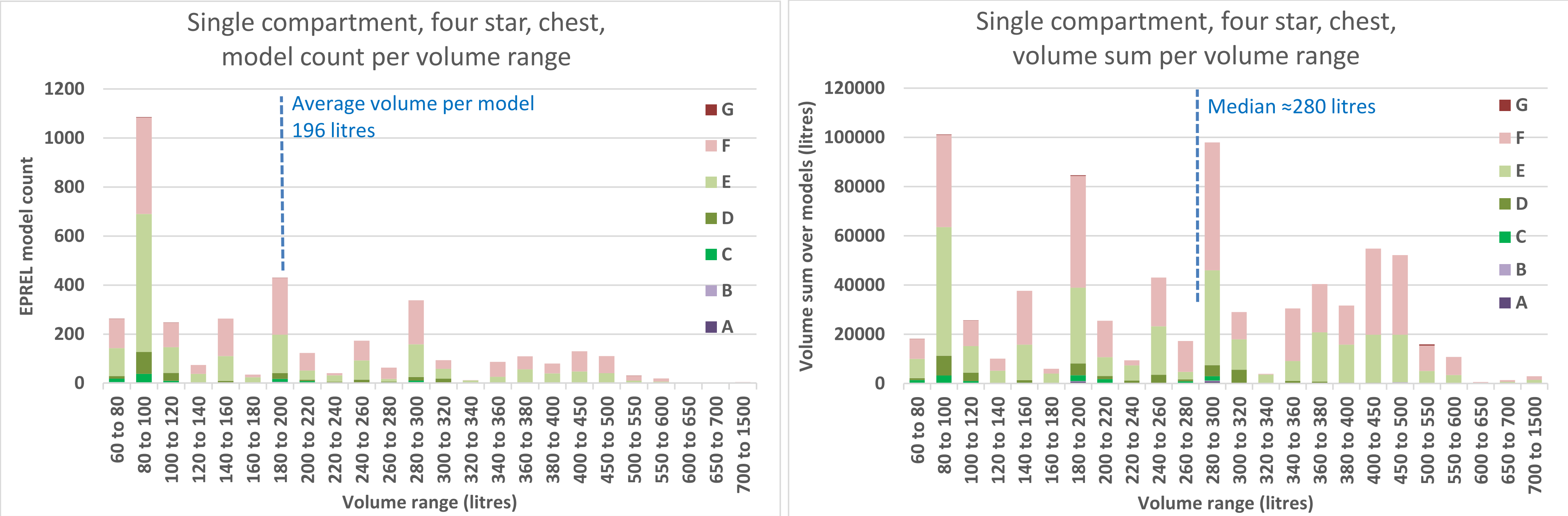

Figure 54: Single-compartment 4-star chest freezer: number of models and sum of net internal volumes per volume range and energy label class (VHK elaboration of EPREL December 2024 data)

Single-compartment 4-star upright freezer models

Table 64 summarizes the EPREL data for 1-compartment 4-star upright freezer models, per energy label class [429].

Single-compartment 4-star upright freezers are 7.2% of the RF models registered in EPREL, represent 6.8% of the cooled volume, and consume 8.5% of the electricity.

26.4% of the 1-compartment 4-star upright freezers is in energy label class F or G [430].

Table 64: Single-compartment upright freezer models per energy label class (VHK elaboration of EPREL December 2024 data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Model count	3	6	80	337	1634	732	8	**2800**
Share of 1-Compartment 4-star upright	0.1%	0.2%	2.9%	12.0%	58.4%	26.1%	0.3%	100.0%
Share of all models	0.0%	0.0%	0.2%	0.9%	4.2%	1.9%	0.0%	7.2%
Model count, share free-standing	0.1%	0.2%	2.9%	10.9%	48.2%	21.7%	0.3%	84.2%
Model count, share built-in	0.0%	0.0%	0.0%	1.2%	10.1%	4.5%	0.0%	15.8%
Total net volume (litres)	821	1276	21461	88346	397501	167861	2357	**679624**
Volume share of 1-Compartment 4-star upright	0.1%	0.2%	3.2%	13.0%	58.5%	24.7%	0.3%	100.0%
Volume share of All non-excluded	0.0%	0.0%	0.2%	0.9%	4.0%	1.7%	0.0%	6.8%
Average total net volume (litres)	274	213	268	262	243	229	295	**243**
External volume (litres)	2387	3620	60391	237237	1034486	431911	5969	**1776001**
Ext. Volume share of 1-Comp. 4-star upright	0.1%	0.2%	3.4%	13.4%	58.2%	24.3%	0.3%	**100.0%**
Average external volume (litres)	796	603	755	704	633	590	746	**634**
Average external / internal volume ratio	2.91	2.86	2.82	2.70	2.66	2.62	2.99	**2.66**
Annual Energy Consumption (kWh/a)	303	692	12516	65075	377764	204143	5643	**666136**
AEC share of 1-Compartment 4-star upright	0.0%	0.1%	1.9%	9.8%	56.7%	30.6%	0.8%	**100.0%**
AEC share of All non-excluded	0.0%	0.0%	0.2%	0.8%	4.8%	2.6%	0.1%	8.5%
Average AEC (kWh/a)	101	115	156	193	231	279	705	**238**
Specific AEC (kWh/a/litre)	0.37	0.55	0.61	0.77	1.01	1.27	4.34	1.05

[429] In the overview of all 1-compartment models, upright freezer data referred to any type of freezer compartment. Here the data are only for the four-star compartments. This explains the small differences with data presented earlier.

[430] It has not verified if these models are low-noise (the supplied EPREL extract did not contain these data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Average EEI	41	51	64	80	100	125	353	**103**

Single-compartment 4-star upright freezers have an average net volume of 242 litres, so they are larger than the chest freezers (196 litres average). Figure 55 (left) shows the distribution of the models over the net volume ranges. Most models are between 140 and 280 litres, with peak model counts in the ranges 160 to 180 and 260 to 280 litres.

Figure 55 (right) shows the distribution of the sum of cooled volumes over the volume ranges. The median volume is around 250 litres, in the sense that half of the cooled volume is provided by models with net volume below 250 litres, and the other half by models with volume larger than 250 litres. The largest sum of volumes is found in the range 260 to 280 litres.

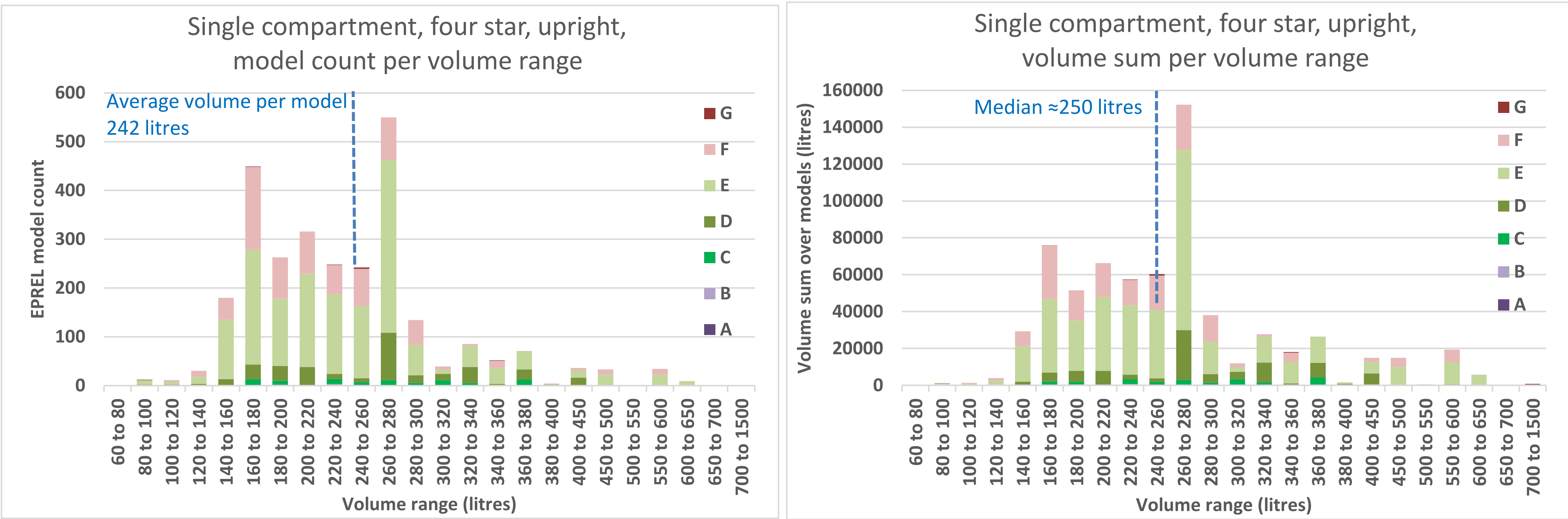

Figure 55: Single-compartment 4-star upright freezer: number of models and sum of net internal volumes per volume range and energy label class (VHK elaboration of EPREL December 2024 data)

Combi models, distribution over compartment types

Table 65 summarizes the EPREL data for Combi RF models [431], per energy label class.

Combis are 53.4% of the RF models registered in EPREL, represent 66.1% of the cooled volume, and consume 61.8% of the electricity.

27.3% of the combis is in energy label class F or G [432].

Table 65: Combi models per energy label class (VHK elaboration of EPREL December 2024 data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Model count	**147**	**204**	**1147**	**2641**	**11009**	**5607**	**92**	**20847**
Share of Combis	0.7%	1.0%	5.5%	12.7%	52.8%	26.9%	0.4%	100.0%
Share of all models	0.4%	0.5%	2.9%	6.8%	28.2%	14.4%	0.2%	53.4%
Model count, share free-standing	0.7%	0.9%	5.0%	10.5%	42.7%	23.1%	0.4%	83.3%
Model count, share built-in	0.0%	0.1%	0.5%	2.2%	10.1%	3.8%	0.0%	16.7%
Total net volume (litres)	**59514**	**74193**	**402114**	**863216**	**3467334**	**1656113**	**39975**	**6562458**
Volume share of Combis	0.9%	1.1%	6.1%	13.2%	52.8%	25.2%	0.6%	100.0%
Volume share of All non-excluded	0.6%	0.7%	4.0%	8.7%	34.9%	16.7%	0.4%	66.1%
Average total net volume (litres)	405	364	351	327	315	295	435	315
Average refrigerated volume	279	256	244	233	225	211	296	224
Average freeze volume	126	108	107	94	90	84	138	90
External volume (litres)	125735	161326	865551	1864969	7327693	3534001	86224	**13965499**
External Volume share of 1-Compartment	0.9%	1.2%	6.2%	13.4%	52.5%	25.3%	0.6%	**100.0%**
Average external volume (litres)	855	791	755	706	666	630	937	**670**
Average external / internal volume ratio	2.13	2.19	2.18	2.19	2.14	2.16	2.21	**2.16**
Annual Energy Consumption (kWh/a)	16720	27312	187356	503732	2528419	1546106	44872	**4854517**
AEC share of 1-Compartment	0.3%	0.6%	3.9%	10.4%	52.1%	31.8%	0.9%	**100.0%**
AEC share of All non-excluded	0.2%	0.3%	2.4%	6.4%	32.2%	19.7%	0.6%	61.8%
Average AEC (kWh/a)	114	134	163	191	230	276	488	**233**
Specific AEC (kWh/a/litre)	0.29	0.38	0.49	0.63	0.81	1.04	1.42	0.82

[431] Except minibars and models declared to be for wine storage.

[432] It has not verified if these models are low-noise (the supplied EPREL extract did not contain these data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Average EEI	40	51	64	80	100	124	191	**101**

Table 66 provides the model count breakdown per compartment type combination for combi models, per energy label class.

By far the most frequent combination (85.4% of all combis) is a fresh-food compartment plus a 4-star freezer compartment. Details for this combination are provided in the next section.

Table 66: Combi model counts per compartment type combination and per energy label class (VHK elaboration of EPREL December 2024 data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125		**Share of**
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**	**Combis**
Model count - all Combi types	**147**	**204**	**1147**	**2641**	**11009**	**5607**	**92**	**20847**	
Model count - Fresh Food + 4-Star	37	91	713	2042	9822	5014	76	**17795**	85.4%
Model count - Fresh Food + Any Other Freezer	32	24	53	130	693	439	9	**1380**	6.6%
Model count - Any Other Refrig. + 4-Star	7	10	21	50	237	46	2	**373**	1.8%
Model count - Any Other Refrig. + Any Other Freezer	0	0	0	3	15	4	4	**26**	0.1%
Model count - 4-Star + Any Freezer compartment	0	0	0	0	15	16	0	**31**	0.1%
Model count - Fresh Food + Any Refrig. compartment	71	79	360	415	226	88	1	**1240**	5.9%
Model count - Other combinations	0	0	0	1	1	0	0	**2**	0.0%

Combi models with fresh-food refrigerated compartment plus four-star freezer compartment

Table 67 summarizes the EPREL data for combi models with a fresh-food and a 4-star freezer compartment, per energy label class.

Combis fresh-food + 4-star are 45.6% of the RF models registered in EPREL, represent 55.4% of the cooled volume, and consume 53.1% of the electricity.

28.6% of the combis with fresh-food and 4-star freezer compartments is in energy label class F or G [433].

Table 67: Combi models fresh-food + 4-star freezer, per energy label class (VHK elaboration of EPREL December 2024 data).

EEI **Class**	< 41 **A**	41-51 **B**	51-64 **C**	64-80 **D**	80-100 **E**	100-125 **F**	> 125 **G**	 **All**
Model count	37	91	713	2042	9822	5014	76	**17795**
Share of Combis fresh-food + 4-star	0.2%	0.5%	4.0%	11.5%	55.2%	28.2%	0.4%	100.0%
Share of all Combis	0.2%	0.4%	3.4%	9.8%	47.1%	24.1%	0.4%	85.4%
Share of all models	0.1%	0.2%	1.8%	5.2%	25.2%	12.8%	0.2%	45.6%
Model count, share free-standing	0.2%	0.5%	3.7%	9.5%	44.2%	24.2%	0.4%	82.8%
Model count, share built-in	0.0%	0.0%	0.3%	1.9%	11.0%	3.9%	0.0%	17.2%
Total net volume (litres)	14764	31958	238163	643640	3043085	1497747	36526	**5505883**
Volume share of Combi fresh-food + 4-star	0.3%	0.6%	4.3%	11.7%	55.3%	27.2%	0.7%	100.0%
Volume share of All non-excluded	0.1%	0.3%	2.4%	6.5%	30.6%	15.1%	0.4%	55.4%
Average total net volume (litres)	399	351	334	315	310	299	481	**309**
Average fresh-food refrigerated volume	281	248	233	226	222	214	324	**222**
Average 4-star freezer volume	118	103	101	89	87	85	157	**88**
External volume (litres)	31172	70722	516246	1396024	6461437	3191647	78052	**11745301**
Ext. Volume share of fresh-food + 4-star	0.3%	0.6%	4.4%	11.9%	55.0%	27.2%	0.7%	**100.0%**
Average external volume (litres)	842	777	724	684	658	637	1027	**660**
Average external / internal volume ratio	2.11	2.21	2.17	2.17	2.12	2.13	2.14	**2.13**
Annual Energy Consumption (kWh/a)	4061	11667	112155	378172	2238271	1395832	34629	**4174787**
AEC share of Combis fresh-food + 4-star	0.1%	0.3%	2.7%	9.1%	53.6%	33.4%	0.8%	**100.0%**
AEC share of All non-excluded	0.1%	0.1%	1.4%	4.8%	28.5%	17.8%	0.4%	**53.1%**
Average AEC (kWh/a)	110	128	157	185	228	278	456	**235**
Specific AEC (kWh/a/litre)	0.28	0.37	0.47	0.59	0.74	0.93	0.95	**0.76**

[433] It has not verified if these models are low-noise (the supplied EPREL extract did not contain these data).

EEI	< 41	41-51	51-64	64-80	80-100	100-125	> 125	
Class	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**All**
Average EEI	40	51	64	80	100	124	158	**103**

Combis with a fresh-food and 4-star freezer compartment have an average net total volume of 309 litres (222 litres refrigerated and 88 litres frozen). Figure 56 (left) shows the distribution of the models over the net volume ranges. Most models are in the ranges 200-220, 240-260, 260-280 and 320-340 litres.

Figure 56 (right) shows the distribution of the sum of cooled volumes over the volume ranges. The median volume is around 330 litres, in the sense that half of the cooled volume is provided by models with net volume below 330 litres, and the other half by models with volume larger than 330 litres. The largest sum of volumes is found in the range 320 to 340 litres, but there are various ranges with a large volume contribution.

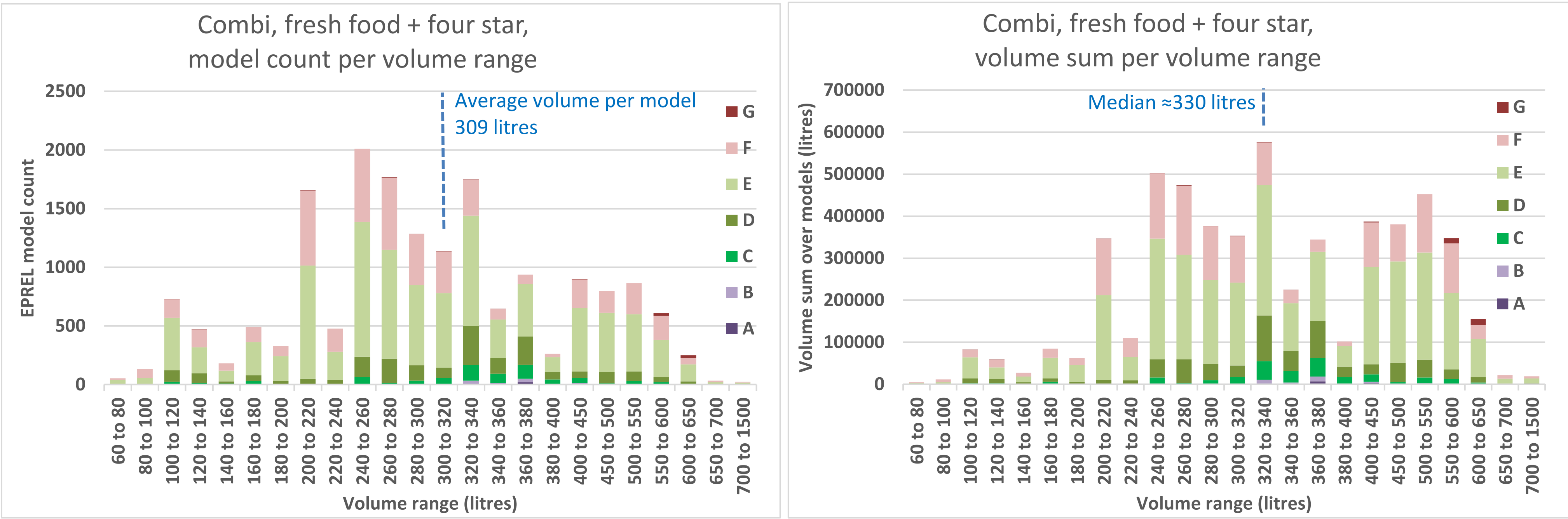

Figure 56: Combi models fresh-food + 4-star freezer: number of models and sum of net internal volumes per volume range and energy label class (VHK elaboration of EPREL December 2024 data)

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