RESEARCH PROJECTS

Long Term Impact of PFAS on Food Safety and Regulation

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FSA Research and Evidence

This report was commissioned by the Food Standards Agency to examine the pathways by which per- and polyfluoroalkyl substances (PFAS) enter foods consumed in the UK, estimate current dietary exposure across population groups to support prioritisation, and explore how future exposure patterns may evolve, including potential influence of PFAS substitutions. The assessment combined a targeted review, structured appraisal of evidence quality, dietary exposure modelling based on National Diet and Nutrition Survey data, and horizon-scanning analysis.

The available evidence indicated that PFAS enter the UK food system through multiple interacting pathways, including environmental contamination, agricultural production, food processing, food contact materials and waste-management systems. Circular economy practices, such as land application of biosolids, may further reintroduce PFAS into agricultural systems.

The dietary exposure assessment focused on PFOS, PFOA, PFHxS and PFNA (PFAS-4), for which the European Food Safety Authority has established a tolerable weekly intake (TWI) of 4.4 ng kg^{-1} body weight per week. Under a central-tendency (mean) scenario, estimated dietary exposure to PFAS-4 exceeded the TWI across all UK age groups on a body weight basis, with the highest relative exposure observed in toddlers and young children. The main contributors to the estimated PFAS-4 intake were fish and fish dishes, meat and meat products, vegetables and vegetables products and dishes, fruit and eggs. It is important to note that the assessment is subject to substantial uncertainties, such as heterogeneous occurrence data with limited UK-specific coverage and different analytical approaches. While exceedances are of potential toxicological concern, the results may not reflect typical exposure scenarios and should be interpreted as screening-level indicators for prioritisation rather than measures of individual risk.

Substitution towards short-chain, ultra-short-chain and other fluorinated alternatives may alter the composition of PFAS exposure, while environmental persistence and circular material flows may contribute to the continued recirculation of PFAS within the food system. The findings in the report highlight the importance of targeted monitoring, improved UK-relevant occurrence data, broader analytical coverage of PFAS and precursors, and regulatory approaches that consider persistence, mobility and cumulative exposure at a class or property level.

Lay Summary

Per- and polyfluoroalkyl substances (PFAS), often referred to as “forever chemicals”, are a large and diverse group of man-made substances that have been widely used for decades in industrial processes and consumer products because of their resistance to grease, heat, stains and water. These same properties make PFAS extremely persistent in the environment. As a result, they can accumulate over time in soil, water, wildlife and the human body. Some PFAS are known to be associated with adverse health effects, such as effects on the immune system, including reduced responses to vaccination, changes in blood cholesterol, effects on liver function, and impacts on growth and development. Because many PFAS remain in the environment as well as the human body for years, long-term, low-level exposure is an important consideration for food safety and public health.

This report examines how PFAS enter foods consumed in the United Kingdom, the contribution of diet to overall PFAS exposure in the UK population, and how these patterns may change going forward. The assessment brings together evidence from scientific studies conducted in the UK and Europe and integrates these data with UK food-consumption information from the National Diet and Nutrition Survey (2019–2023).

PFAS can enter the food system through multiple pathways. Environmental contamination allows PFAS to move from soil, freshwater and marine systems into crops, livestock and fish. Additional inputs can occur during food processing and through contact with some food-contact materials, particularly grease-resistant paper and board. Once PFAS are present in food, they are not readily removed by washing, preparation or cooking.

The quantitative assessment of this work focuses on four PFAS: PFOS, PFOA, PFHxS and PFNA (referred to collectively as PFAS-4), for which a health-based guidance value (HBGV) has been established by the European Food Safety Authority (EFSA). These substances are well characterised, are known to accumulate in humans, and are consistently detected in human blood.

The results indicate that five food groups account for most dietary exposure to PFAS-4, i.e. fish, meat, vegetables, fruit and eggs. When typical UK dietary patterns are considered, estimated dietary exposure exceeds the HBGV across all age groups, with higher exposure on a body weight basis in younger children. While these exceedances are of potential toxicological concern, there are several uncertainties associated with these findings which make it difficult to conclude on actual risk. Monitoring data for PFAS are uneven across food categories, many PFAS are not routinely measured, and occurrence data is derived from studies using different analytical methods and geographical locations, with limited UK data. Therefore, the results may not be reflective of actual exposure but rather represent a screening-level approach intended to highlight prioritisation rather than suggest individual risk. Nonetheless, the evidence indicates that dietary exposure to PFAS is widespread and reflects long-term, diffuse environmental contamination rather than isolated or short-term sources.

Dietary exposure is likely to persist unless upstream inputs of PFAS to the environment and food system are reduced. Although some historically used PFAS have been restricted, they can be replaced by other PFAS that could remain persistent and mobile, meaning that overall exposure may simply change in composition rather than decline.

The findings in the report highlight the importance of targeted monitoring of key food groups, improved UK-relevant data on PFAS occurrence, and regulatory approaches that address PFAS as a class rather than on a substance-by-substance basis.

Executive Summary

Per- and polyfluoroalkyl substances (PFAS) are a large class of synthetic chemicals that are highly resistant to degradation and widely distributed in the environment as a result of historical and ongoing uses across multiple sectors. Their persistence, mobility and capacity for accumulation in humans and wildlife have led to increasing concern regarding long-term exposure, including through the diet. In response, the Food Standards Agency commissioned this work to examine the pathways by which PFAS enter foods consumed in the UK, to estimate current dietary exposure across population groups with a view to prioritisation, and to consider how future exposure patterns may evolve and what role substitutions may play.

The assessment integrates four complementary strands of work: a targeted review of UK- and EU-relevant evidence on PFAS sources, pathways and occurrence in foods; a structured appraisal of evidence quality using an adapted criteria for reporting and evaluating exposure data (CREED) framework; quantitative dietary exposure modelling aligned with UK consumption patterns from the National Diet and Nutrition Survey (NDNS, 2019–2023); and a horizon-scanning exercise to identify plausible

future developments relevant to PFAS exposure through the food system and effect of potential substitutions. The scope of the assessment focuses on dietary exposure and food-relevant matrices; drinking water and non-dietary exposure routes such as consumer products are considered only where they inform understanding of food-system pathways.

Evidence synthesis demonstrated that PFAS enter the UK food system through multiple, interacting pathways spanning environmental contamination, agricultural production, food processing, packaging, retail handling and waste-management systems. Environmental reservoirs arising from industrial emissions, firefighting foam use, wastewater treatment and waste disposal can provide sustained inputs of PFAS to soils, freshwater and marine systems. These reservoirs may subsequently act as sources of PFAS uptake by crops, livestock and fish. Post-harvest transfers may also occur from food-contact materials and processing environments, particularly under conditions that could increase PFAS transfer to food, such as elevated temperature, contact with high-fat foods, or extended contact times. Circular economy practices, including composting and land application of biosolids, create feedback loops that can also reintroduce PFAS into agricultural systems.

The quantitative exposure assessment focused on four PFAS: PFOS, PFOA, PFHxS and PFNA (collectively PFAS-4), for which the European Food Safety Authority (EFSA) has established a group tolerable weekly intake (TWI) of 4.4 ng kg^{-1} body weight per week. These four substances were selected by EFSA because they are toxicologically well characterised, consistently detected in food and human biomonitoring studies, and hence form the current basis for regulatory risk assessment. Dietary exposure was estimated by combining harmonised PFAS-4 occurrence data from the literature (UK and EU data) with NDNS consumption and body weight data, using a central-tendency (mean) scenario representing typical long-term exposure.

The results indicated that, under the central-tendency scenario, estimated dietary exposure to PFAS-4 exceeds the EFSA TWI across all UK age groups when expressed on a body weight basis. The highest relative exposure occurs in toddlers (1.5–3 years), followed by young children aged 4–10 years, reflecting lower body weight rather than higher absolute food intake. While the estimated exposures are of potential toxicological concern, it is difficult to infer the actual risk for consumers given the uncertainties arising from the available database. PFAS concentrations across different food categories were derived from different studies and therefore based on varied approaches, analytical methods and geographical locations, with limited UK data. Furthermore, consistent with a screening-level approach, the exposure assessment was based on the conservative assumption that PFAS are present across all food categories

simultaneously, using first-tier NDNS categories only, which is likely to overestimate actual dietary exposure. Conversely, limited data or data gaps for some food categories may lead to an underestimation of total exposure. While a potential risk cannot be excluded, the estimated exposures are subject to a high degree of uncertainty and therefore may not be representative of typical exposure scenarios and exceedances should be considered in line with these uncertainties. The report did not undertake a risk assessment, but the exposure assessment provides a screening-level estimate based on available data and is intended to inform prioritisation and future work rather than to characterise individual risk.

Fish and fish dishes, meat and meat products, vegetables and vegetable products and dishes, fruit, and eggs account for the majority of estimated PFAS-4 intake. These findings are consistent with known accumulation mechanisms, including aquatic bioaccumulation, feed-mediated transfer to animal products and soil-to-crop pathways. Other food categories either contribute less to overall intake or remain poorly characterised due to limited available occurrence data.

The exposure assessment is subject to several important uncertainties. UK-specific monitoring data are uneven across food categories, analyte coverage varies substantially between studies, and many PFAS and precursor compounds are not routinely measured. As a result, total dietary PFAS burden may be subject to either over- or underestimation. Risk ratios, based on the ratio between estimated exposure and the HBGVs, were provided in this report as screening indicators to support evidence-based prioritisation and should not be interpreted as quantitative measures of potential health risks.

The horizon-scanning analysis undertaken in this report indicated that future dietary exposure to PFAS is unlikely to decline in the absence of upstream intervention. Restrictions on historically used PFAS have frequently driven substitution towards short-chain, ultra-short-chain and other fluorinated alternatives, many of which retain problematic properties such as persistence and, in some cases, high environmental mobility. This suggests that overall exposure is likely to change in composition rather than decrease. Long environmental residence times, transboundary transport and circular material flows further limit the effectiveness of compound-specific controls.

The evidence highlights the importance of defining high-contribution food categories, improved UK-relevant occurrence data, broader analytical coverage of PFAS and precursors, and consideration of persistence, mobility and cumulative exposure of these substances at a class or property level to ensure proportionate protection of public health.

Glossary

Abbreviations/key terms	Definition
ADI	Acceptable Daily Intake
AFFF	Aqueous film forming foam (firefighting foam historically containing PFAS)
ANSES	French Agency for Food, Environmental and Occupational Health & Safety
ARfD	Acute Reference Dose
BfR	German Federal Institute for Risk Assessment
Bioavailability	The proportion of a chemical that is available for absorption by an organism following exposure. In environmental and food safety contexts, this reflects how much of a substance present in a medium (e.g. food, soil, water) can be taken up into the body and reach target tissues.
Biomagnification	The process by which the concentration of a chemical increases a successively higher levels of a food chain. This occurs when a substance is taken up by organisms faster than it is eliminated and is transferred efficiently from prey to predator, leading to higher concentrations in organisms at higher trophic levels.
CLO	Compost-Like Outputs (from mixed organics)
COT	Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment
CREED	Criteria for Reporting and Evaluating Exposure Data
diPAP / PAPs	Polyfluoroalkyl phosphate esters (precursors present in paper/board FCMs)
DNEL	Derived no-effect level
ECHA	European Chemicals Agency
EFSA	European Food Safety Authority
EOF	Extractable Organic Fluorine (a bulk screening metric)
EPA	Environmental Protection Agency
EXTR	Extrapolated evidence category
FMPs	Fluorochemical manufacturing plants
FTOH	Fluorotelomer alcohols (common PFAS precursors)
HBGV	Health-based guidance value
HFPO	Hexafluoropropylene Oxide (also known as GenX)
ICP-MS / LC-MS	Analytical techniques used in PFAS detection
INT	International evidence category
ITV	Indicative Toxicity Value
FCM	Food contact materials
LC-MS/MS	Liquid chromatography-tandem mass spectrometry – an analytical technique that separates compounds in a liquid sample (LC), breaks them into fragments (MS1) and analyses these fragments (MS2) to identify and quantify components with high sensitivity and specificity.
LOD	Limit of detection
LOQ	Limit of quantification
MRL	Minimum risk level
Mobility	The tendency of a chemical to move through environmental media, facilitating long-range environmental dispersion and transfer between compartments (e.g. from soil to water or water to biota).

Abbreviations/key terms	Definition
Moiety	A specific, identifiable part or functional group or structural component of a molecule responsible for its characteristic chemical reactions or physical properties.
NDNS	National Diet and Nutrition Survey (2019-2023): a continuous, cross-sectional UK-wide programme that assesses the food consumption, nutrient intake and nutritional status.
NHMRC	National Health and Medicinal Research Council
OS-RfD	Organ-specific Reference Dose
Persistence	The tendency of a chemical to remain in the environment over long periods due to resistance to physical, chemical or biological degradation. Persistent substances degrade slowly, allowing them to accumulate in environmental compartments and contribute to long-term exposure, even after emissions or use have ceased.
PFAA	Perfluoroalkyl acids (terminal PFAS degradation products)
PFAS	Per- and polyfluoroalkyl substances
PFAS-4	A grouping of four specific per- and polyfluoroalkyl substances: PFOS, PFOA, PFNA, PFHxS
PFBA	Perfluorobutanoic acid
PFBS	Perfluorobutane sulfonic acid
PFCA	Perfluoroalkyl carboxylic acids (subset of PFAAs)
PFDA	Perfluorodecanoic acid
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexane sulfonic acid
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFPrA	Perfluoropropanoic Acid
PFSA	Perfluoralkyl sulphonic acids (subset of PFAAs)
PMT/vPvM	Persistent, mobile toxic / very persistent, very mobile.
QA/QC	Quality assurance / quality control
RAC	Risk Assessment Committee
RfD	Reference Dose
RIVM	National Institute for Public Health and the Environment
TDI	Tolerable Daily Intake
TFA	Trifluoroacetic acid (ultra-short-chain PFAS)
TWI	Tolerable Weekly Intake
UK REACH	UK Registration, Evaluation, Authorisation and Restriction of Chemicals
WWTP	Wastewater Treatment Plant

1. Introduction

Per- and polyfluoroalkyl substances (PFAS), commonly referred to as ‘forever chemicals’, are a large and structurally diverse class of synthetic organofluorine compounds that are characterised by exceptionally stable carbon-fluorine bonds (Buck et al., 2011). This chemical stability means that they are resistant to thermal, chemical and biological degradation, resulting in significant environmental persistence (Cousins et al., 2019).

Since first being produced in the mid-twentieth century, PFAS have been used extensively in industrial processes and consumer products for their various valuable properties including water-, oil- and heat-resistance. Some of the most prominent applications for PFAS include firefighting foams, textiles, non-stick cookware, coatings, electronics manufacturing and food contact materials (Buck et al., 2011; EFSA, 2025a). As a consequence of their widespread use, PFAS have become globally distributed and are now ubiquitously detected in water, soil, biota and human populations.

The surfactant properties and relatively weak sorption demonstrated by many PFAS compounds mean that they are also highly mobile in aqueous systems, facilitating their long-range transport through groundwater, rivers and marine systems (Cousins et al., 2019). Additionally, a number of PFAS compounds have been shown to accumulate in environmental matrices such as soil, water and biota where they remain bioavailable over long timescales, creating environmental reservoirs and accumulating and, in some cases, biomagnifying within both aquatic and terrestrial food webs (Ecke et al., 2025; Houde et al., 2011; Kelly et al., 2024). This raises concerns for food safety and can ultimately lead to potential long-term exposure for the human population (Ohorro & Ngole-Jeme, 2026; Polychonidou & Nag, 2025).

The UK food system presents multiple, interacting routes by which PFAS can reach the plate. Environmental reservoirs from historic and ongoing uses can transfer PFAS to primary food production via irrigation water and atmospheric deposition to soils; land-applied bioresources (e.g. biosolids, composts) and recycled fibre streams can seed and re-seed agricultural soils. Post-harvest steps, including processing, contact with food-contact materials (FCMs) such as grease-resistant papers and boards, and retail handling, can add further inputs, particularly for hot or fatty foods.

Although thousands of PFAS exist, toxicological evidence and regulatory assessments have historically focused on a smaller number of well-studied compounds, particularly perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), perfluorohexane sulfonic acid (PFHxS), and perfluorononanoic acid (PFNA) (referred to collectively as PFAS-4). Studies have shown that this group of PFAS are persistent and widely detected in humans and wildlife with epidemiological and experimental evidence indicating that exposure to these four PFAS may be associated with a range of adverse health outcomes, including effects on immune function, lipid metabolism, liver physiology and developmental outcomes, and reduced antibody responses to vaccination in children (EFSA, 2020; Grandjean et al., 2015). Other effects of PFAS exposure reported in the literature include increased serum cholesterol, liver enzyme changes, reduced birth weight

and potential endocrine disruption, although the strength of evidence for these endpoints vary across compounds and exposure levels (Fenton et al., 2021; Post et al., 2012).

Parallel regulatory developments have occurred internationally. Assessments by international authorities and agencies have progressively lowered tolerable exposure thresholds as the evidence base has expanded. The European Food Safety Authority (EFSA) published a comprehensive scientific opinion in 2020 establishing a group tolerable weekly intake (TWI) of 4.4 ng per kg body weight per week for the sum of PFAS-4 (EFSA, 2020). An assessment conducted by the EFSA CONTAM Panel (2020) concluded that dietary exposure for parts of the European population may exceed this threshold, particularly among high consumers of contaminated foods such as fish and eggs. Recent developments at the EU level, including the European Commission's consideration of a broad PFAS restriction and EFSA's ongoing evaluation of highly persistent and mobile substances such as trifluoroacetic acid (TFA), which is increasingly detected as both a direct contaminant and a transformation product of some PFAS, highlight the increasing regulatory focus on cumulative exposure, persistence and mobility rather than individual compounds alone. In the United States, the Environmental Protection Agency (EPA) has issued updated toxicity assessments and drinking-water standards reflecting increasing evidence of adverse effects at very low PFAS exposure levels (US EPA, 2024d). Similarly, the Australian National Health and Medical Research Council (NHMRC) updated national drinking water guidelines in 2025 to reflect revised toxicological benchmarks and emerging PFAS risk assessments (NHMRC, 2025). Within the UK, the Committee on Toxicology of Chemicals in Food, Consumer Products and the Environment (COT) has considered PFAS risks in food and drinking water and issued interim positions highlighting the need for improved occurrence data and exposure assessment (COT, 2023). UK regulatory frameworks are evolving through the application of the persistent, mobile and toxic (PMT) and very persistent, very mobile (vPvM) classification approach under UK REACH and environmental policy, reflecting a shift toward regulating substances based on persistence and mobility characteristics rather than only traditional bioaccumulation metrics (Environment Agency, 2025).

In response to regulatory controls on a number of historically used PFAS, industrial use has progressively shifted towards alternative substances, such as polymeric and ether-linked PFAS, shorter-chain PFAS and a range of non-PFAS replacements. While some of these substitutions have reduced bioaccumulation potential, many retain the key properties of concern, including high environmental persistence and mobility. As a result, the substitution of regulated PFAS has altered the composition of environmental contamination and exposure profiles rather than

eliminated exposure. Emerging evidence indicates that new alternatives and their transformation products are increasingly detected in water, soils and food-system matrices.

1.1. Research questions

This assessment focuses on addressing four central research questions:

1. PFAS entry pathways: Through which environmental, agricultural, processing and packaging pathways do PFAS enter foods consumed in the UK?
2. Regulatory and monitoring priorities: Which PFAS compounds and food categories represent the highest priority for monitoring and regulatory consideration within the UK context, based on their toxicological relevance, occurrence patterns and contribution to dietary exposure?
3. Current population exposure: What are the estimated current dietary exposures to PFAS among UK consumers, across population sub-groups?
4. Future and emerging risks: How might emerging PFAS uses, substitution patterns, regulatory developments and environmental processes influence future PFAS exposure across the UK food system?

These research questions guided the evidence gathering, data harmonisation, exposure modelling and horizon-scanning activities undertaken in the report.

1.2. Project scope

The scope of this assessment focused on PFAS concentrations in foods and food-relevant matrices (environmental media, food contact materials and processing environments) that contribute to dietary exposure. Non-dietary exposure routes (e.g. drinking water, indoor dust, consumer products) are outside the primary scope, except where they support interpretation of PFAS movement through the UK food system.

Dietary exposure estimates in this report reflect foods consumed in the UK regardless of origin, using consumption patterns from the National Diet and Nutrition Survey (NDNS). To ensure that PFAS concentration inputs are representative of products available to the UK market, the occurrence data used in this assessment were restricted to studies conducted in the UK and the EU.

This restriction was necessary because foods produced for domestic sale in non-EU countries are often subject to different systematic processes than in the UK and the EU (i.e. agricultural practices, PFAS-use restrictions, food-contact material regulations and environmental contamination profiles). A further consideration is that many PFAS occurrence studies outside the UK and EU cannot reliably be assumed to reflect the PFAS profile of foods destined for UK consumers, whose export supply chains frequently operate under different standards. Including such datasets would introduce unnecessary uncertainty into UK exposure estimates.

By contrast, EU occurrence data are generated within regulatory frameworks, production systems and packaging standards that are broadly aligned with those applied to foods supplied to the UK market. Prioritising UK and EU datasets therefore ensured stronger methodological comparability, more realistic exposure estimates and a proportionate evidence base for decision-making.

While high-contamination 'hotspot' datasets (e.g. measurements taken near fluorochemical production facilities) were considered within this report, they were reviewed qualitatively to contextualise the wider evidence base but excluded from quantitative exposure modelling to prevent distortion of population-level estimates.

1.3. Approach

This work applied a multi-component approach designed to produce a proportionate, evidence-based assessment of PFAS occurrence and dietary exposure within the UK food system. The approach integrates four components:

1. Targeted evidence identification: A review was undertaken to identify empirical measurements of PFAS in foods, FCMs and food-relevant environmental or processing matrices. Only studies meeting predefined inclusion criteria for analytical quality and relevance were carried forward.

2. Evidence appraisal using an adapted criteria for reporting and evaluating exposure data (CREED) framework. This provided a transparent and consistent basis for rating studies as high, moderate or limited confidence based on sampling design, analytical methods, reporting quality and relevance to UK dietary exposure.

3. Harmonisation and integration with UK dietary data: PFAS concentrations were normalised into consistent units and mapped to NDNS food categories to enable comparison across studies. PFAS-4 (PFOS, PFOA, PFHxS and PFNA) were

used as the primary basis for quantitative exposure modelling because they are the only PFAS with an EFSA HBGV and have the strongest, most consistent measurement coverage across food-occurrence datasets. This provides a coherent regulatory benchmark and improves comparability across studies. Harmonised concentration values were then combined with NDNS consumption data and UK-specific body weights to generate age-stratified exposure estimates.

4. Forward-looking assessment: A structured horizon-scanning exercise was conducted to identify plausible future PFAS uses, substitution trends and system-level developments that may influence food-system exposure in the coming decade.

Together, these steps provide a proportionate, transparent and reproducible framework for assessing PFAS occurrence, current dietary exposure and potential future risks within the context of the UK food system. Given the widespread occurrence of PFAS and the complexity of monitoring a large number of substances in both domestically produced and imported foods, UK-specific occurrence data remains uneven across food categories and matrices. While much of the available PFAS occurrence evidence therefore derives from European and international studies, this assessment aims to synthesise UK-relevant data where available and contextualise international evidence for the UK food system.

The following sections describe the methods used to identify, appraise and synthesise evidence (section 2), the results of the pathway mapping, occurrence review and exposure assessment (sections 3.1-3.4), the horizon-scanning analysis (section 3.5), and synthesis and conclusions (sections 4-5).

2. Materials and Methods

2.1. Literature review approach

This literature review was designed as a targeted evidence synthesis to support pathway identification, prioritisation and exposure assessment, rather than a fully systematic review intended to exhaustively capture all PFAS literature. This approach was selected to balance breadth of coverage with relevance to the UK food system and to enable integration of heterogeneous evidence into system-level conceptual mapping.

2.1.1. Information sources

To build a comprehensive evidence base, the review looked across both academic research and authoritative grey literature. Peer-reviewed material was located using major scientific repositories that cover environmental chemistry, toxicology, food safety, and exposure science, including ScienceDirect, Pubmed and Google Scholar. The sources were chosen because they offer broad coverage of the analytical and environmental sciences where studies on PFAS concentrations in foods or food-related systems are commonly published.

2.1.2. Search strategy and scope

The literature review identified empirical measurements of PFAS in foods, FCMs where migration to food was demonstrated, and environmental media with credible transfer to food (e.g. irrigation water, biosolids applied to land). Searches spanned peer-reviewed and authoritative grey sources (2015 onward; English language), with priority given to UK and EU data to maximise relevance to the foods available on the UK market. Limiting searches to the past decade reflects major advances in PFAS analytical methods, broader contemporary PFAS definitions, and a substantial expansion of evidence for both historically used and replacement PFAS, ensuring that the review is aligned with current regulatory understanding and exposure patterns. Search strings (see Appendix Table 1 and Appendix Table 2) combined PFAS synonyms with food/matrix terms (e.g. *fish, milk, eggs, vegetables, packaging, migration, concentration, occurrence*) and were adapted for each repository.

2.1.3. Study eligibility and selection

Titles and abstracts were screened to exclude duplicates, non-food related studies, modelling-only papers, studies lacking quantitative analytical results and other irrelevant information (e.g. toxicology without occurrence measurements, packaging studies without demonstrated migration to food). Full texts were subsequently evaluated against predefined inclusion criteria:

- Numerical PFAS concentrations reported in foods or food-relevant environmental or material matrices;
- Analytical methods described with sufficient detail to ensure specificity, sensitivity and sample characterisation; and
- Adequate metadata to permit harmonisation of units, limits of detection/quantification (LOD/LOQs) and sample characterisation.

Priority was given to studies providing quantitative metrics such as detection frequencies, concentration ranges and LOD/LOQs. Studies based solely on modelling, mass-balance assumptions or speculative discussions, as well as those lacking unambiguous compound identification, were excluded. These steps ensured that the evidence base comprised reliable, reproducible measurements that could be meaningfully integrated across diverse sources. A summary of study inclusion and exclusion at each screening stage is provided in Figure 1. The article screening process led to the identification of 71 articles, of which 17 related to sources and pathways for PFAS into and through the UK food system, 52 reported PFAS concentrations in food from- or relevant to the UK, and 16 articles reported on PFAS in food contact materials, noting that some publications related to more than one topic.

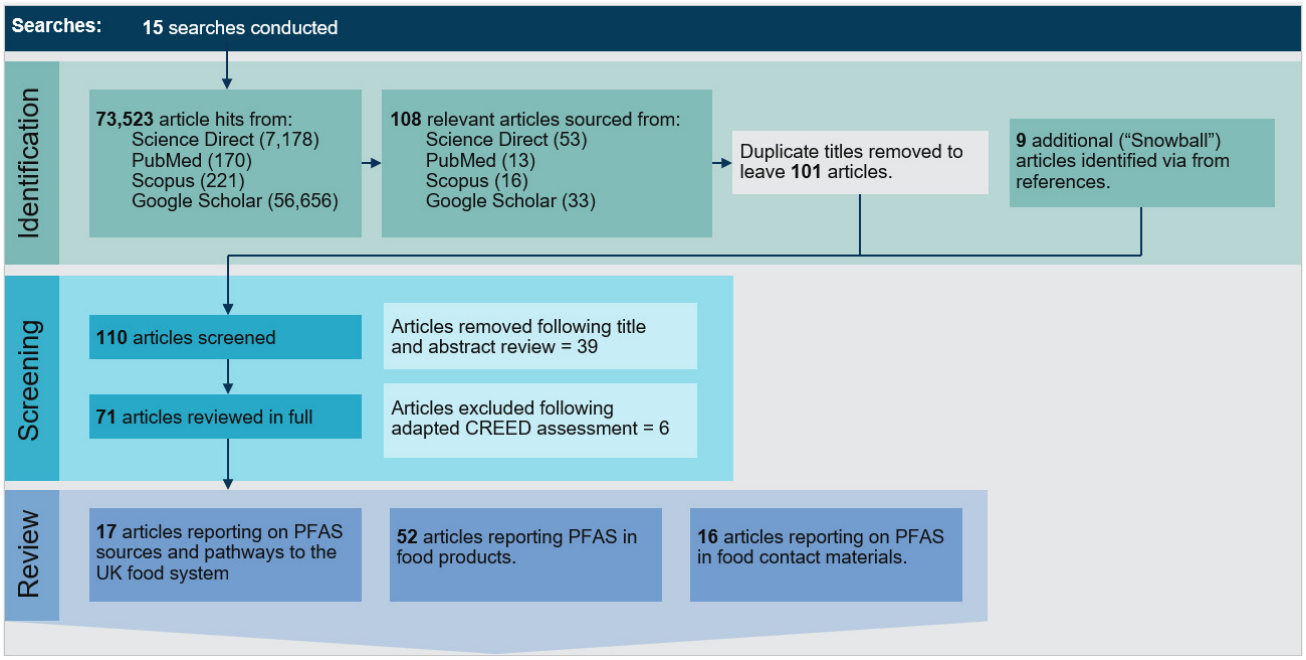

Figure 1. Article identification and screening phases for PFAS source and pathway identification, and PFAS concentrations in food.

2.1.4. Data review and extraction

Information was extracted from all studies that met the inclusion criteria and captured in a structured template (Supplementary Document 1). This template captured details such as the type of food or matrix studied, how and where samples were collected, the PFAS compounds analysed, the concentrations measured, and any available information on analytical methods or quality control. Where possible, foods were mapped onto NDNS categories to allow for later alignment with consumption data and dietary exposure modelling. Where studies reported total PFAS values directly, these values were extracted as reported; where only individual PFAS concentrations were available, the summed value was calculated for this assessment as described in section 2.3.

In addition to recording concentration values, the review also documented important contextual information. This included whether the study took place in the UK, whether the sampling approach was representative, and whether detection limits were appropriate to support meaningful comparisons with other work. Including this information ensured that the evidence synthesis could take into account differences in study design, analytical sensitivity and geographic relevance.

2.1.4.1. Strength and reliability assessment

Not all studies provide the same level of reliability, especially in a field where analytical methods have evolved quickly. To ensure transparency and proportionality in how evidence was used, each eligible study was evaluated for methodological strength and relevance prior to inclusion in quantitative analysis. A structured evidence-quality appraisal using an adapted version of the CREED framework (Merrington et al., 2024) was applied to document confidence in sampling design, analytical methodology, food characterisation and reporting completeness. CREED is specifically designed to appraise exposure datasets and is well suited to PFAS research, where variability in sampling strategies, analytical sensitivity and reporting practices can substantially influence the reliability of concentration estimates. This appraisal informed how individual datasets were weighted in the synthesis and whether they were used for quantitative exposure estimation or qualitative contextualisation.

The detailed assessment of protocol and criteria are described below, and study-level confidence ratings are reported in Appendix A, with the full study appraisal provided in Supplementary Document 1.

The adapted CREED protocol focused on aspects most critical for dietary exposure assessment rather than undertaking a full methodological audit. The appraisal considered five broad domains:

1. Sampling design and reporting: Whether the study clearly described how samples were collected, in what context (e.g. retail, market basket, composite sampling), from which locations, over what timescale and the number of replicates.

2. Food characterisation and relevance: Whether the foods or matrices analysed were clearly identified, appropriately described and relevant to UK diets, and whether sufficient detail was available to classify items into NDNS categories.

3. Analytical methods: Whether PFAS compounds were clearly listed, whether the analytical technique was appropriate (e.g. liquid chromatography-tandem mass spectrometry

(LC-MS/MS)), whether validated or widely accepted methods were used, and whether key elements of quality assurance (QA) and quality control (QC) were reported.

4. Reporting of concentration data: Whether the study provided units, summary statistics, ranges, and, where possible, individual measurement values; whether detection and quantification limits were stated; and whether the treatment of non-detects was clearly described.

5. PFAS coverage and relevance: Whether the range of PFAS measured was appropriate for contemporary understanding of PFAS occurrence in foods, and whether the selection of compounds was justified.

Whether a study met the criteria fully, partially or not at all for each domain was recorded with qualitative notes captured to document specific strengths, limitations or contextual considerations (e.g. unusually high detection limits or limited information on sampling strategies). This created a structured profile of strengths and weaknesses for every study, ensuring that subjective judgement was minimised and that decisions were traceable. Based on the combined profile across domains, each study was assigned an overall confidence rating:

1. High-confidence studies typically had clear sampling descriptions, appropriate analytical methods, transparent reporting of concentration data and sufficient information to assign food groups reliably.

2. Moderate-confidence studies met many of the criteria but had some gaps, for example, incomplete QA/QC information, higher detection limits or limited sampling detail.

3. Limited-confidence studies showed substantial methodological gaps, such as unclear sampling strategies, missing analytical details or insufficiently described food items. In some cases, these studies were still included where data were valuable for under-represented food categories, but their limitations were clearly noted.

Confidence ratings were used to guide the proportional use of evidence within the assessment. High-confidence studies formed the primary basis for quantitative exposure calculations, moderate-confidence studies were used where higher-quality data were unavailable for a given NDNS food category and limited-confidence studies were excluded from quantitative

modelling but retained for qualitative contextualisation and identification of data gaps. Study-level confidence assessments are summarised in Appendix Table 3 and referenced where relevant in the Results and Discussion section of this report (section 3).

2.1.5. Evidence synthesis

Following on from the data extraction and quality appraisal, the evidence base was synthesised to develop an integrated understanding of PFAS occurrence, pathways and potential dietary exposure within the UK food system.

Qualitative evidence was used to inform pathway determination for the conceptual map of PFAS movement through the UK food system. This evidence was reviewed across environmental sources, primary production processes, packaging and retail stages, with particular attention to patterns relating to transfer pathways, including plant uptake from soil, biomagnification in fish, migration from food-contact materials, and transfer during processing and retail handling. These lines of evidence were integrated to support the development of the conceptual food-system map, enabling qualitative linkage of PFAS sources to the receiving food categories and identification of accumulation points and feedback loops.

PFAS occurrence data were grouped by NDNS food category and compared across studies, noting where specific PFAS or PFAS groups appeared frequently or at higher concentrations. Differences between studies were interpreted taking account of the confidence ratings derived from the adapted CREED assessment, as well as the differences in study design, analytical sensitivity and reporting.

The synthesis also captured evidence gaps and limitations, including food categories with sparse or no data, limited UK-specific monitoring and inconsistent analyte coverage. This information informed the uncertainty discussion and helped to guide the horizon-scanning component of this report, as well as the identification of priorities for future surveillance and research.

2.1.6. Approach limitations

The nature of rapid and targeted reviews mean that it is possible that some relevant studies were not captured in the search. This is particularly likely for studies from less accessible sources or those predating the chosen 2015 reporting threshold. Variability across studies in sampling design, analytical capability and reporting practices also introduced challenges. For instance, some older studies used higher detection limits, meaning that non-detects cannot consistently be compared with more recent findings. The availability of UK-specific data was uneven across food categories,

requiring careful consideration when drawing conclusions about national relevance. These limitations are discussed in the relevant aspects of the Results and Discussion section (section 3) to support transparent and appropriate interpretation of the findings.

2.2. Conceptual mapping

A systems-mapping approach was used to characterise how PFAS move from environmental and material sources into foods consumed in the UK. The conceptual map provides a unifying framework that links evidence on PFAS sources, transfer mechanisms and accumulation points across the UK food system. To achieve this the conceptual map integrated evidence from the literature review, data extracted on occurrence and pathways, and mechanistic understanding of PFAS behaviour across environmental and food-system compartments. Its purpose is to provide a qualitative, evidence-grounded representation of the major sources, transfer routes and accumulation points relevant to dietary exposure.

2.3. PFAS occurrence and exposure by food category in the UK food system

This section integrates data, toxicological benchmarks, and dietary consumption patterns to characterise PFAS exposure across different food categories within the UK. By combining harmonized occurrence data with population-level intake, it enables a structured comparison of relative contributions to overall dietary exposure and highlights potential key drivers. The approach also supports identification of priority food categories and data gaps, while providing a transparent basis for interpreting exposure estimates in relation to health-based guidance values.

2.3.1. Toxicological data extraction

A targeted literature search was conducted to identify HBGVs for PFAS published by regulatory authorities since the publication of the EFSA Scientific Opinion on the risk to human health related to the presence of PFAS in food in 2020.

Search terms included ‘PFAS’, ‘perfluoro’, ‘polyfluoro’, ‘perfluoroalkyl’, ‘polyfluoroalkyl’, ‘PFOS’, ‘PFOA’, ‘PFHxS’ and ‘PFNA’. The review focused on Tolerable Daily Intake (TDI), Tolerable Weekly Intake (TWI), and oral Reference Dose (RfD) values. Other values such as Derived No Effect Levels (DNELs), Minimal Risk Levels (MRLs), and indicative Toxicity Values (iTVs) were excluded because they are derived for broader or scenario-specific exposure contexts and not directly comparable to oral intake-based guidance values (e.g. TDI, TWI, RfD) used for dietary risk assessment. All websites were accessed in January 2026. Identified HBGVs were recorded

as reported in the source documents and harmonised to a daily equivalent value (ng kg^{-1} bw d^{1-}). For each value, the critical organ/system, effect, species, point of departure, and uncertainty factors applied were extracted and documented (Supplementary Document 2). The overall confidence level assigned by the authority (high, medium, or low) was recorded. In the limited number of cases where the report from the authority establishing the HBGV did not include any rationale or justification for its derivation, a low confidence rating was assigned.

2.3.2. PFAS occurrence data collation

PFAS occurrence data in food were extracted from the identified peer-reviewed literature and recorded in a harmonised food data matrix (Supplementary Document 3). The extracted information included the food category, PFAS reported, concentration values and units. Concentrations were harmonised to ng g^{-1} where required, and food matrices were mapped to NDNS food categories and subcategories (Appendix Table 8) to support comparison across studies and subsequent dietary exposure assessment. Food contact materials were also recorded where relevant; however, because they do not correspond to an NDNS food category, they were considered separately and were not treated as a direct dietary consumption category.

2.3.2.1. Identification of Total PFAS and PFAS-4 values from each publication

Mean and maximum values for Total PFAS, PFOS, PFOA, PFHxS and PFNA were identified from the publications, where available, and added to the harmonised food data matrix.

The total of all PFAS values (Total PFAS) was taken directly from the original publications where reported. Where not reported, it was calculated as the sum of all quantified PFAS reported for the same study and food category.

Individual concentrations of PFOS, PFOA, PFHxS and PFNA were recorded where available, and PFAS-4 was calculated as the sum of these four substances.

It is important to note that publications may not consistently analyse or report the same PFAS substances. For example, in rare cases, some publications contained information from different studies within the same publication, or a high PFAS-4 value was driven by an unusually elevated concentration in one sample, while other samples showed low or undetected concentrations. Therefore, Total PFAS and PFAS-4 values are not directly comparable.

2.3.2.2. Study selection for exposure calculations

The PFAS concentrations used for the dietary exposure calculations were selected from the harmonised occurrence dataset. Publications classified as high confidence using the adapted CREED framework were prioritised. Where high-confidence studies were available for a given food category, moderate-confidence studies were excluded from the exposure calculations. Where no high-confidence studies were available, moderate-confidence studies were used. Studies classified as limited confidence were excluded from the exposure assessment entirely. The number and confidence level of studies used for each food category were documented in Appendix C2.

2.3.2.3. Selection of concentration values for the exposure assessment

PFAS-4 was prioritised for the exposure calculations, given the availability of a HBGV, i.e. the EFSA TWI, while Total PFAS provided broader context on PFAS occurrence.

For each food category, the mean and maximum concentrations used in the occurrence and exposure assessment (section 3.3.3) corresponded to the highest reported values identified in the selected publications. The highest mean concentration and the highest maximum concentration were identified separately and may therefore originate from different publications. This approach was applied to support a conservative screening-level estimate of dietary exposure. As a result, the selected values should be interpreted as conservative inputs rather than as estimates of actual average concentrations in the UK diet.

Mean values were used for the exposure calculations because, unlike medians, they provide an estimate of average concentrations that also reflects the influence of higher and lower reported values relevant to exposure assessment. Maximum values were used to represent the conservative worst-case scenario for each food category, used as a screening tool to identify food types or supply chains that may warrant prioritisation for further monitoring.

2.3.3. Food category exposure calculations

Dietary exposure to PFAS across the different food categories was calculated on a body weight basis (Supplementary Document 3) according to the following equation:

$$Dietary\ exposure = \frac{PFAS\ concentration\ \left(ng\ g^{-1}\right) \times Food\ consumption\ (g)}{body\ weight\ (kg)}$$

The PFAS-4 concentrations used for the dietary exposure calculations by food category were obtained from the harmonised occurrence dataset as described in section 2.3.2.

Food consumption values were based on the mean daily intake across the UK population (i.e. population-based, instead of consumer-based) for each food category and age group, expressed as grams per day (g d^{-1}), using age categories as reported in the NDNS (2019-2023) and adjusted to reflect weekly consumption. Mean population intakes were selected to provide a nationally representative estimate of typical dietary exposure across the whole population, consistent with a deterministic screening-level exposure assessment. Inclusion of non-consumers results in lower average intake values for some food categories compared with consumer-only estimates; however, this approach avoids over-weighting infrequently consumed foods and aligns with the objective of assessing overall population-level dietary exposure rather than high-consumer scenarios. Implications for higher-exposure sub-groups are considered separately where relevant.

Population-based body weights by age group were used to calculate the dietary exposure to PFAS. The mean body weights were calculated from the NDNS (2019-2023) and are provided in Table 1. As NDNS data are not available for children under 1.5 years of age, this age group was not included in the assessment.

Table 1. Population-based body weight per age group from NDNS years 12-15 (2019-2023).

Age group, years	Body weight, kg
1.5-3	14.6
4-10	28.1
11-18	57.3
19-64	79.9
65-74	78.3
75+	72.2

2.3.4. Risk ratio methodology

Dietary exposure estimates were compared to the respective HBGV across the different food categories (Appendix Table 8). An exposure below the HBGV would be considered acceptable, whereas an exposure over the HBGV would be considered a potential health concern.

Risk ratios can be used to visualise potential health concerns for certain food categories and age groups to allow ranking across the PFAS and food categories. Risk ratios were derived according to the following equation:

$$Risk\ ratio = \frac{Estimated\ exposure}{HBGV}$$

A risk ratio lower than 1 indicates that dietary exposure to PFAS does not exceed the HBGV, and therefore no health concern would be expected for that food category. A ratio higher than 1 indicates that dietary exposure to PFAS exceeds the HBGV and therefore the exposures are of potential concern, the higher the ratio, the more likely the potential concern.

The risk ratio calculation method used in this report was aligned with the approach described by Van der Fels-Klerx et al. (2018). However, it is important to note that, in this assessment, risk ratios are used as a supportive tool to help identify foods and exposure groups that may be of higher risk from PFAS exposure and should not be interpreted as a quantitative measure of risk.

2.3.5. Methodological limitations and interpretation

Substantial variability in data reporting across studies was observed. Mean concentrations and maximum concentrations of Total PFAS were captured in the food data matrix, where available, to illustrate variability across studies. Studies did not consistently analyse or report the same PFAS, and Total PFAS values therefore varied, depending on the PFAS measured and reported by each study. As a result, Total PFAS should be interpreted as an indicative overview of reported occurrence rather than as a precise quantitative measure.

The individual PFAS concentrations used to calculate PFAS-4 were selected from the study and, where relevant, the specific food group (e.g. cheese) within each primary food category (e.g. milk and milk products and alternatives) in which the highest PFAS-4 value was identified. Depending on data availability, the mean and maximum concentrations applied in the exposure assessment (section 3.3.3) may therefore originate from different publications or from different food types within the same primary category. These values are not directly comparable and should be interpreted as conservative inputs for level exposure assessment. In addition, measured values were not always available for all individual PFAS-4; where one or more compounds were not reported, this was highlighted on a case-by-case basis.

Because the exposure assessment used the highest reported mean and maximum concentrations from the selected literature, the results are intentionally conservative. They are suitable for screening-level interpretation but do not reflect actual average UK dietary exposure.

2.4. Whole-diet exposure assessment of PFAS in the UK population

To estimate dietary exposure to PFAS within the UK population, harmonised PFAS concentration data were combined with national food consumption data derived from the NDNS (2019-2023).

The quantitative dietary exposure assessment focused on the PFAS-4 (PFOS, PFOA, PFHxS and PFNA) for which a group HBGV was available. Harmonised PFAS-4 concentration data derived through the occurrence determination process described in section 2.3 were paired with NDNS mean daily consumption values for each first-tier food category (Appendix Table 8).

A central-tendency scenario, based on mean PFAS-4 concentrations, was calculated to represent typical long-term dietary exposure. Exposures were normalised to age-specific average body weights and compared against the EFSA TWI of 4.4 ng kg^{-1} bw w^{-1}.

2.4.1. Exposure calculation framework

Dietary exposure was estimated by combining concentration and consumption data:

1. Assignment to NDNS categories

For each first-tier NDNS category (Appendix Table 8), the selected PFAS-4 concentration was paired with the category's mean daily consumption value (g d^{-1}).

2. Category-level intake estimation

$$Dietary\ intake\ \left(ng\ day^{-1}\right) = Concentration\ \left(ng\ g^{-1}\right) \times Consumption\ \left(g\ d^{-1}\right)$$

3. Whole diet exposure

Intakes from the first tier NDNS food categories were summed to estimate total dietary exposure to PFAS-4 for the central-tendency scenario.

4. Population subgroup analyses

Calculations were conducted for NDNS-defined age groups. Exposures were normalised using population-based average body weights for each subgroup (Table 1) recognising that children may have higher body weight normalised exposure. Weekly exposure estimates for each age group were compared against the EFSA TWI, and risk ratios were calculated as described in section 2.3.4.

2.4.2. Limitations and uncertainty

Key sources of uncertainties include:

- Heterogeneous analyte coverage across studies,
- Variation in analytical detection limits and treatment of non-detects,
- Limited UK-specific data for some food categories,
- Reliance on whole-population mean consumption rather than individual-level intake distributions, and
- Application of mean occurrence values to entire first-tier NDNS food categories, and all categories simultaneously across the whole diet.

2.5. Horizon scanning

To explore how future PFAS applications, substitution trends and cross-section developments may influence the UK food system over the coming decade, a horizon scanning evaluation of the literature was performed. As there is currently little to no predictive evidence around future PFAS uses and emerging applications sit outside the food sector, a structured horizon-scanning approach was used. This method is well-suited to fast-moving topics where decisions must rely on triangulating signals of change rather than on long time-series or formal forecasts. The goal was not to predict single outcomes, but to highlight plausible pathways, document the assumptions and uncertainties, and produce policy-relevant early warning for surveillance and research planning.

2.5.1. Evidence identification and use

To identify forward-facing signals, an additional literature search was undertaken specifically for this component. The search focused on terms related to:

- Future or emerging PFAS uses and PFAS substitution trends,
- New fluorinated materials,
- Cross-sector PFAS pathways with indirect relevance to food,
- Environmental behaviour of short-chain and polymeric PFAS,
- Regulatory restrictions likely to alter PFAS use profiles.

As horizon-scanning is concerned with credible future developments, the search strategy prioritised relevance and mechanistic insight rather than volume. The targeted search returned a relatively small set of documents, and 11 sources met the relevant criteria and were taken forward for detailed review.

This limited number is expected for a horizon-scanning exercise: literature specifically addressing future PFAS applications and forward-looking cross-sector pathways is inherently sparse, fragmented across disciplines, and often embedded within broader environmental or materials contexts.

2.5.2. Extraction and interpretation

For each included source, the review extracted information relating to:

- The future-facing signal (e.g. growing reliance on short-chain PFAS, expansion of PFAS-treated fibres, increased circular-economy flows involving organofluorines),
- The mechanistic basis for food-system relevance (e.g. high mobility, environmental persistence, accumulation in biosolids),
- The potential route to food-system entry (soil, water, feed, aquaculture inputs, packaging, processing), and
- Any uncertainties (e.g. limited toxicological evidence for substitutes, unknown adoption scale, lack of monitoring).

These extracted insights were then compared across sources to identify recurring themes, converging pathways, and credible scenarios by which PFAS or PFAS substitutes could interact with the food system.

As empirical datasets relating to future PFAS applications and use were lacking, a mechanism-based inference method was applied. This allowed for plausible pathways to be considered without implying greater certainty than is supported by the evidence.

2.5.3. Uncertainty and proportionality

Uncertainties are inherent with horizon scanning, particularly where there is only sparse literature, limited monitoring of (potential) substitutes, unclear adoption trajectories, and variable regulatory timelines. Rather than weakening the analysis, this helps to:

- Focus attention on areas where monitoring is most justified,
- Highlight where future research is needed,

- Avoid over-interpretation of early signals, and
- Support proportionate policy development.

3. Results and Discussion

3.1. Literature overview

The evidence base identified for this assessment is heterogeneous both in scope – the parts of the food system and PFAS examined – and depth, reflected in the level of detail, analytical sensitivity and reporting robustness. This variability reflects the current nature of PFAS monitoring across the food system. Most available studies focus on a limited number of food categories and varied groups of PFAS compounds, with substantial variation in sampling context, analytical sensitivity and reporting practices.

Data availability was skewed towards fish and other aquatic foods, followed by offal and animal-derived products, reflecting their known relevance for PFAS bioaccumulation. In contrast, plant-based foods, processed products and composite foods were comparatively under-represented in the literature, and where data are available, they were often limited to small sample numbers or restricted compound lists. This imbalance has important implications for the evaluation and estimation of dietary exposure, as it constrains confidence across several of the NDNS food categories despite their contribution to overall consumption.

Given the multiple interacting routes by which PFAS can enter foods, this assessment adopts a systems-level perspective spanning environmental inputs, agricultural production, food processing, packaging and consumption. Table 2 summarises the distribution of studies included in this assessment grouped by thematic categories. In total, 71 articles were identified and evaluated. As a number of studies addressed more than one theme, papers were counted in every category to which they contributed. Table 2 therefore provides an indication of the relative strengths of evidence available to support different lines of analysis, rather than a measure of study quality.

Table 2. Summary of included literature by evidence theme. A number of studies addressed more than one theme; thus, papers were counted in every category to which they contributed. With regard to article geography, UK refers to UK-based studies or research foci, Europe refers to those applied to or relevant to the EU, ROI (region of interest) refers to studies that apply to or are of relevance to one region of the rest of the world, and Global refers to studies that have an international focus spanning global or multiple geographies.

Evidence theme	Description	Total articles	UK	Europe	ROI	Global
PFAS sources	Studies identifying environmental, agricultural,	**33**	3	18	4	10

Evidence theme	Description	Total articles	UK	Europe	ROI	Global
	industrial, waste-related or packaging-related origins of PFAS entering the food system.					
Contamination pathways	Studies describing how PFAS reach food via environmental transport, agricultural inputs, processing, packaging, or supply-chain movement.	**19**	2	7	2	9
PFAS concentrations in food and food contact materials	Studies providing numerical PFAS occurrence data in food commodities (measured concentrations, detection frequencies, market surveys, monitoring studies).	**43**	1	29	6	10
Accumulation points in the food chain	Studies examining biomagnification, trophic transfer, processing-related accumulation, packaging-to-food migration or other system-level concentration drivers.	**33**	3	18	4	10
Identified evidence gaps	Studies that explicitly highlight major data gaps, uncertainty areas, or methodological limitations relevant to PFAS in food systems.	**9**	0	2	0	7

The combined evidence base shows a broad but uneven distribution of studies across PFAS themes and geographies:

- Studies reporting PFAS concentrations in food (43 articles) originated predominantly from EU and non-EU countries, with only one referring to UK-specific datasets.
- Evidence on accumulation points (33 articles) was mainly driven by the analysis of high-accumulation matrices such as fish, shellfish, meat and eggs. These data were derived mainly from EU or global studies rather than being from UK-specific investigations.

- Pathway-specific evidence (19 articles) mostly originated from globally- or European-focused review articles rather than regional primary research. This highlights a lack of single studies tracing PFAS movement between environmental compartments, agricultural systems and food products.
- Evidence gaps and limitations such as a lack of harmonisation with regard to analytical approaches, limited data on newer or emerging PFAS, and the scarcity of real-world migration or transfer studies, were explicitly identified in only nine articles, with most representing global reviews.

Overall, EU and global studies dominate the evidence base, while UK-specific evidence was comparatively scarce across all thematic areas.

Across the literature, analytical information was inconsistent with a broad range of PFAS groupings, detection limits and analytical approaches reported. As a result, estimates derived from these data inherently reflect both measured concentrations and gaps in analytical coverage.

Evidence relating to sources and transfer pathways was similarly varied. Environmental and production-stage studies provided mechanistic insight into PFAS movement through soils, water, biota and food-contact materials, but direct measurement of transfer between stages was limited. Consequently, pathway interpretation relied upon the integration of multiple lines of evidence rather than single end-to-end datasets.

Overall, the literature identified through the targeted review support a qualitative understanding of key PFAS exposure pathways and identified food categories likely to contribute to dietary intake. Further, it also highlights significant data gaps and uncertainties that must be considered in the exposure assessment and risk interpretation. These characteristics shape the structure of the results presented herein and inform the uncertainty discussion and horizon-scanning analysis.

3.2. PFAS sources and pathways in the UK food system

This section synthesises evidence on the principal sources of PFAS and the pathways through which they may enter and move within the UK food system. The subsections below describe potential entry points spanning environmental reservoirs, agricultural inputs and post-harvest contact and processing pathways. The available evidence is heterogeneous in both scope and geographic coverage, and UK-specific measurements were

limited for several pathways. Accordingly, this section draws on international evidence where relevant and interprets it considering UK production practices, supply-chain characteristics and regulatory context.

3.2.1. PFAS Entry Points in the UK Food System

3.2.1.1. Environmental Sources

PFAS enter the UK food system indirectly through their persistent presence in environmental media arising from industrial manufacture and use, firefighting foam applications, PFAS-containing products (such as greaseproof paper, non-stick cookware, or pesticides) and waste management pathways. Releases to air, soils, surface waters, groundwater and marine environments through historic and contemporary activities result in long-term environmental reservoirs that underpin subsequent food-chain transfer (Costello & Lee, 2024; Eze et al., 2024; Melnyk et al., 2025).

3.2.1.1.1. Industrial Manufacture and Direct Release

Direct PFAS emissions from fluorochemical manufacturing plants (FMPs) have been identified internationally as major historical and contemporary point sources to the environment. Releases may occur via stack emissions, wastewater effluent, cooling water discharges and surface run-off associated with polymer production, surfactant synthesis and related fluorochemical processes, leading to the emission of PFAS to surface waters, groundwaters, surrounding soils and air (Costello & Lee, 2024; Melnyk et al., 2025). Volatile and semi-volatile precursors released to air can undergo regional transport and are returned to land and water bodies through dry and wet atmospheric deposition, establishing diffuse sources that may later influence food-chain exposure (Melnyk et al., 2025).

Although large-scale PFAS manufacture has declined in the UK, legacy industrial uses (e.g. metal plating, textile and paper treatments, fluoropolymer processing) have contributed to localised soil and water contamination that remains relevant due to the highly persistent nature of PFAS (Costello & Lee, 2024). Additionally, international evidence reports PFAS detected in soils, rainwater and crop tissues downwind of manufacturing facilities, with short-chain PFAS (e.g. PFBA, PFPeA, PFHxA) frequently dominating atmospheric transport and deposition patterns (D'Ambro et al., 2021).

A number of UK sites have been reported as potential 'high-risk sites' or 'hotspots' for PFAS contamination, including High Bentham, North Yorkshire; Thornton-Cleveleys, Lancashire; Duxford, Cambridgeshire; Moreton-in-the-Marsh, Cotswolds; RAF bases and airports nationwide (Hosea & Salvidge, 2025; Neill & Colley, 2024), providing strong evidence

that long-lived soil and groundwater plumes at such sites can migrate to streams, rivers, estuaries and coastal waters, creating downstream linkages to freshwater and marine food webs (Ohorro & Ngole-Jeme, 2026).

3.2.1.1.2. Aqueous film-forming foams (AFFF)

Aqueous film-forming foams (AFFF) are highly effective fire suppression agents used to extinguish liquid fuel (Class B) fires. They work by creating a foam blanket that smothers the fire, seals in vapours and cools the fuel in order to prevent reignition. Traditionally, AFFF formulations relied on PFAS-containing surfactants, which helped to promote some of the key properties required for effective fire suppression e.g. heat resistance, extreme stability and surface tension below that of hydrocarbon-based fuels.

Applications of AFFF at airports, military installations, fire-training grounds and petrochemical facilities are widely recognised as major localised PFAS sources, with products historically containing long-chain PFAS (carbon chain length ≥6; e.g. PFOS, PFOA, PFHxS) and precursor compounds (Eze et al., 2024; Melnyk et al., 2025).

3.2.1.1.3. PFAS-containing products and diffuse releases

PFAS are used across a wide range of applications, including textiles, stain-repellent coatings, personal care products, cleaning products, metal-plating baths, paper and packing materials, electronics and industrial fluids, from which PFAS and precursor compounds can be released to municipal wastewater and industrial effluents by use, laundering and disposal (Eze et al., 2024; Melnyk et al., 2025).

Given the limited efficacy of conventional waste-treatment processes for PFAS removal, PFAS can partition to treated effluent (discharged to receiving waters) and concentrate in sewage sludge or biosolids, which may be applied to land. This sustains diffuse inputs across catchments and is therefore relevant to food system exposure pathways (Eze et al., 2024; Ramírez Carnero et al., 2021).

3.2.1.1.4. Waste streams: Landfill leachate, biosolids, compost and paper-derived residues

Landfill leachate and sewer-bound wastes act as continuing sources of PFAS to surface waters; where leachate is directed to sewers, wastewater treatment processes transfer a fraction of PFAS to effluent while concentrating another fraction in biosolids (Rigby et al., 2021).

PFAS have been reported in compost-like outputs (CLO) and paper-derived residues associated with recycled fibre and food-service papers, reflecting PFAS use in oil- and grease-resistant coatings. Where such materials are

applied to land as soil conditioners, soil PFAS reservoirs are created and PFAS enter organic-waste cycles (Jovanović et al., 2024; Saffari Aman et al., 2026; Timshina et al., 2024).

3.2.1.1.5. Food-related environmental media

Soils

Soils act as primary PFAS sinks, facilitating root uptake of mobile short-chain PFAS and soil or dust ingestion by grazing livestock and outdoor poultry (Costello & Lee, 2024; Rigby et al., 2021). UK evidence demonstrates PFAS in soils, including agricultural contexts, with profiles commonly featuring PFOA, PFBA, PFOS and other short-chain PFCAs (Beriro et al., 2025). Legacy paper-sludge inputs and other historical sources can increase PFAS concentrations and broaden the range of PFAS and precursors in affected soils (Fabregat-Palau et al., 2025).

Freshwater systems

PFAS occur widely in rivers, lakes and groundwater due to wastewater treatment plant (WWTP) effluents, industrial discharges, run-off from contaminated sites and AFFF-impacted areas, forming exposure routes to irrigation water, livestock drinking supplies and freshwater fisheries (Eze et al., 2024; Melnyk et al., 2025).

Marine environments

PFAS detected in UK and European coastal waters can be transferred into edible fish and shellfish via waterborne uptake and trophic transfer, with PFOS and long-chain PFCAs frequently reported alongside selected alternatives and precursors (Bedi et al., 2023; Fernandes et al., 2018; Young et al., 2022).

Air and atmospheric deposition (to soil and water)

PFAS and their volatile/semi-volatile precursors emitted to air from industrial sources and firefighting activities, can undergo regional and long-range transport, and are returned via dry and wet deposition to soils, surface waters and plant canopies, thereby re-seeding terrestrial and aquatic exposure pathways (Melnyk et al., 2025).

Field observations near industrial sources and urban regions frequently highlight the prominence of short-chain PFAS (e.g. PFBA, PFPeA, PFHxA) in rainwater and vegetation, consistent with high atmospheric mobility (Lasters et al., 2024).

3.2.1.2. Agricultural Inputs

Agricultural inputs represent a primary mechanism by which PFAS may be introduced to food-producing environments, with land-applied bioresources (i.e. waste-derived organic materials applied to soil), recycled

industrial residues, irrigation waters, agrochemicals and feed-related inputs all contributing to soil and water burdens that subsequently influence crop uptake and livestock exposure (Biswas et al., 2025; Costello & Lee, 2024).

3.2.1.2.1. Land-applied bioresources (biosolids, composts, digestates)

PFAS have been reported in sewage-sludge/biosolid streams destined for UK agricultural use, as well as in compost-like outputs from mixed municipal organics; land application of these materials therefore acts as a sustained, diffuse source of PFAS to agricultural soils (Rigby et al., 2021; Timshina et al., 2024).

Once introduced to soil, PFAS are available for root uptake by plants, particularly the more mobile short-chain PFAAs, for ingestion via soil and dust by grazing livestock and outdoor poultry, and for mobilisation to porewater and drainage paths that link fields to adjacent freshwaters (Biswas et al., 2025; Costello & Lee, 2024).

3.2.1.2.2. Recycled paper/paper-sludge residues and other industrial by-products

Historical recycling of paper-sludge and fibre residues to farmland has resulted in legacy PFAS and precursor burdens in some European agricultural soils, with non-target analyses revealing broad chemical profiles that include fluorotelomer- and PAP-derived substances (Fabregat-Palau et al., 2025). These residues provide long-term soil reservoirs relevant to crop uptake and onward transfer.

More broadly, recycled fibre streams associated with packaging and paper treatment have been identified as potential upstream PFAS sources to waste-derived soil inputs, underscoring the linkage between packaging supply chains and agricultural contamination within circular economy loops (including water) (Jovanović et al., 2024; Saffari Aman et al., 2026).

3.2.1.2.3. Irrigation water and on-farm water use

Where treated effluent, surface water downstream of urban discharges or groundwater influenced by legacy sites is used for irrigation, PFAS present in water may be transferred to field soils and crop root zones, providing a route into edible tissues for more mobile compounds (Eze et al., 2024; Melnyk et al., 2025).

Although UK-specific evidence for widespread irrigation with wastewater is limited, this pathway is recognised as plausible under certain local conditions and has been observed internationally; its inclusion is therefore

warranted for UK systems mapping and for risk-based surveillance of catchments with higher likelihood of use (Biswas et al., 2025; Costello & Lee, 2024).

3.2.1.2.4. Agrochemicals (fertilisers, pesticides, adjuvants)

PFAS and PFAS-containing moieties have been reported in some fertiliser and pesticide formulations, either as intentional functional components to impart performance (e.g. surfactancy, repellence) or as manufacturing residues/impurities. While routine agricultural use within the UK appears limited, imports and legacy stocks remain relevant considerations for exposure mapping (Biswas et al., 2025; Eze et al., 2024). Short-chain PFAS species and precursors present in such inputs have greater mobility in soil-plant systems, reinforcing the need to consider formulation composition where these inputs are used (Costello & Lee, 2024).

3.2.1.2.5. Feed materials, bedding and on-farm circularity

PFAS present in forage crops, fodder, fish-derived meals or locally sourced feed ingredients may be transferred to livestock and poultry, with serum-protein binding and egg deposition contributing to measurable burdens in animal-derived foods under impacted conditions (Gallocchio et al., 2022; Lasters et al., 2022). On-farm reuse of manures, bedding and organic residues can recirculate PFAS within holdings, creating repeated low-level soil inputs and potential accumulation in free-range systems where animals have direct soil access (Costello & Lee, 2024; Rigby et al., 2021).

3.2.1.2.6. Pathway implications for UK food production

In combination, agricultural inputs establish soil-centred exposure hubs that facilitate plant uptake and livestock contact, while also shaping porewater and drainage outflows that connect field to freshwater bodies and, ultimately, estuarine and marine systems (Biswas et al., 2025; Costello & Lee, 2024). The persistence and diversity of PFAS present in bioresources and recycled residues, time-integrated accumulation in soils and recirculation through on-farm nutrient loops should be anticipated, highlighting the potential for targeted UK surveillance where biosolids/compost use, legacy paper-sludge application or effluent-influenced irrigation are more likely (Fabregat-Palau et al., 2025; Rigby et al., 2021; Timshina et al., 2024).

3.2.1.3. Post-harvest contact and processing pathways

3.2.1.3.1. Source potential: Food-contact materials and packaging

PFAS have been incorporated into some paper, board and plant-based FCMs for oil and grease resistance, water repellence and thermal stability. Their use in FCMs therefore represents a potential post-harvest pathway

through which PFAS may be transferred to foods relevant to the UK diet (Lerch et al., 2023; Ramírez Carnero et al., 2021), although migration into food from these sources has not been demonstrated. European retail studies, including studies containing samples obtained from the UK market, have identified both target PFAS and broad extractable organofluorine compounds (EOF; compounds that contain a carbon-fluorine bond, but are not necessarily PFAS, can include pharmaceuticals and agrochemicals) in a range of take-away and retail food papers and boards, supporting the possibility of direct migration to food (Di Mario et al., 2024; Dueñas-Mas et al., 2023; Nxumalo et al., 2024; Vázquez Loureiro et al., 2024).

Analysis of raw-material indicates that virgin and secondary fibre streams used to manufacture paper-based FCMs may already contain multiple PFAS as a result of recycled materials usage or PFAS within raw materials. This indicates that upstream contamination can enter the supply chain before conversion to finished FCM formats (Jovanović et al., 2024). Targeted, suspect and non-targeted analytical approaches have identified the co-occurrence of known and previously unreported PFAS species in consumer packaging, demonstrating the need to consider analytical methodologies that capture the full PFAS signature of a given sample, rather than relying on narrow target lists (Stroski et al., 2024). UK-relevant screening has detected EOFs in multiple FCM formats, indicating that UK retail can encounter both identified PFAS and a non-targeted fluorine fraction (Nxumalo et al., 2024).

Globalised food and packaging supply chains may result in heterogeneous PFAS profiles (Nxumalo et al., 2024; Ramírez Carnero et al., 2021), supporting considerations of imported FCMs and highlighting the need for inclusion of FCMs in UK market-based monitoring alongside supplier assurance.

Whilst UK specific data are scarce, market surveys of fast-food and take-away packaging in France and Belgium report frequent detections of short-chain PFCAs, fluorotelomer sulfonates and PAP-derived species in wrappers, bags and boxes, confirming the occurrence of a range of PFAS in some end use FCMs and identifying substances for which migration may warrant further investigation (Di Mario et al., 2024; Dueñas-Mas et al., 2023). Targeted and non-targeted screening of retail FCMs (e.g. fast-food wrappers, bakery papers, pizza boxes, paper cups, muffin liners) has detected short-chain PFCAs (e.g. PFPeA, PFHxA), PFSAs (e.g. PFOS), fluorotelomer alcohols (FTOHs) and PAP-derived species, confirming a diverse PFAS profile in end-use items (Stroski et al., 2024; Vázquez Loureiro et al., 2024). Investigations of “sustainable” or “compostable” food ware

similarly report detectable migration of PFAS, underscoring that plant-based biodegradable substances are not inherently PFAS-free without supply-chain controls (Simonetti et al., 2024).

However, it should be noted that the available evidence on the occurrence of PFAS in FCMs does not demonstrate migration into food or that FCMs make a significant contribution to overall dietary PFAS exposure.

Disposal pathways for PFAS-treated paper and board can reintroduce PFAS to the organic resource cycle: fibre-based FCMs entering food-waste streams and composting have been shown to contribute PFAS to compost leachates, which may then be applied to land or otherwise mobilised in the environment (Saffari Aman et al., 2026; Timshina et al., 2024). This could create a positive feedback loop whereby packaging-derived PFAS may return to agriculture soil. This linkage aligns the FCM pathway with the circular flows of PFAS movement through the UK food system (Saffari Aman et al., 2026; Timshina et al., 2024).

3.2.1.3.2. Release and amplification: Processing, preparation and handling conditions

PFAS may migrate into foods during post-harvest processing through interactions with treated surfaces, processing equipment, thermal conditions and precursors transformation processes. Although evidence is less extensive than for environmental and packaging pathways, several studies provide mechanistic support for PFAS contamination during food processing.

The mechanistic drivers of migration observed across studies are consistent with diffusion-controlled transfer, where heat, time, matrix (fat/emulsifiers) and surface area-to-mass ratios govern flux from FCM to food (Lerch et al., 2023; Ramírez Carnero et al., 2021). The frequent presence of precursors chemistries (e.g. diPAPs, FTOH) in fibre-based FCMs implies potential transformation into perfluoroalkyl acids (PFAAs) during storage, heating or ingestion, which would alter the PFAS profile observed in foods after contact (Lerch et al., 2023; Ramírez Carnero et al., 2021).

Conditions such as baking, microwaving, toasting or grilling may facilitate the degradation of precursor PFAS (e.g. FTOHs, diPAPs) present in contact materials, resulting in increased concentrations of terminal PFAAs in finished products (Lerch et al., 2023; Vázquez Loureiro et al., 2024). This is particularly relevant to ready-to-eat and baked foods, where both elevated temperature and longer contact durations are encountered during preparation.

Experimental migration studies repeatedly show the role of matrix properties, especially high fat content, moisture and emulsifiers, in facilitating PFAS transfer from processing-contact surfaces, mirroring

patterns seen in packaging-related migration (Vázquez Loureiro et al., 2024). As processing often precedes packaging, these interactions may create multi-step contributions (processing to packaging to food), especially in thermally processed foods.

Processing activities that involve contact with PFAS-treated liners, coated conveyor belts, non-stick surface or heat-resistant gaskets can act as point sources, with studies noting measurable PFAS transfer from contact materials during processing or heating episodes (Genualdi et al., 2021). Non-targeted and suspect-screening work has further indicated that fluoropolymers and precursor-bearing coatings in processing environments may contribute to low-level residues, particularly under reported heating cycles, although, systematic quantification remains limited (Lerch et al., 2023; Stroski et al., 2024).

While UK-specific empirical data for processing environments are limited, the existing evidence base supports its inclusion as a secondary but plausible route, particularly for heat-processed, fatty or ready-to-eat products typical of UK retail (Genualdi et al., 2021). Processing is therefore treated as a distinct post-harvest source node in the conceptual pathway mapping with connections to both packaging contact and domestic preparation.

Retail environments introduce opportunities for additional PFAS transfer through packaging interactions, storage conditions, surface contact and temperature-dependent migration in store and during distribution.

Many foods remain in direct contact with packaging for extended periods during retail display, transport and storage. Evidence from migration studies shows that longer storage times, especially at ambient or elevated temperatures, amplify PFAS transfer from fibre-based packaging into products, particularly for fatty, moist or ready-to-eat items (Lerch et al., 2023; Vázquez Loureiro et al., 2024). This aligns with the detection of short-chain PFCAs, PFSAs and diPAP-derived species in commercially packaged foods across multiple surveys.

Migration studies and market findings converge on hot, fatty and ready-to-eat foods, baked goods and microwave-heated items as higher risk combinations when contact with treated papers or boards is prolonged or at elevated temperature (Lerch et al., 2023; Vázquez Loureiro et al., 2024). Surveys of fast-food packaging similarly point to fried and oily foods as common contexts for PFAS-positive FCMs, aligning with the physicochemical drivers noted above (Di Mario et al., 2024; Dueñas-Mas et al., 2023).

Retail counters where cheeses, baked goods, charcuterie, cooked meats or pastries are wrapped or rewrapped on-site frequently use grease-resistant papers to maintain product integrity. Studies of fast-food and take-away

FCMs demonstrate that such papers often contain PFAS capable of transferring to foods under typical handling conditions (Di Mario et al., 2024; Dueñas-Mas et al., 2023). While UK-specific counter-service data are limited, these retail practices are common across UK supermarkets and bakeries.

Although low temperatures generally slow PFAS migration, transfer is not eliminated; instead, migration profiles shift, with short-chain PFAS showing higher mobility over extended storage durations. Evidence from food simulant studies indicates that refrigerated conditions can still support low-level PFAS transfer during long-term storage (Vázquez Loureiro et al., 2024).

Non-targeted packaging studies have identified fluorinated residues on FCM-adjacent surfaces, such as shelves, cutting areas and wrapping stations (Stroski et al., 2024). While these have not been directly quantified for retail food transfer, they represent a plausible ancillary source given the frequent handling of PFAS-positive packaging.

Direct UK empirical studies that isolate retail handling and storage as distinct PFAS transfer drivers (e.g. counter-wrapping practices, in-store display duration/temperature, repackaging) were not identified in the extracted literature. The inclusion of this pathway in the UK food-system map is therefore inferred from European and international evidence demonstrating PFAS presence in fast-food/take-away packaging (France, Belgium) and migration under retail-like conditions (temperature, contact time, matrix fat), alongside UK-market packaging screenings that indicate measurable organofluorine in fibre-based FCMs sold in UK retail (Di Mario et al., 2024; Dueñas-Mas et al., 2023; Lerch et al., 2023; Nxumalo et al., 2024; Vázquez Loureiro et al., 2024).

Experimental migration assessments, conducted with food simulants and/or real food matrices, have shown transfer of PFAS for paper- and plant-based FCMs under typical contact times and temperatures, corroborating the feasibility of post-harvest PFAS inputs to food (Simonetti et al., 2024; Vázquez Loureiro et al., 2024).

Considered in combination, experimental migration studies provide confirmatory support for the post-harvest relevance of PFAS in paper- and plant-based FCMs, rather than introducing new pathways beyond those identified through market surveys and screening studies. The consistency of findings across simulate-based and real-food experiments indicates that contact with treated fibre-based materials can contribute to PFAS presence in foods under realistic use conditions, including for items marketed as ‘sustainable’ or ‘compostable’. This reinforces the importance of considering FCMs as part of integrated exposure assessment and

highlights the need for supply-chain controls and market-based monitoring rather than reliance on material classification alone (Lerch et al., 2023; Simonetti et al., 2024; Vázquez Loureiro et al., 2024).

3.2.2. PFAS Pathways Through the Food System

The PFAS entry points to the UK food system outlined in section 3.2.1 combine into directional pathways that describe how PFAS may move through the UK food system. These flows connect source nodes (e.g. environmental reservoirs, agricultural inputs, FCMs) to receiving nodes (e.g. crops, livestock products, processed foods) and correspond directly to the conceptual map (Figure 2, section 3.2.3), where each arrow represents an evidence-supported transfer. Table 3 summarises these flows using paired "Source → Receiving" nodes, providing a high-level representation of how PFAS are transferred and circulated within the UK food system.

3.2.3. Conceptual map

The conceptual map (Figure 2) provides a systems-level framework illustrating the pathways through which PFAS move through the UK food system. It encompasses foods consumed in the UK, including imported products, to reflect real dietary exposure.

The evidence shows that PFAS contamination in the UK food system can occur from multiple interacting sources operating across environmental, agricultural, processing, packaging, retail and waste-management domains.

Some pathways create circular feedback loops from packaging and retail back to agricultural soils and water, potentially contributing to the recirculation of PFAS through environmental reservoirs. The conceptual map therefore represents a system influenced by both historical contamination and contemporary inputs, with implications for surveillance, exposure assessment and regulatory priorities.

3.3. PFAS occurrence and exposure by food category in the UK food system

This section presents occurrence-based prioritisation and screening-level exposure indicators at the individual food category level; synthesis of these data into whole-diet exposure profiles is provided in section 3.4.

The objective of this stage was to identify the potential health concerns for certain food categories and age groups. Although the literature contains many PFAS measurements, analyte lists, detection limits and reporting conventions vary substantially between studies. As a result, it was not possible to construct a fully quantitative ranked list of individual PFAS with sufficient reliability. This approach therefore combines harmonised

Table 3. PFAS pathways through the UK food system presented as paired nodes. Qualitative synthesis from the screened literature. Evidence base codes: UK = direct UK / UK market evidence; EU = European evidence; INT = International evidence; EXTR* = extrapolated to UK from EU / INT studies (e.g. UK-market fibre-based FCMs showing measurable organofluorine).

Source node	Transfer drivers / mechanism	Receiving node	Evidence base	Example PFAS classes (qualitative)	Citations
Industrial manufacture, AFFF use, consumer product use, landfill leaching, WWTP releases.	Direct emissions, effluent, runoff; atmospheric transport and wet/dry deposition to soil and/or water.	Environmental reservoirs: air (depositions), soil, freshwater, marine water).	UK / EU / INT	Long- and short-chain PFCAs and PFSAs; precursors (FTOHs, FT(S)A).	Costello and Lee (2024); Baqar et al. (2024); Melnyk et al. (2025)
Environment: Soil (background/ historically used PFAS, including bioresources and paper-sludge legacy).	Soil-plant transfer (higher mobility for short-chain PFAS), site history.	Crops (leafy/root; cereals).	UK / EU / INT	Short-chain PFCAs; some long-chain PFCAs; occasional PFSAs / precursors.	Beriro et al. (2025); Biswas et al. (2025); Fabregat-Palau et al. (2025)
Environment: Freshwater, estuarine, marine water and sediments.	Aqueous uptake and trophic transfer.	Fish and shellfish.	UK / EU	PFOS, long-chain PFCAs; selected alternatives.	Fernandes et al. (2018); Junqué et al. (2026); Young et al. (2022)
Bioresources: Biosolids, Compost-like outputs, compost, and recycled paper and board residues.	Land application entering soil reservoirs.	Agricultural soils.	UK / EU / INT	Mixed: PFOS often dominant in biosolids; short-chain PFCAs prevalent in compost leachates.	Rigby et al. (2021); Timshina et al. (2024); Saffari Aman et al. (2026)
Irrigation water: Effluent-influenced or surface water.	Root-zone loading during irrigation.	Crops (particularly, leafy/root).	EU / INT / EXTR	Short-chain PFCAs, some PFSAs.	Costello and Lee (2024); Melnyk et al. (2025)
Food, forage, soil, dust, drinking water.	Ingestion by livestock and poultry.	Livestock products (meat, offal, eggs).	EU / INT / EXTR	Varied profiles spanning long- and short-chain PFAS.	Gallocchio et al. (2022); Death et al. (2021); Lasters et al. (2022)
FCM (including some paper, board, plant/fibre-based materials).	Potential migration under time, temperature, high fat content; precursor transformation.	Processed or ready-to-eat foods; hot, fatty foods; baked goods.	UK / EU	Short-chain PFCAs, FTSs; PAP-derived substances, FTOHs; non-targeted organofluorine.	Vázquez Loureiro et al. (2024); Lerch et al. (2023); Simonetti et al. (2024); Stroski et al. (2024); Jovanović et al. (2024); Nxumalo et al. (2024)
Processing contact materials and equipment.	Contact with treated surfaces or liners; thermal processing steps.	Processed or ready-to-eat foods; hot, fatty foods; baked goods.	EU / INT / EXTR	PFAAs from precursor degradation; matrix-dependent.	Lerch et al. (2023); Vázquez Loureiro et al. (2024); Genualdi et al. (2021)
Retail handling and storage	Prolonged contact with	Counter-wrapped	UK / EU	Similar to FCM migration	Dueñas-Mas et al. (2023); Di Mario et al.

Source node	Transfer drivers / mechanism	Receiving node	Evidence base	Example PFAS classes (qualitative)	Citations
(display, transport, re-wrapping).	grease-resistant papers; time and temperature effects.	bakery and deli items; chilled ready-to-eat foods.		classes; short-chain species prominent.	(2024); Vázquez Loureiro et al. (2024); Nxumalo et al. (2024)
Circular flows: FCM, consumer waste and recycled fibre used to produce organic bioresources.	Composting, curing, leachate transfer; potential subsequent land application.	Agricultural soils (feedback loop).	UK / EU / INT	Short-chain PFCAs dominant in leachates; mixed classes in organics.	Timshina et al. (2024); Saffari Aman et al. (2026); Rigby et al. (2021)

* Transfer pathway demonstrated in EU/international studies and considered plausible for the UK, but for which direct UK transfer evidence was not identified.

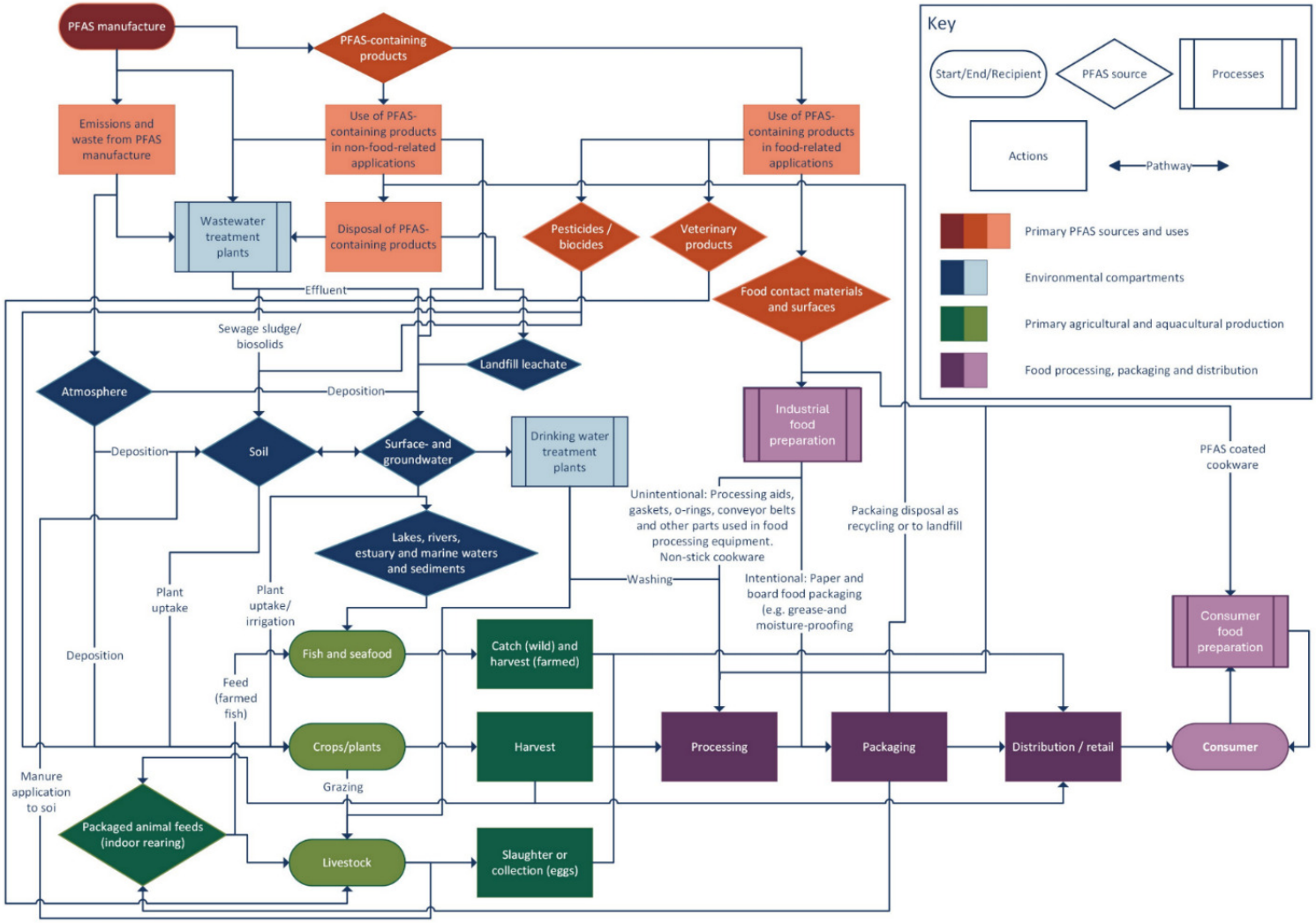

Figure 2. Conceptual map illustrating the pathways and compartments governing the flow of PFAS through the UK food system. Primary sources and uses (red) represent industrial manufacture, product use and waste disposal activities leading to environmental release or food exposure. Environmental compartments (blue) include air, soil, surface water, groundwater, wastewater and associated treatment systems, which govern PFAS fate and transport. Primary agricultural production (green) captures the transfer of PFAS into crops, livestock and aquatic food production via processes such as deposition, irrigation, plant uptake, grazing and feed inputs. Post-harvest food processing, packaging and distribution (purple) represent potential additional PFAS inputs arising from food contact materials, processing equipment, packaging and handling prior to consumption. Arrows indicate potential transfer pathways between compartments; the map is qualitative and intended to support exposure pathway identification rather than quantitative mass balance.

occurrence data, the toxicological benchmark (EFSA TWI) and adapted-CREED confidence ratings to identify where surveillance and risk-reduction efforts would offer the strongest benefits.

3.3.1. Toxicological data extraction and alignment

A range of HBGVs have been established by regulatory authorities to support the interpretation of chemical exposure and the protection of public health. These include the Tolerable Daily Intake (TDI), defined as the estimate of the amount of a substance in food or drinking water which is not added deliberately (e.g. contaminants) and which can be consumed daily over a lifetime without presenting an appreciable risk to health (EFSA, 2025b). Similarly, the Tolerable Weekly Intake (TWI) represents the amount that can be ingested on a weekly basis over a lifetime without appreciable risk to health (EFSA, 2025c); it can be applied when substances accumulate or have long half-lives. The oral Reference Dose (RfD), derived primarily by the US Environmental Protection Agency (US EPA), is an estimate of the daily oral exposure likely to be without significant risk of adverse effects during a lifetime (US EPA, 2025b). Together, these values provide benchmarks against which estimated dietary exposures, in this case to PFAS, can be compared.

A total of 13 HBGVs derived by the European Food Safety Authority (EFSA), the US Environmental Protection Agency (US EPA), and the Australian National Health and Medical Research Council (NHMRC) were identified (Supplementary Document 2).

In 2020, EFSA published the scientific evaluation on the risks to human health related to the presence of perfluoroalkyl substances (PFASs) in food. EFSA performed the assessment for the sum of PFOS, PFHxS, PFNA, PFOA, based on similar effects on animals, toxicokinetics and observed concentrations in human blood. Effects on the immune system were considered the most critical and a TWI value of 4.4 ng kg^{-1} bw w^{-1} for the sum of the four PFAS was established. This TWI value was considered protective for the other potential critical endpoints (increase in serum cholesterol, reduced birth weight and high serum levels of the liver enzyme alanine transferase (ALT)) considered in the previous Opinion on PFOS and PFOA from 2018 (EFSA CONTAM Panel, 2020).

From 2021 to 2025, the US EPA reviewed the toxicological properties of nine PFAS and their related salts. RfD values were derived from human or animal studies (rat, mice) for the following PFAS based on the critical effects: perfluorobutanoic acid (PFBA), perfluorodecanoic acid (PFDA), PFHxS, perfluorohexanoic acid (PFHxA), PFOA, PFOS, perfluorobutane sulfonic acid (PFBS), hexafluoropropylene oxide (HFPO, also known as GenX) and perfluoropropanoic acid (PFPrA) as indicated in Table 4. Where

subchronic and chronic values were available, the chronic value was selected. Organ specific Reference Dose (osRfD) derived for the specific organ effects were not included since the oral RfD derived for the compound covers the individual osRfD.

Assessments by other Agencies, i.e. the European Chemicals Agency (ECHA), the French Agency for Food, Environmental and Occupational Health & Safety (ANSES), the German Federal Institute for Risk Assessment (BfR), the Dutch National Institute for Public Health and the Environment (RIVM), the UK Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (COT), the Danish EPA (MST), the Swedish EPA (Naturvårdsverket) and Health Canada were used to understand the current status on PFAS toxicological evaluation worldwide:

- EFSA's HBGV was adopted by other European agencies, including ANSES, BfR, RIVM, and the Swedish EPA.
- ECHA's Risk Assessment Committee (RAC) is currently evaluating the universal restriction proposal on all PFAS which was submitted in January 2023 by the national authorities of the Netherlands, Germany, Denmark, Norway and Sweden, which covered all PFAS and all uses.
- Although Health Canada and the Danish EPA have derived TDI values in the past, they no longer establish any TDI or TWI values, which may be associated with a general broader evolution in risk assessment and increasing consideration of cumulative exposures and substance-group approaches.
- The UK COT has published a statement evaluating the scientific basis of EFSA's new TWI for the sum of four PFAS (COT, 2022) and an interim position paper on PFAS (COT, 2023). COT's current work on PFAS is being undertaken by a dedicated subgroup and is expected to include the derivation of one or more HBGVs, as supported by the available evidence.

The NHMRC released version 4 of the Australian Drinking Water Guidelines in 2025, including TDI values for PFOA, PFOS, and PFHxS which are presented in Table 5 (NHMRC, 2011. Version 4.0 Updated June 2025).

3.3.2. PFAS data collation and harmonisation

The mean and maximum values of the individual PFOA, PFOS, PFHxS, PFNA and mean and maximum of Total PFAS reported in the publications identified during the literature phase were collected and expressed in ng g^{-1} as previously described (section 2.3.1; Supplementary Document 3). Some studies reported mean values or ranges for all the PFAS detected

Table 4. US EPA RfD values for PFBA, PFDA, PFHxS, PFHxA, PFOA, PFOS, PFBS, HFPO (GenX) and PFPrA.

Substance	Reference Dose (RfD) as stated in the report, mg kg^{-1} d^{-1}	Daily equivalent HBGV value, ng kg^{-1} bw d^{-1}	Critical organ/ system	Critical effect	Species	Reference
PFBA	1 x 10 -3	1000	Endocrine, hepatic	Increased hepatocellular hypertrophy (liver), decreased total T4 (thyroid)	Rat	(US EPA, 2022)
PFDA	2 x 10 -9	0.002	Immune	Decreased serum antibody concentrations for tetanus and diphtheria in children at age 7 years and PFDA measured at age 5 years	Human	(US EPA, 2024c)
PFHxS	4 x 10 -10	0.0004	Developmental, Immune	Decreased serum anti-tetanus antibody concentration in children at age 7 years	Human	(US EPA, 2025a)
PFHxA	5 x 10 -4	500	Developmental	Decreased postnatal (PND 0) body weight in F1 Sprague-Dawley male and female rats	Rat	(US EPA, 2023a)
PFOA	3×10−8	0.03	Immune, developmental, and cardiovascular	Decreased anti-tetanus and anti-diphtheria antibody concentrations in children, decreased birth weight, and increased total cholesterol	Human	(US EPA, 2024b)
PFOS	1×10−7	0.1	Developmental, Cardiovascular	Decreased birth weight in infants. Increased total cholesterol in 20- to 80-year-old adults	Human	(US EPA, 2024a)
PFBS	0.0003	300	Thyroid	Thyroid (decreased serum total thyroxine, T4) in neonatal mice offspring	Mice	(US EPA, 2021b)
HFPO (GenX)	0.000003 (3 x 10-6)	3	Liver	Liver constellation of lesions in parental female mice	Mice	(US EPA, 2021a)
PFPrA	0.0005 or 5 × 10−4	500	Liver	Increased relative liver weight in rats	Rat	(US EPA, 2023b)

Table 5. NHMRC TDI values for PFOA, PFOS, and PFHxS.

Substance	Tolerable Daily Intake (TDI) as stated in the report	Daily equivalent HBGV value, ng kg^{-1} bw d^{-1}	Critical organ/ system	Critical effect	Species	Reference
PFOA	1946 ng kg^{-1} bw d^{-1} (0.001946 mg kg^{-1} bw d^{-1})	1946	Cancer	Pancreatic acinar adenomas and adenocarcinomas in rats	Rat	(US EPA, 2024c)
PFOS	728 ng kg^{-1} bw d^{-1} (0.000728 mg kg^{-1} bw d^{-1})	728	Bone marrow	Bone marrow effects (extramedullary haematopoiesis and bone marrow hypocellularity) in rats	Rat	(US EPA, 2024c)
PFHxS	2916 ng kg^{-1} bw d^{-1} (0.002916 mg kg^{-1} bw d^{-1})	2916	Thyroid	Thyroid effects (i.e. decreased thyroxine (T4) levels) in male rats	Rat	(US EPA, 2024c)

individually. For these studies, the mean values for each detected PFAS were added together to calculate the mean of Total PFAS. When studies reported mean PFAS concentrations for multiple samples within the same subcategory and provided sample sizes, overall mean concentrations were calculated using sample-size weighted averages, rather than simple arithmetic means of reported values.

Studies that reported only aggregate PFAS values across multiple food categories, rather than providing concentrations for individual food categories, were noted explicitly in the harmonised food data matrix since these values cannot be directly compared to other PFAS concentrations found in distinct food categories. Studies which reported multiple values or means for PFAS concentrations in foods which belong to the same subcategory (i.e. chicken livers reported separately from beef livers, but both classified as offal), were averaged together. For review papers which report values from other sources, the original sources were searched for and included separately. However, if a source was unavailable, the data reported in the review paper was collected in the data matrix as derived from the review paper. Sources in reviews which were outside of scope (i.e. from a different location or before 2015) were not considered or included.

3.3.3. Occurrence, exposure to PFAS and risk ratio

The sum of PFOA, PFNA, PFHxS and PFOS (PFAS-4) was prioritised in this assessment because, according to EFSA, these four PFASs account for the majority of the PFAS burden observed in human serum. They share similar toxicokinetic characteristics, including comparable accumulation patterns and long biological half-lives. Moreover, animal studies show that these compounds generally elicit similar types of effects. Although this may also apply to other PFASs, the key human studies did not report these additional substances in participants' blood (EFSA, 2020).

PFAS exposure was evaluated for the different food categories using the harmonised dataset that resulted from the data collation and harmonisation step as described in section 2.3.2.

Weekly dietary exposure to PFAS-4 was calculated and risk ratios were derived for the different NDNS Food Categories, using the EFSA TWI of 4.4 ng kg^{-1} bw w^{-1}, while Total PFAS was used to provide broader context on PFAS occurrence.

The PFAS detected for each food category and publication, and the exposure and risk ratio calculations are included in a food data matrix (Supplementary Document 3). It is important to note that in this assessment the risk ratios should be interpreted qualitatively rather than as measures of health risk. The results are summarised below.

- Cereals and cereal products

Two articles about PFAS quantification in cereals and cereal products were identified in the literature, one of them was considered of high confidence (paper 71; see Supplementary Document 3) and the other one of moderate confidence. The high confidence publication was used for the assessment and the occurrence of PFAS in cereal and cereal products is summarized in Table 6.

Table 6. PFAS occurrence in cereals and cereal products.

	Total PFAS, ng g^{-1}	PFOS, ng g^{-1}	PFOA, ng g^{-1}	PFHxS, ng g^{-1}	PFNA, ng g^{-1}	PFAS-4 sum, ng g^{-1}
mean	0.07*	-	0.04	-	-	0.04*
max	0.22*	-	0.14	-	-	0.14*

*calculated

PFOS, PFHxS and PFNA were not detected in the samples analysed in the study. The exposure to PFAS-4 from cereal and cereal products was below or around the established EFSA TWI of 4.4 ng kg^{-1} bw w^{-1} in most cases, except for the maximum in toddlers and young children. Exposure and risk ratio for this food category are presented by age group in Table 7 with the highest exposure highlighted in bold.

Table 7. PFAS calculated exposure and risk ratio from cereals and cereal products.

Age group		Total PFAS exposure, ng kg-1 bw w-1		PFAS-4 exposure*, ng kg-1 bw w-1	PFAS-4 Risk ratio
1.5-3	**mean**	6.51	**mean**	3.44	0.78
	max	20.45	**max**	**13.01**	2.96
4-10	**mean**	4.34	**mean**	2.29	0.52
	max	13.64	**max**	8.68	1.97
11-18	**mean**	2.60	**mean**	1.37	0.31
	max	8.17	**max**	5.20	1.18
19-64	**mean**	1.65	**mean**	0.87	0.20
	max	5.19	**max**	3.31	0.75
65-74	**mean**	1.61	**mean**	0.85	0.19
	max	5.06	**max**	3.22	0.73
75+	**mean**	1.67	**mean**	0.88	0.20
	max	5.26	**max**	3.35	0.76

* PFAS-4 exposure calculated based on PFOA.

- Milk and milk products and alternatives

A total of six articles were identified in the literature, three of them of high quality and three of moderate quality. The three papers of high quality (paper ref. 36, 38 and 71; see Supplementary Document 3) were considered for the assessment. The occurrence of PFAS in milk products is summarised in Table 8.

Table 8. PFAS occurrence in milk and milk products.

	Total PFAS, ng g^{-1}	PFOS, ng g^{-1}	PFOA, ng g^{-1}	PFHxS, ng g^{-1}	PFNA, ng g^{-1}	PFAS-4 sum, ng g^{-1}
mean	2.64*	0.019	-	-	-	0.019*
max	5.20*	0.028	-	-	-	0.028*

*calculated

PFOA, PFHxS and PFNA were not detected in the samples analysed from the selected studies. The exposure to PFAS-4 from milk and milk products was below the established EFSA TWI of 4.4 ng kg^{-1} bw w^{-1} for all age groups. Exposure and risk ratio for this food category are presented by age group in Table 9.

Table 9. PFAS calculated exposure and risk ratio from milk and milk products.

Age group		Total PFAS exposure, ng kg-1 bw w-1		PFAS-4 exposure*, ng kg-1 bw w-1	PFAS-4 Risk ratio
1.5-3	**mean**	364.34	**mean**	2.62	0.60
	max	717.91	**max**	3.87	0.88
4-10	**mean**	167.27	**mean**	1.20	0.27
	max	329.60	**max**	1.77	0.40
11-18	**mean**	67.25	**mean**	0.48	0.11
	max	132.52	**max**	0.71	0.16
19-64	**mean**	49.91	**mean**	0.36	0.08
	max	98.34	**max**	0.53	0.12
65-74	**mean**	63.50	**mean**	0.46	0.10
	max	125.12	**max**	0.67	0.15
75+	**mean**	77.43	**mean**	0.56	0.13
	max	152.58	**max**	0.82	0.19

* PFAS-4 exposure calculated based on PFOS.

- Eggs and egg dishes

A total of thirteen articles were identified in the literature, eleven of them of high quality and two of moderate quality. The eleven papers of high quality (paper ref. 1, 4, 28, 33, 36, 39, 65, 66, 68, 69 and 71; see Supplementary Document 3) were considered for the assessment.

Two studies were excluded from the calculations (paper ref 28 and 66) as PFAS were measured in homegrown eggs near a fluorochemical plant in Antwerp (Belgium). The occurrence of PFAS in egg and egg dishes is summarised in Table 10.

Table 10. PFAS occurrence in eggs and egg dishes.

	Total PFAS, ng g^{-1}	PFOS, ng g^{-1}	PFOA, ng g^{-1}	PFHxS, ng g^{-1}	PFNA, ng g^{-1}	PFAS-4 sum, ng g^{-1}
mean	5.03*	2.5	0.3	0.1	0.2	3.10*
max	31.2	24.8	2.7	5.2	2	34.7*

*calculated

The exposure to mean PFAS-4 concentration from eggs and egg dishes was below or around the established EFSA TWI of 4.4 ng kg^{-1} bw w^{-1} in most cases, except for toddlers. The exposure to maximum PFAS-4 was over the EFSA TWI for all age groups. Exposure and risk ratio for this food category are presented in Table 11, with the highest exceedance highlighted in bold.

Table 11. PFAS calculated exposure and risk ratio from eggs and egg dishes.

Age group		Total PFAS exposure, ng kg-1 bw w-1		PFAS-4 exposure*, ng kg-1 bw w-1	PFAS-4 Risk ratio
1.5-3	**mean**	20.55	**mean**	**12.66**	2.88
	max	127.44	**max**	**141.74**	32.21
4-10	**mean**	10.16	**mean**	6.26	1.42
	max	63.01	**max**	70.08	15.93
11-18	**mean**	5.16	**mean**	3.18	0.72
	max	32.01	**max**	35.60	8.09
19-64	**mean**	7.93	**mean**	4.89	1.11
	max	49.20	**max**	54.72	12.44
65-74	**mean**	6.64	**mean**	4.09	0.93
	max	41.17	**max**	45.79	10.41
75+	**mean**	6.71	**mean**	4.13	0.94
	max	41.61	**max**	46.28	10.52

* PFAS-4 exposure calculated based on PFOS, PFOA, PFHxS and PFNA.

- Fats and oils

One publication of moderate confidence was identified for the fats and oils food category (paper ref 16; see Supplementary Document 3). More than 50 PFAS were analysed in different animal and vegetable oils, with fish oil being the one with the highest mean Total PFAS concentration (701.97 ng g^{-1}). No maximum values were reported in this publication. The PFAS occurrence is summarised in Table 12.

Table 12. PFAS occurrence in fats and oils.

	Total PFAS, ng g^{-1}	PFOS, ng g^{-1}	PFOA, ng g^{-1}	PFHxS, ng g^{-1}	PFNA, ng g^{-1}	PFAS-4 sum, ng g^{-1}
mean	701.97*	0.52	0.48	0.51	0.53	2.04*
max	-	-	-	-	-	-

*calculated

The exposure to PFAS-4 was below the EFSA TWI of 4.4 ng kg^{-1} bw w^{-1} for all the age groups as presented in Table 13.

Table 13. PFAS calculated exposure from fats and oils.

Age group		Total PFAS exposure, ng kg-1 bw w-1		PFAS-4 exposure*, ng kg-1 bw w-1	PFAS-4 Risk ratio
1.5-3	**mean**	932.08	**mean**	2.70	0.61
	max	-	**max**	-	-
4-10	**mean**	587.40	**mean**	1.70	0.39
	max	-	**max**	-	-
11-18	**mean**	249.03	**mean**	0.72	0.16
	max	-	**max**	-	-
19-64	**mean**	310.05	**mean**	0.90	0.20
	max	-	**max**	-	-
65-74	**mean**	466.90	**mean**	1.35	0.31
	max	-	**max**	-	-
75+	**mean**	550.66	**mean**	1.60	0.36
	max	-	**max**	-	-

* PFAS-4 exposure calculated based on PFOS, PFOA, PFHxS and PFNA.

- Meat and meat products

A total of twelve papers were identified in the literature, seven of them were considered of high confidence (paper ref 4, 33, 38, 39, 65, 67 and 71; see Supplementary Document 3) and five of them of moderate confidence for the assessment. The occurrence of PFAS in meat and meat products is summarised in Table 14.

Table 14. PFAS occurrence in meat and meat products.

	Total PFAS, ng g^{-1}	PFOS, ng g^{-1}	PFOA, ng g^{-1}	PFHxS, ng g^{-1}	PFNA, ng g^{-1}	PFAS-4 sum, ng g^{-1}
mean	19.61*	0.78	0.04	0.13	0.09	1.04*
max	35	4.22	0.04	0.19	0.30	4.75*

*calculated

The PFAS-4 concentrations resulted in a consumer exposure above the EFSA TWI of 4.4 ng kg^{-1} bw w^{-1} for all age groups. Since the exposure calculations for meat and meat products category are based on offal and offal products and dishes, the resulting exposure estimates may represent an overestimation for the primary category. Exposure and risk ratio for this food category are presented by age group in Table 15 with the highest exceedance highlighted in bold.

Table 15. PFAS calculated exposure and risk ratio from meat and meat products.

Age group		Total PFAS exposure, ng kg-1 bw w-1		PFAS-4 exposure, ng kg-1 bw w-1	PFAS-4 Risk ratio
1.5-3	**mean**	711.76	**mean**	**37.75**	8.58
	max	1270.35	**max**	**172.41**	39.18
4-10	**mean**	510.42	**mean**	27.07	6.15
	max	910.99	**max**	123.63	28.10
11-18	**mean**	345.66	**mean**	18.33	4.17
	max	616.94	**max**	83.73	19.03
19-64	**mean**	230.02	**mean**	12.20	2.77
	max	410.55	**max**	55.72	12.66
65-74	**mean**	199.16	**mean**	10.56	2.40
	max	355.45	**max**	48.24	10.96
75+	**mean**	210.58	**mean**	11.17	2.54
	max	375.85	**max**	51.01	11.59

* PFAS-4 exposure calculated based on PFOS, PFOA, PFHxS and PFNA.

- Fish and fish dishes

A total of eleven publications were identified in the literature, eight of them considered of high quality (paper refs 2, 8, 9, 30, 33, 39, 70 and 71; see Supplementary Document 3) and three of them of moderate quality.

One high confidence study (paper ref 70) reporting high values of mean and maximum total PFAS (43.6 ng g^{-1} and 172 ng g^{-1}, respectively), was excluded from the calculations as some of the measurements were taken in the Ghent-Terneuzen Canal and the authors stated that high concentrations could be probably attributed to a fluorochemical plant located in Zwijndrecht near Antwerp. The PFAS occurrence in fish and fish dishes is summarised in Table 16.

Table 16. PFAS occurrence in fish and fish dishes.

	Total PFAS, ng g^{-1}	PFOS, ng g^{-1}	PFOA, ng g^{-1}	PFHxS, ng g^{-1}	PFNA, ng g^{-1}	PFAS-4 sum, ng g^{-1}
mean	13.20*	4.34	0.07	-	2.06	6.47*
max	20.13	55.85	9.77	0.12	1.19	66.93*

*calculated

PFHxS was detected in fish and fish dishes in some high-confidence publications, however it was not detected in the study containing the highest PFAS-4 mean value that was selected for the exposure assessment. The mean and maximum PFAS-4 concentrations resulted in a consumer exposure above the EFSA TWI of 4.4 ng kg^{-1} bw w^{-1} for all age groups. Exposure and risk ratio for this food category are presented by age group in Table 17 with the highest exceedance highlighted in bold.

Table 17. PFAS calculated exposure from fish and fish dishes.

Age group		Total PFAS exposure, ng kg-1 bw w-1		PFAS-4 exposure*, ng kg-1 bw w-1	PFAS-4 Risk ratio
1.5-3	**mean**	89.79	**mean**	**44.01**	10
	max	156.45	**max**	**455.28**	103.47
4-10	**mean**	50.79	**mean**	24.89	5.66
	max	88.49	**max**	257.51	58.52
11-18	**mean**	20.08	**mean**	9.84	2.24
	max	34.99	**max**	101.81	23.14
19-64	**mean**	26.48	**mean**	12.98	2.95
	max	46.14	**max**	134.26	30.51
65-74	**mean**	31.62	**mean**	15.50	3.52
	max	55.10	**max**	160.33	36.44
75+	**mean**	35.91	**mean**	17.60	4.00
	max	62.58	**max**	182.10	41.39

* PFAS-4 exposure calculated based on PFOS, PFOA and PFA (mean) and PFOS, PFOA, PFHxS and PFNA (max).

- Vegetables and vegetable products and dishes

A total of six papers were identified in the literature, five of high confidence (ref 38, 39, 60, 64 and 71; see Supplementary Document 3) and one of moderate confidence.

One high confidence publication was excluded (paper ref 64) since it included data on a contaminated site in northern Italy. The occurrence of PFAS in vegetables and vegetable products and dishes from the four remaining publications is summarised in Table 18.

Table 18. PFAS occurrence in vegetable and vegetable products and dishes.

	Total PFAS, ng g^{-1}	PFOS, ng g^{-1}	PFOA, ng g^{-1}	PFHxS, ng g^{-1}	PFNA, ng g^{-1}	PFAS-4 sum, ng g^{-1}
mean	4.02*	0.03	0.37	0.08	0.02	0.51*
max	7.32*	0.83	3.03	0.75	0.30	4.91*

*calculated

The mean and maximum PFAS-4 concentrations resulted in a consumer exposure above the EFSA TWI of 4.4 ng kg^{-1} bw w^{-1} for all age groups. Exposure and risk ratio for this food category are presented by age group in Table 19 with the highest exceedance highlighted in bold.

Table 19. PFAS calculated exposure and risk ratio from vegetable and vegetable products and dishes.

Age group		Total PFAS exposure, ng kg-1 bw w-1		PFAS-4 exposure*, ng kg-1 bw w-1	PFAS-4 Risk ratio
1.5-3	**mean**	175.68	**mean**	**22.29**	5.07
	max	319.90	**max**	**214.58**	48.77
4-10	**mean**	117.40	**mean**	14.89	3.38
	max	213.77	**max**	143.39	32.59
11-18	**mean**	58.06	**mean**	7.37	1.67
	max	105.72	**max**	70.92	16.12
19-64	**mean**	58.11	**mean**	7.37	1.68
	max	105.82	**max**	70.98	16.13
65-74	**mean**	66.70	**mean**	8.46	1.92
	max	121.45	**max**	81.46	18.51
75+	**mean**	63.67	**mean**	8.08	1.84
	max	115.94	**max**	77.77	17.68

* PFAS-4 exposure calculated based on PFOS, PFOA, PFHxS and PFNA.

- Nuts and seeds

One publication of high quality was identified in the literature (paper ref 60; see Supplementary Document 3). PFAS occurrence in nuts and seeds is presented in Table 20.

Table 20. PFAS occurrence in nuts and seeds.

	Total PFAS, ng g^{-1}	PFOS, ng g^{-1}	PFOA, ng g^{-1}	PFHxS, ng g^{-1}	PFNA, ng g^{-1}	PFAS-4 sum, ng g^{-1}
mean	2.53*	0.01	0.15	-	-	0.16*
max	-	0.04	0.49	-	-	0.53*

*calculated

The mean and maximum PFAS-4 concentrations resulted in a consumer exposure below the EFSA TWI of 4.4 ng kg^{-1} bw w^{-1} for all age groups. The exposures and risk ratios for this food category are presented in Table 21.

Table 21. PFAS calculated exposure from nuts and seeds.

Age group		Total PFAS exposure, ng kg-1 bw w-1		PFAS-4 exposure*, ng kg-1 bw w-1	PFAS-4 Risk ratio
1.5-3	**mean**	2.06	**mean**	0.13	0.03

Age group		Total PFAS exposure, ng kg-1 bw w-1		PFAS-4 exposure*, ng kg-1 bw w-1	PFAS-4 Risk ratio
	max	-	**max**	0.43	0.10
4-10	**mean**	0.93	**mean**	0.06	0.01
	max	-	**max**	0.19	0.04
11-18	**mean**	0.46	**mean**	0.03	0.01
	max	-	**max**	0.10	0.02
19-64	**mean**	0.89	**mean**	0.06	0.01
	max	-	**max**	0.19	0.04
65-74	**mean**	0.78	**mean**	0.05	0.01
	max	-	**max**	0.16	0.04
75+	**mean**	0.63	**mean**	0.04	0.01
	max	-	**max**	0.13	0.03

* PFAS-4 exposure calculated based on PFOS and PFOA.

- Fruit

Two publications of high quality were identified in the literature (paper ref 60 and 71; see Supplementary Document 3). The mean and maximum values for Total PFAS and PFAS-4 are presented in Table 22.

Table 22. PFAS occurrence in fruit.

	Total PFAS, ng g^{-1}	PFOS, ng g^{-1}	PFOA, ng g^{-1}	PFHxS, ng g^{-1}	PFNA, ng g^{-1}	PFAS-4 sum, ng g^{-1}
mean	2.85*	0.02	0.22	0.07	0.03	0.34*
max	2.98*	0.24	1.20	0.85	0.55	2.83*

*calculated

The maximum PFAS-4 concentration resulted in a consumer exposure above the EFSA TWI for all age groups. However, the exposure to the mean PFAS-4 concentration from fruit was below the EFSA TWI of 4.4 ng kg^{-1} bw w^{-1} for all age groups except toddlers and young children. Exposure and risk ratio for this food category are presented in Table 23, with the highest exceedance highlighted in bold.

Table 23. PFAS calculated exposure from fruit.

Age group		Total PFAS exposure, ng kg-1 bw w-1		PFAS-4 exposure*, ng kg-1 bw w-1	PFAS-4 Risk ratio
1.5-3	**mean**	198.41	**mean**	**23.67**	5.38
	max	207.46	**max**	**197.02**	44.78
4-10	**mean**	79.34	**mean**	9.46	2.15
	max	82.95	**max**	78.78	17.90
11-18	**mean**	22.83	**mean**	2.72	0.62
	max	23.88	**max**	22.67	5.15

Age group		Total PFAS exposure, ng kg-1 bw w-1		PFAS-4 exposure*, ng kg-1 bw w-1	PFAS-4 Risk ratio
19-64	**mean**	20.12	**mean**	2.40	0.55
	max	21.03	**max**	19.97	4.54
65-74	**mean**	28.60	**mean**	3.41	0.78
	max	29.90	**max**	28.40	6.45
75+	**mean**	32.47	**mean**	3.87	0.88
	max	33.95	**max**	32.24	7.33

* PFAS-4 exposure calculated based on PFOS, PFOA, PFHxS and PFNA.

- Sugar, preserves and confectionery

One publication of high confidence was identified in the literature (paper ref 71; see Supplementary Document 3). No PFAS were detected in the samples analysed in this study and therefore no exposure to PFAS could be calculated from this food category.

- Non-alcoholic beverages

One publication of moderate confidence was identified in the literature (paper ref 16; see Supplementary Document 3) and used for the assessment. The mean for Total PFAS and PFAS-4 identified from this publication in soluble coffee are presented in Table 24.

Table 24. PFAS occurrence in non-alcoholic beverages.

	Total PFAS, ng g^{-1}	PFOS, ng g^{-1}	PFOA, ng g^{-1}	PFHxS, ng g^{-1}	PFNA, ng g^{-1}	PFAS-4 sum, ng g^{-1}
mean	1436.79*	0.34	0.34	0.36	0.34	1.38*
max	-	-	-	-	-	-

*calculated

The mean PFAS-4 concentrations resulted in a consumer exposure above the EFSA TWI of 4.4 ng kg^{-1} bw w^{-1} for all age groups. Exposure and risk ratio for this food category are presented in Table 25. Since the only available data is on soluble coffee, the calculations for non-alcoholic beverages represent an overestimation.

Table 25. PFAS calculated exposure from non-alcoholic beverages.

Age group		Total PFAS exposure, ng kg-1 bw w-1		PFAS-4 exposure*, ng kg-1 bw w-1	PFAS-4 Risk ratio
1.5-3	**mean**	485234.52	**mean**	466.06	105.92
	max	-	**max**	-	-
4-10	**mean**	349041.28	**mean**	335.25	76.19
	max	-	**max**	-	-
11-18	**mean**	221357.39	**mean**	212.61	48.32

Age group		Total PFAS exposure, ng kg-1 bw w-1		PFAS-4 exposure*, ng kg-1 bw w-1	PFAS-4 Risk ratio
	max	-	**max**	-	-
19-64	**mean**	181620.24	**mean**	174.44	39.65
	max	-	**max**	-	-
65-74	**mean**	170944.31	**mean**	164.19	37.32
	max	-	**max**	-	-
75+	**mean**	161312.52	**mean**	154.94	35.21
	max	-	**max**	-	-

* PFAS-4 exposure calculated based on PFOS, PFOA, PFHxS and PFNA from soluble coffee.

- Infant and toddler foods and milks

Three publications were identified in the literature, two of them of high confidence and one of moderate confidence. The two publications of high confidence (paper ref. 38 and 45; see Supplementary Document 3) were considered for the assessment. The occurrence of PFAS in infant and toddler foods and milks is summarised in Table 26.

Table 26. PFAS occurrence in infant and toddler foods and milks.

	Total PFAS, ng g^{-1}	PFOS, ng g^{-1}	PFOA, ng g^{-1}	PFHxS, ng g^{-1}	PFNA, ng g^{-1}	PFAS-4 sum, ng g^{-1}
mean	0.24	0.001	0.002	-	0.003	0.006*
max	0.23*	0.002	0.002	-	0.003	0.007*

*calculated

PFHxS was not detected in the samples analysed in the study selected for the assessment. The mean PFAS-4 concentration resulted in a consumer exposure below the EFSA TWI of 4.4 ng kg^{-1} bw w^{-1} for toddlers and young children. The calculated maximum Total PFAS concentration was lower than the reported mean Total PFAS concentration, as these values were derived from different studies. Therefore, the maximum Total PFAS concentration was excluded from the exposure estimation. Exposure and risk ratio for this food category are presented by age group in Table 27.

Table 27. PFAS calculated exposure from infant and toddler foods and milks.

Age group		Total PFAS exposure, ng kg-1 bw w-1		PFAS-4 exposure*, ng kg-1 bw w-1	PFAS-4 Risk ratio
1.5-3	**mean**	0.92	**mean**	0.02	0.01
	max	-	**max**	0.03	0.01
4-10	**mean**	0.02	**mean**	<0.01	<0.01
	max	-	**max**	<0.01	<0.01

* PFAS-4 exposure calculated based on PFOS, PFOA and PFNA.

- Savoury sauces, spices, condiments and other ingredients

Two references were identified from the literature and considered of high confidence for the assessment (paper ref 36 and 71; see Supplementary Document 3). Mean and maximum Total PFAS and PFAS-4 values are summarised in Table 28.

Table 28. PFAS occurrence in savoury sauces, spices, condiments and other ingredients.

	Total PFAS, ng g^{-1}	PFOS, ng g^{-1}	PFOA, ng g^{-1}	PFHxS, ng g^{-1}	PFNA, ng g^{-1}	PFAS-4 sum, ng g^{-1}
mean	0.67*	0.12	0.24	0.03	0.04	0.43*
max	2.05*	0.54	1.05	0.05	0.09	1.72*

*calculated

The PFAS-4 concentrations resulted in a consumer exposure around or below the EFSA TWI for most of the age groups, with the exceptions of the maximum in toddlers and young children. Exposure and risk ratio for this food category are presented in Table 29 with the highest exceedance highlighted in bold.

Table 29. PFAS calculated exposure from savoury sauces, spices, condiments and other ingredients.

Age group		Total PFAS exposure, ng kg-1 bw w-1		PFAS-4 exposure*, ng kg-1 bw w-1	PFAS-4 Risk ratio
1.5-3	**mean**	3.52	**mean**	2.26	0.51
	max	10.78	**max**	**9.04**	2.05
4-10	**mean**	2.38	**mean**	1.52	0.35
	max	7.27	**max**	6.10	1.39
11-18	**mean**	1.61	**mean**	1.03	0.23
	max	4.92	**max**	4.13	0.94
19-64	**mean**	1.17	**mean**	0.75	0.17
	max	3.58	**max**	3.01	0.68
65-74	**mean**	1.09	**mean**	0.70	0.16
	max	3.35	**max**	2.81	0.64
75+	**mean**	1.07	**mean**	0.69	0.16
	max	3.28	**max**	2.75	0.63

* PFAS-4 exposure calculated based on PFOS, PFOA, PFHxS and PFNA.

- Other food categories

No studies reporting PFAS measurements were identified in the available literature for the following four food categories: savoury snacks, alcoholic beverages, soup and dietary supplements, meal replacements and sports foods.

Summary of PFAS occurrence and exposure in all food categories

A summary of the total PFAS and PFAS-4 occurrence identified for each food category are presented in Appendix C2, together with the number of references from the literature used for the assessment and the level of confidence assigned.

When considering mean concentrations of PFAS-4, the food categories eggs and egg dishes, meat and meat products, fish and fish dishes, vegetables and vegetable products, and fruit resulted in exposures above the EFSA TWI (Table 30). The data of non-alcohol beverages cannot be considered representative since the PFAS concentrations were measured in soluble coffee only, in a single publication of moderate confidence.

Based on PFAS occurrence data combined with NDNS food consumption patterns, preliminary screening indicates higher per-kg exposure potential in younger age groups (1.5-3 and 4-10 years); these patterns are quantified and discussed in detail in section 3.4.

Table 30. Dietary PFAS-4 Exposure by Food Category in Comparison with the EFSA Tolerable Weekly Intake (TWI).

Food category (NDNS)	PFAS-4 (mean) exposure	PFAS-4 (max) exposure
Cereals and cereal products	Below the EFSA TWI for all age groups	Above the EFSA TWI for 1.5-3, 4-10 and 11-18 age groups; below EFSA TWI for the rest
Milk and milk products and alternatives	Below the EFSA TWI for all age groups	Below the EFSA TWI for all age groups
Eggs and egg dishes	Above EFSA TWI for 1.5-3 age group; around or below EFSA TWI for the rest	Above the EFSA TWI for all age groups
Fats and oils	Below the EFSA TWI for all age groups	NA
Meat and meat products	Above the EFSA TWI for all age groups	Above the EFSA TWI for all age groups
Fish and fish dishes	Above the EFSA TWI for all age groups	Above the EFSA TWI for all age groups
Vegetables and vegetable products and dishes	Above the EFSA TWI for all age groups	Above the EFSA TWI for all age groups
Nuts and seeds	Below the EFSA TWI for all age groups	Below the EFSA TWI for all age groups
Fruit	Above EFSA TWI for 1.5-3 and 4-10 age groups; below EFSA TWI for the rest	Above the EFSA TWI for all age groups
Sugar, preserves and confectionery	ND	ND
Non-alcoholic beverages (soluble coffee only)	Above the EFSA TWI for all age groups	NA

Food category (NDNS)	PFAS-4 (mean) exposure	PFAS-4 (max) exposure
Infant and toddler foods and milks	Below the EFSA TWI for all the relevant age groups	Below the EFSA TWI for all the relevant age groups
Savoury sauces, spices, condiments and other ingredients	Below the EFSA TWI for all age groups	Above EFSA TWI for 1.5-3 and 4-10 age groups; below EFSA TWI for the rest

NA= value not available
ND= PFAS were not detected for this category

3.3.4. Food contact materials

Eight publications were identified in the literature on FCM, three of them of high confidence (paper ref 6, 50 and 55; see Supplementary Document 3) and five of them of moderate confidence.

One of the three studies of high confidence identified FCMs as the primary source of PFAS in food-waste (FW) compost, based on analyses of various compost types, including municipal food-waste compost and compost derived solely from food or yard waste (paper ref 50). The other two studies included data on PFAS in FCM (including muffin cups, plates, drinking cups, popcorn bags, fast food wrapper and boxes) that could potentially migrate into food (paper ref 6 and 55). Across these studies, the mean and maximum Total PFAS concentrations ranged from 6.44 to 22.74 ng g^{-1} and from 12.86 to 352.10 ng g^{-1}, respectively. The mean and maximum concentrations for the sum of PFOS, PFOA, PFHxS and PFNA (PFAS-4) were 0.16 ng g^{-1} and 3.69 ng g^{-1}, respectively. Among the PFAS quantified, PFOS was reported at the highest concentration, followed by PFHxS > PFOA > PFNA.

The available evidence indicates that FCMs may act as a source of PFAS, with the potential for migration into food and subsequent contribution to overall human exposure.

3.3.5. Key messages

- PFAS concentrations reported in UK-relevant food categories show high variability across studies, with data quality and coverage differing markedly between food groups.
- Screening-level comparisons against the EFSA health-based guidance value indicate that eggs, meat, fish, and vegetables products and dishes and fruit warrant prioritisation for further assessment.

- Younger age groups, particularly toddlers aged 1.5-3 years, show higher potential exposure on a body weight basis when occurrence data are combined with consumption patterns.

These findings provide the inputs for whole-diet exposure synthesis and population-level interpretation presented in section 3.4.

3.4. Whole-diet exposure assessment of PFAS in the UK population

This section synthesises the occurrence and exposure indicators reported in section 3.3 into a whole-diet exposure assessment for the UK population. It does not introduce new occurrence data; rather, it integrates food-category PFAS-4 concentrations with NDNS whole-population mean consumption patterns mapped to data from NDNS first-tier food categories (Appendix Table 8). Exposure estimates were calculated as described in section 2.4.1, and compared against the EFSA TWI of 4.4 ng kg^{-1} bw w^{-1}.

The central-tendency (mean) thereby represents the typical long-term dietary exposure and the principal basis for understanding ongoing population exposure. However, this assessment is intended as a screening-level indicator to support prioritisation and should not be interpreted as quantitative estimates of individual health risk.

A worst-case scenario was initially considered, however exposures from such a scenario would provide a significant overestimation, as it is highly unlikely that an individual would be exposed to every food group at the highest PFAS concentration, both in the short and long term; therefore, it has not been included in this report.

The non-alcoholic beverages food category was excluded from the whole-diet exposure assessment because the available occurrence data were limited to soluble coffee and were therefore not considered representative of the category as a whole.

3.4.1. Age-stratified exposure

Combined (both male and female) exposure for each age group under the central-tendency scenario is presented in Table 31 as ng kg^{-1} bw w^{-1} with risk ratios and with the highest exceedance highlighted in bold.

Table 31. PFAS-4 exposure from the whole diet by age group, central-tendency (mean). EFSA TWI = 4.4 ng kg^{-1} bw w^{-1} used to calculate the risk ratio value (RR=exposure/TWI).

Age group, years	Central-tendency (mean) exposure, ng kg^{-1} bw w^{-1}	Risk ratio
1.5 – 3	**151.56**	34.44
4 – 10	89.37	20.31
11 – 18	45.09	10.25
19 – 64	42.78	9.72
65 – 74	45.44	10.33
75+	48.62	11.05

Based on the mean PFAS-4 occurrence values applied, estimated whole-diet exposure exceeded the EFSA TWI across all age groups. PFAS-4 exceedance was largest in toddlers (1.5–3 years) who had the highest exposure on a body weight basis: 151.56 ng kg^{-1} bw w^{-1}, which is substantially above the 4.4 ng kg^{-1} bw w^{-1} TWI. This was followed by young children aged 4–10 years, for whom estimated exposure was 89.37 ng kg^{-1} bw $week^{-1}$. Estimated exposure in the remaining age groups was notably lower, ranging from 42.78 to 48.62 ng kg^{-1} bw $week^{-1}$.

While the estimated exposures and exceedances described above are of toxicological concern, it is difficult to infer the actual risk for consumers given the uncertainties arising from the available database and the approach taken. PFAS concentrations across different food categories were derived from different studies and therefore based on varied approaches, analytical methods and geographical locations, with limited UK data. In some instances, PFAS-4 concentrations were reported directly, while in others they were calculated (section 2.3.2). Furthermore, consistent with a screening-level approach, the exposure assessment was based on the conservative assumption that PFAS are present across all food categories simultaneously, using first-tier NDNS categories only, which is likely to overestimate actual dietary exposure. Conversely, limited data or data gaps for some food categories may lead to an underestimation of total exposure. While a potential risk cannot be excluded, the estimated exposures are subject to a high degree of uncertainty and therefore may not be representative of typical exposure scenarios and exceedances should be considered in light of these uncertainties. The report did not undertake a risk assessment, but the exposure assessment aimed to identify population groups of potential concern, i.e. toddlers and young children, and hence can inform future work.

The same applied to the risk ratio, which was used in this context as a visualisation tool, again to identify population groups of higher concern, and do not represent a quantitative measure of risk.

Given that estimated exposure under the central-tendency scenario already exceeded the EFSA TWI, exceedance under a worst-case scenario would be observed across all age groups, at higher values. Hence, the central-tendency scenario is sufficient for the identification of vulnerable population groups, and a worst-case scenario is not required.

Potential differences between the sexes have not been assessed here due to a lack of data; while consumption data are available separately for males and females, body weights derived from the NDNS and used in this assessment are combined across both sexes.

3.4.2. Food category drivers of PFAS-4 exposure

Figure 3 illustrates total PFAS-4 estimated exposure for each NDNS age group, with stacked contributions by NDNS food category. The figure demonstrates that some food categories dominate the PFAS-4 intake. Detailed occurrence data and screening-level risk ratios by individual food category are presented in section 3.3; this sub-section focuses on their relative contribution once combined across the full diet.

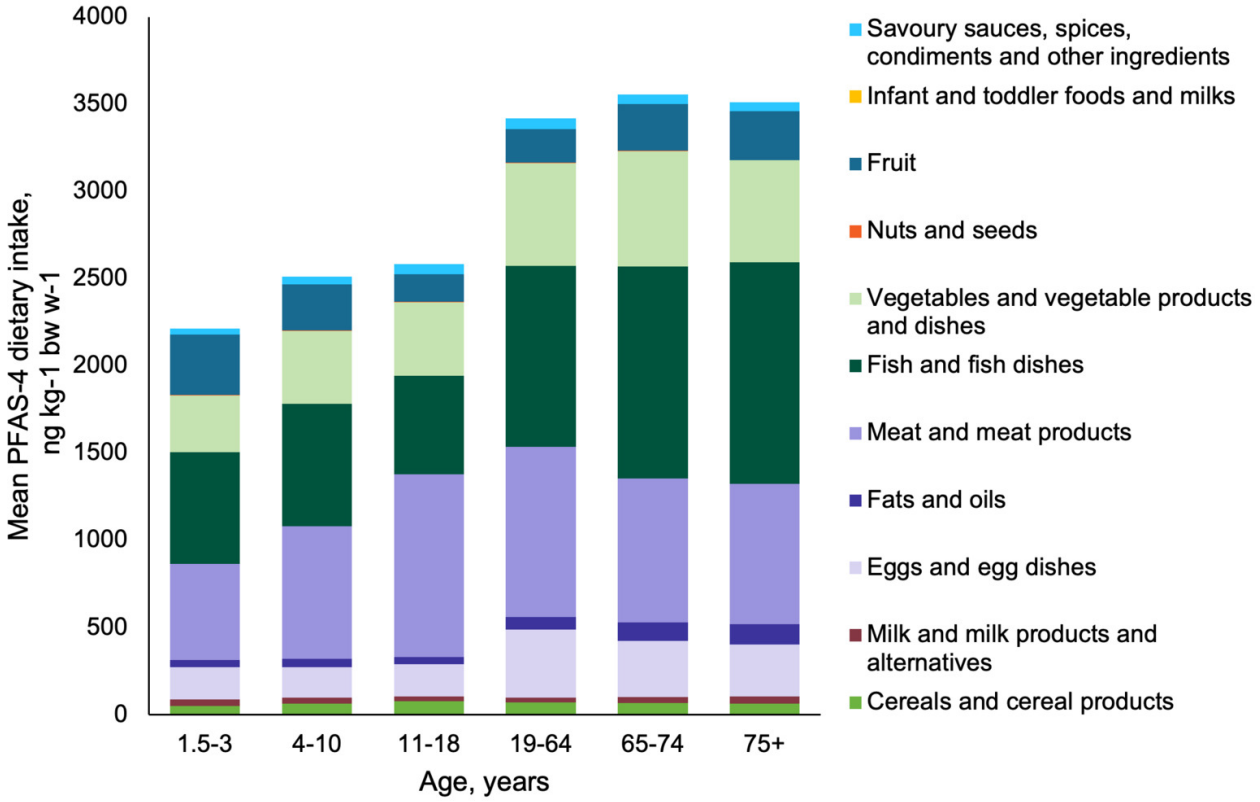

Figure 3. PFAS-4 dietary intake (ng kg-1 bw w-1) by NDNS food category for each age group, for the central tendency (mean) scenario. Food groups for which no PFAS concentrations were reported or not detected are excluded.

Exposure in adults (19–64 years) is dominated by fish and fish dishes (30%), meat and meat products (29%), and vegetables and vegetable products and dishes (17%), together accounting for 76% of total PFAS-4 exposure. Combined with secondary contributions from eggs and egg dishes (11%) and fruit (6%) these five highest food categories account for over 90% of dietary PFAS-4 exposure, highlighting priority categories for surveillance and supplier assurance. For toddlers (1.5–3 years) the ranking is similar, led by fish and fish dishes (29%) and meat and meat products (25%), with fruit (16%) and vegetables and vegetable products and dishes (15%) also being a noticeable source of PFAS-4 intake.

When integrated across the whole diet, these patterns are consistent with the source-to-plate pathways and accumulation points identified in earlier sections of this report. Fish and certain animal products dominate through aquatic accumulation and feed/forage pathways, while some plant categories contribute via environmental inputs and contact materials.

3.4.3. Implications of UK dietary exposure findings

The exposure findings have several implications for surveillance, supply-chain oversight and risk communication within the UK food system:

- **Dietary PFAS-4 exposure in the UK is shaped by both PFAS-4 occurrence and consumption across major food groups.** The largest contributors include widely consumed first-tier NDNS categories, such as fish, meat, vegetables, fruit and eggs. This suggests that overall exposure may arise from regular consumption across core components of the diet, rather than from a small number of highly contaminated or niche foods alone. Consequently, categories with high measured PFAS-4 concentrations, such as fats and oils, do not necessarily have the highest contribution to total exposure as they are consumed less frequently or in smaller amounts. Interpretation of these findings should also take account of the broad nature of first-tier NDNS categories, as important differences between individual products within the same food group may influence data availability or monitoring needs.
- **Observed exposure patterns point to upstream and environmental drivers as key determinants of dietary intake.** The prominence of fish, animal-derived products, vegetables and fruit implies that aquatic bioaccumulation,

livestock production systems and soil-to-crop transfer mechanisms are likely to be important influences on exposure.

- **Age-related differences in exposure are primarily influenced by food consumption relative to body weight.** The higher body weight normalised exposure estimated for toddlers reflects their lower body weight in combination with typical consumption patterns for this age group, indicating that higher exposure can arise from regular diets rather than from specific or unusual food choices.
- **PFAS persistence and repeated dietary exposure from major food groups indicate the potential for chronic exposure.**
- **Uncertainties in the database.** The exposure estimates should be interpreted in light of conservative modelling assumptions, including the use of the highest mean PFAS value for each food category and the assumption that PFAS are present across all categories simultaneously. These assumptions may overstate typical exposure where elevated concentrations are not representative of all foods within a category or would not occur across the whole diet at the same time. As the assessment used first-tier NDNS categories, product-level differences in PFAS occurrence may be masked; further disaggregation would therefore support more targeted interpretation and monitoring.
- **Data gaps and differences in analytical coverage limit the certainty and granularity of the assessment.** Variability in occurrence data, analytical scope, PFAS analyte coverage, concentration ranges, treatment of non-detects and food-category coverage all affect confidence in the exposure estimates. This is particularly relevant where sampling may have been targeted, such as in food groups suspected to accumulate PFAS, or where individual food categories are poorly represented. Limited evidence for some categories should not be interpreted as evidence of low contribution; rather, it indicates that their contribution to total dietary exposure may not be fully characterised. The main sources of uncertainty are described in Appendix C and should inform interpretation of the findings presented in this section.

- **A potential exposure pathway arising from FCMs supports the need for a systems-level interpretation of dietary PFAS exposure.** Evidence indicates that PFAS can migrate from certain FCMs, including some grease-resistant paper and board and materials under particular conditions of use. However, the contribution of FCMs to population-level dietary exposure cannot be robustly quantified from dietary survey data alone, as these datasets do not routinely capture the food-specific characteristics, packaging formats and use conditions that influence migration. As a result, FCMs should be considered a potential contributor to dietary PFAS exposure, but we cannot attribute dietary PFAS exposure to FCMs linked to any specific foods or consumption behaviours.

3.4.4. Key messages

- When PFAS-4 concentrations are combined across the whole diet, estimated exposures exceed the EFSA TWI on a body weight basis in all NDNS age groups under the central-tendency scenario.
- The highest per-kg body weight exposures occur in toddlers and young children (1.5-3 and 4-10 years), reflecting higher intake relative to body weight.
- However, due to the high degree of uncertainty in the occurrence data, the exposures may not be representative of typical exposure scenarios and exceedances should be considered carefully. The report did not undertake a risk assessment, but the exposure assessment rather aimed to identify population groups of potential concern, i.e. toddlers and young children, and hence can inform future work.
- The food categories that dominate PFAS-4 intake across all age groups are fish and fish dishes, meat and meat products and vegetables and vegetable products. Fruit also contributes to PFAS-4 intake among toddlers and young children, while eggs and egg dishes contribute additionally among adults.

3.5. Horizon scanning

This section provides a forward-looking horizon-scanning assessment of how PFAS-related risks to the UK food system may evolve over the next decade. The focus is thereby on evaluating how existing environmental reservoirs, ongoing emissions from non-food sectors, substitution patterns, and regulatory responses may influence future dietary exposure and long-term public-health risk. By integrating current exposure evidence with consideration of emerging substances and regulatory developments, this assessment is intended to support proportionate and proactive strategy for addressing potential risks within the UK food system. This horizon-scanning analysis is exploratory and forward-looking; it does not quantify future exposure or risk but identifies plausible developments and pathways that may influence dietary PFAS exposure over time, based on emerging evidence and established PFAS behaviour.

This section therefore builds directly on the pathways and exposure patterns identified in sections 3.2 to 3.4 and considers whether those same mechanisms are likely to persist, increase or change in composition. These include long environmental and biological residence times of historically used PFAS, the increasing diversity of replacement fluorinated substances and the continued functioning of indirect exposure pathways such as soil-to-crop transfer, livestock and aquaculture uptake, FCM migration and circular economy recycling flows.

As predictive modelling and direct evidence on future PFAS applications are limited, this assessment does not attempt to forecast specific exposure levels. Instead, it draws on well-established evidence regarding PFAS persistence, bioaccumulation, human pharmacokinetics and industrial substitution behaviour to identify plausible future exposure trajectories, rather than precise outcomes. This approach is consistent with established horizon-scanning methodology for complex environmental contaminants, where long time-lags, diffuse sources and cross sector interactions constrain formal prediction.

Importantly, this section interprets future risk in the context of the empirical findings presented in earlier sections. The occurrence patterns, dominant food-group contributors and age-stratified exposure exceedances identified in sections 3.3 and 3.4 provide a concrete baseline against which emerging risks are assessed. Horizon scanning therefore addresses not only what may change, but also what is likely to remain problematic under plausible future regulatory, industrial and environmental conditions.

3.5.1. Emerging PFAS applications and substitution trends

A key insight from the PFAS literature is that (regulatory) substitution is unlikely to rapidly reduce overall environmental or human exposure to PFAS. Current restrictions of PFOS, PFOA and related acids have led to widespread replacement with short-chain PFAS, ether-PFAS (e.g. GenX, HFPO-DA, DONA, 6:2 Cl-PFESA), oxo-acids, telomer alcohols and ultra-short chain PFAS (e.g. TFA), many of which are now reported with increasing frequency in environmental monitoring programmes (Brase et al., 2021; Brunn et al., 2023; Eze et al., 2024; Mahoney et al., 2022).

Whilst these substances are often introduced in response to compound-specific regulatory restrictions, some retain key physicochemical properties of concern, including persistence, mobility and resistance to conventional water treatment. These properties may allow continued transfer through environmental compartments relevant to food production. As a result, substitution is more likely to result in a change in PFAS composition rather than a clear reduction in overall exposure potential.

Some non-polymeric fluorinated substances and side-chain fluorinated compounds used as substitutes may still generate terminal perfluoroalkyl acids (PFAAs) through environmental or biological transformation. Any proposed universal PFAS restriction should seek to address this challenge by moving away from substance-by-substance regulation towards a group-based approach, reducing the risk of regrettable substitution and providing a more consistent framework for managing persistent fluorinated substances.

Importantly, the long environmental residence times of historically used PFAS mean that new substitutes may be introduced into systems already burdened by historical contamination. Consequently, future exposure profiles are likely to reflect additive or cumulative exposure to multiple PFAS classes rather than replacement of one substance by another. This additive pattern of exposure has implications beyond simple concentration trends. Historically released PFAS remain present in soils, waters and biota for decades, while newer PFAS and PFAS-related substances are introduced concurrently through substitution. As a result, overall exposure may increase or remain stable even where concentrations of individual regulated compounds decline.

Evidence on mixture toxicity for PFAS remains limited; however, toxicological assessments increasingly recognise that co-exposure to multiple PFAS with shared properties such as persistence, mobility and protein binding may contribute to adverse effects that are not fully captured by single-compound evaluations. From a horizon-scanning

perspective, this supports the concern that substitution may lead to more complex exposure profiles, rather than unequivocal risk reduction, where cumulative and class-level exposure are not considered.

This dynamic has implications for both environmental loading and long-term human body burden, even where individual compounds exhibit lower bioaccumulation in specific organisms.

Figuière et al. (2025) identified approximately 325 PFAS applications across 18 use categories, with technically suitable PFAS-free alternatives identified for only 40 of these applications. This highlights limitations to rapid substitution, particularly in sectors requiring chemical durability or surface-active properties. Focusing specifically on FCMs, PFAS were identified as serving four functional applications, three of which were considered potentially suitable for phase-out, with one remaining unclear. However, as illustrated in the conceptual PFAS flow map (Figure 2) and pathway synthesis (Table 3), removal of PFAS from FCMs alone is unlikely to eliminate PFAS exposure from the UK food system, given the multiple upstream sources and indirect pathways by which PFAS reach food.

This highlights a potential limitation of the PFAS-4 approach. Although concentrations of the compounds included in the PFAS-4 group may decrease over time, this metric does not capture other PFAS that may increase as a consequence of substitution. Future assessments should therefore place greater emphasis on a broader range of PFAS when evaluating dietary exposure.

Consequently, even as PFAS such as PFOS and PFOA are phased out, contamination pathways are likely to persist, which highlights the importance of considering PFAS as a class rather than focusing on individual compounds. More broadly, and consistent with trends observed in other regulated chemical classes, progressive tightening of PFAS controls may incentivise a shift towards substances that fall outside existing regulatory definitions or routine analytical panels. Where such substances retain persistence or mobility, this can increase the chemical diversity of fluorinated compounds entering waste streams, soils and agricultural systems rather than eliminating underlying exposure pathways.

Evidence from this review illustrates this clearly: short-chain PFCAs and ether-PFAS are increasingly detected in environmental media, fluorotelomer-derived substances are present in FCMs and the widespread occurrence of ultra-short chain PFAS such as TFA in water, crops and foods all reflect substitution patterns that alter PFAS composition without reducing the overall load and exposure routes of PFAS in the system.

These examples demonstrate that reductions in PFAS-4 concentrations, while important, do not necessarily correspond to proportional reductions in overall PFAS burden. Instead, exposure profiles evolve towards more diverse mixtures of potentially equally persistent and mobile fluorinated substances entering food via soil, water, aquaculture feed and packaging. Hence, future risk management efforts will be less effective if confined to individual substances and should consider the viability of class-based or property-based approaches that capture persistence, mobility and cumulative exposure to provide more robust evaluations.

3.5.2. Continuity and evolution of food-system entry pathways

PFAS contamination of the food system is expected to continue to arise predominantly from indirect pathways associated with non-food industrial activities. Release from manufacturing, historical and ongoing use of firefighting foams, wastewater treatment processes, landfill leachate and degradation of consumer products introduce PFAS into environmental compartments where they persist and migrate across interconnected systems (Kannan et al., 2026; Ohorro & Ngole-Jeme, 2026; Srivastava & Srivastava, 2025).

These pathways are structurally resilient as they are driven by persistence, environmental mobility and cross sector material reuse, rather than by intentional food-sector applications. As such, substitution trends are likely to alter the composition of PFAS entering these pathways but not eliminate the pathways themselves.

Although the literature does not provide predictive modelling of future PFAS applications, it consistently indicates that the combination of persistent environmental reservoirs, continued use of fluorinated materials outside the food sector and expansion of circular economy practices will sustain indirect food chain exposure, even under more restrictive regulatory regimes.

3.5.2.1. PFAS entering the food system

Agricultural soils represent one of the most significant interfaces between environmental PFAS contamination and the food chain. PFAS are already present in soils via biosolids, sewage sludge, composts and irrigation inputs; expansion of wastewater reuse and nutrient and carbon recycling is likely to sustain or further increase these inputs over time (Cui et al., 2026; Kannan et al., 2026; Srivastava & Srivastava, 2025).

Wastewater treatment systems are not designed to remove PFAS, resulting in their accumulation in sludge that can be subsequently used as fertiliser (Kannan et al., 2026; Saffari Aman et al., 2026). Compostable FCMs treated

with PFAS can further contaminate compost streams, introducing PFAS into soils under circular-economy practices (Saffari Aman et al., 2026; Timshina et al., 2024). As these practices expand under future sustainability policies, soil-based exposure pathways are likely to remain relevant or increase in importance.

Once in soil, PFAS migrate vertically through soil profiles and contaminate groundwater, especially where irrigation relies on reclaimed or polluted water sources (Ohorro & Ngole-Jeme, 2026; Srivastava & Srivastava, 2025). Their high solubility enhances mobility across catchments and into drinking-water resources (Kannan et al., 2026). Crops grown in contaminated soils absorb PFAS primarily through root uptake, with accumulation documented in edible tissues (Ohorro & Ngole-Jeme, 2026; Srivastava & Srivastava, 2025). Although plant-based foods generally contain lower concentrations than animal-derived products, proximity to industrial activities, wastewater discharge, or contaminated irrigation increases plant contamination (Souza & Domingo, 2025).

PFAS present in contaminated livestock feed and water are efficiently transferred into edible products, including meat, dairy, and eggs, with measurable transfer efficiencies and bioaccumulation particularly for compounds such as PFOS, PFOA, and PFHxS. Moreover, the slow depuration and recirculation of long-chained PFAS within animals, means that contamination persists, even after exposure ceases, so downstream mitigation measures (e.g. changes in processing or packaging) cannot offset contamination that has already been integrated biologically into the animal-derived food matrix (Kannan et al., 2026; Khanashyam et al., 2025; Ohorro & Ngole-Jeme, 2026).

3.5.2.2. Transport, transboundary movement and amplification

Aquatic environments function simultaneously as sinks and sources of PFAS contamination. Industrial discharge, wastewater effluent, and long-range atmospheric transport introduce PFAS into rivers and marine ecosystems, where accumulation occurs across trophic levels (Kannan et al., 2026; Polychonidou & Nag, 2025). Fish consumption is therefore a major dietary exposure route (Polychonidou & Nag, 2025). The key issue is not the existence of these pathways, but their persistence despite regulatory efforts to reduce PFAS emissions and inputs, and their capacity to sustain long-term environmental cycling and human exposure.

In aquatic systems, fish and shellfish are likely to remain disproportionate contributors to dietary exposure because bioaccumulation and trophic transfer operate independently of changes in upstream PFAS composition. In aquaculture, PFAS exposure may persist through multiple routes, including use of surface waters influenced by catchment-scale

contamination and feed inputs derived from contaminated marine or terrestrial sources (Ali et al., 2025). Importantly, shifts towards alternative or plant-based feeds do not necessarily eliminate PFAS exposure, as crops used in feed may themselves be grown on PFAS-affected soils or irrigated with contaminated water.

Long-range atmospheric transport further constrains the effectiveness of national-level controls. Volatile and semi-volatile PFAS precursors emitted from industrial, urban and waste-management sources can undergo regional and intercontinental transport before depositing onto soils and surface waters via wet and dry deposition (Kannan et al., 2026; Srivastava & Srivastava, 2025). As a result, PFAS used or emitted outside the UK may continue to contribute to domestic environmental loading and food chain exposure even under strengthened UK restrictions.

Climate-related processes may act as amplifiers of these transport pathways. Flooding, drought, wildfires and dust mobilisation have the potential to remobilise PFAS stored in soils, sediments and surface residues, increasing their bioavailability and redistribution across the environment (Khanashyam et al., 2025; Ohorro & Ngole-Jeme, 2026). While the literature does not provide quantitative projections of climate-driven changes in PFAS exposure, these mechanisms are consistently identified as plausible modifiers of both spatial distribution and exposure intensity (Teran et al., 2012), Biswas et al. (2018). Climate change is therefore unlikely to create entirely new PFAS pathways, but it may influence future exposure levels by remobilising existing contamination, increasing bioavailability and altering transport dynamics. As a result, climate-driven events may contribute to episodic increases in environmental concentrations and food-chain transfer, even in the absence of new emissions.

Taken together, these transport and amplification processes indicate that future PFAS exposure via food systems will be influenced not only by domestic use and regulation, but also by legacy contamination, long-range transport and environmental change. These factors introduce time lags between regulatory action and measurable reductions in dietary exposure and reinforce the importance of sustained surveillance even where upstream controls are strengthened.

3.5.3. Implications for long-term human health and population exposure

Although there is limited information describing future PFAS applications, the regulatory and public health implications of ongoing substitution trends and persistent exposure pathways can be evaluated using established knowledge of PFAS behaviour, toxicokinetics and exposure dynamics. In this context, key implications arise not from uncertainty about

their future uses alone, but from the long residence time of PFAS in environmental and biological systems and the likelihood that new substances are introduced into an already contaminated baseline.

Historically, compound-by-compound regulation has resulted in instances of “regrettable substitution”, whereby the phased out of PFAS, such as PFOA and PFOS, were replaced with structurally similar short chain, polymeric or ether-based alternatives that retain persistence, mobility, and long-range transport potential (Dosunmu et al., 2025). These substitutes may exhibit lower bioaccumulation in some organisms, yet their higher water solubility facilitates wider dispersion through drinking water systems, irrigation networks and wastewater-derived fertilisers (Kannan et al., 2026). As a result, regulatory progress should consider not only historically used substances, but also potential substitutions and their implications for food-chain exposure to ensure risk management measures remain effective.

A central public health concern arising from these trends is cumulative exposure. Legacy PFAS released historically persist in soils, waters and human tissues for decades, while newer PFAS are introduced concurrently. This suggests that future exposure profiles are likely to reflect additive or cumulative body burdens rather than replacement of one compound by another. Although quantitative data on mixture toxicity remain limited, toxicological evidence increasingly recognises that combined exposure to multiple PFAS may contribute to adverse outcomes, also possibly at concentrations below those predicted from single-compound assessments alone.

Regulatory systems also face structural challenges. Fragmented global governance means that PFAS restrictions vary widely across regions, creating opportunities for market shifting, continued production of alternative PFAS and transboundary contamination. Waste-reuse policies, including biosolid land application, reclaimed water irrigation and composting, may unintentionally redistribute PFAS across agricultural landscapes if not paired with upstream controls and contaminant thresholds. Whilst these circular-economy practices are environmentally motivated, they risk amplifying PFAS circulation through positive feedback loops unless persistence and mobility are explicitly addressed in regulatory design.

From a public health perspective, this dynamic is particularly significant because very few reliable food processing or post-harvest interventions exist to remove PFAS once contamination has occurred (Souza & Domingo, 2025). Risk mitigation therefore depends predominantly on upstream control of emissions, materials and inputs, including industrial discharges, wastewater treatment, packaging design and agricultural resource management. Without harmonised monitoring frameworks that include

precursor compounds and emerging substitutes, contamination may remain undetected until accumulation in livestock, aquaculture and crops has occurred.

Food preparation and domestic handling offer limited scope for reducing exposure to PFAS already in food. Unlike some other contaminants, PFAS are not reliably removed by washing, peeling or cooking, and thermal contact during preparation may in some cases lead to migration from some FCMs. These limitations highlight the fact that future risk reduction should focus on upstream measures such as controlling emissions, materials and inputs, alongside appropriate surveillance and regulatory interventions, rather than downstream consumer-level actions.

Public-health implications extend beyond direct dietary exposure. Chronic ingestion of PFAS at low doses, combined with exposure from drinking water and occupational contact, particularly among agricultural and waste-management workers, contributes to long-term exposure over a lifetime. Toddlers and young children are of particular concern due to higher intake per unit body weight and exposure during sensitive developmental periods. Taken together, these factors indicate that reductions in individual PFAS concentrations may not necessarily result in reduced population-level health risk unless cumulative exposure and persistence are addressed explicitly.

3.5.4. Key messages

- Concerns about PFAS in the UK food system are likely to persist over the next decade because legacy contamination, ongoing non-food emissions and indirect pathways continue to (re-)introduce PFAS into soils, water, livestock, aquaculture products and crops.
- Substitution away from PFOS, PFOA and related historically used PFAS may change the composition of exposure rather than reduce overall exposure potential, particularly where replacement substances remain persistent, mobile or capable of contributing to cumulative PFAS burdens.
- Future dietary exposure is likely to reflect evolving mixtures of historically used PFAS, short-chain PFAS, ether-PFAS, precursors and ultra-short-chain substances such as TFA, with climate-related processes potentially increasing remobilisation and food-chain transfer.
- Risk reduction is likely to depend on upstream controls and expanded monitoring, as PFAS are not reliably removed once incorporated into crops, livestock, aquaculture

products or food-contact materials; monitoring should therefore extend beyond PFAS-4 to include emerging PFAS, precursors, feed, water, soil, compost, and packaging.

3.6. Summary discussion

The available data demonstrate that PFAS contamination within the UK food system arises from multiple interacting pathways. Environmental reservoirs linked to historical and ongoing releases continue to influence primary food production through soil, water and air. Agricultural inputs such as biosolids, composts and recycled residues provide additional diffuse inputs, particularly for more mobile PFAS. Post-harvest stages, including processing environments and some fibre-based food-contact materials, can introduce further contributions under time, temperature and food-matrix conditions.

The dietary exposure modelling shows that, based on the available dataset, UK population-level dietary intakes are above the EFSA TWI for PFAS-4 under typical consumption patterns. The highest exposures occur in younger children and toddlers, a reflection of their lower body weight rather than higher dietary intake. Interpretation of these exceedances must be balanced against the variability and gaps in the underlying occurrence data, which differ substantially in analyte coverage, detection limits and UK relevance. Analytical methods differ widely across studies, detection limits vary, many PFAS (including precursors) are not routinely monitored, and UK-specific datasets are limited for several food categories. The adapted CREED ratings helped contextualise these uncertainties by highlighting where evidence was strongest and where findings should be interpreted cautiously. The exposure scenario presented in this report provides a valuable screening tool but should not be interpreted as representative of typical consumer exposure. The uncertainties are outlined fully in Appendix C.

Nevertheless, the presence of dominant contributing categories, particularly fish, meat and vegetables, creates clear opportunities for targeted surveillance and mitigation. These food categories reflect well-understood mechanisms: aquatic accumulation in fish and shellfish, feed and tissue distribution for offal, and soil or packaging-related inputs for some plant-based foods. The alignment between mechanistic plausibility and observed concentrations strengthens confidence in prioritising control and monitoring efforts in these areas.

Given the findings in this report, a proportionate and effective approach to PFAS risk management in the UK food system should combine targeted surveillance in the highest-contributing categories, upstream controls on inputs to soil and water, and proportionate action on FCMs and processing where occurrence, migration or process data identifies a relevant pathway.

As regulatory and analytical landscapes evolve, including EU guidance, for example EFSA's scientific assessment and update on trifluoroacetic acid (TFA), monitoring frameworks will need to adapt to maintain relevance and address emerging PFAS profiles.

4. Integrated synthesis of PFAS exposure, limitations and future priorities

This report integrated evidence and analysis from four interlinked tasks to provide a holistic view of PFAS behaviour and exposure within the UK food system. The literature review and conceptual map reveal a system characterised by multiple entry points, persistence across environmental and agricultural stages, and feedback loops driven by waste-derived materials. These pathways collectively explain why PFAS occur in certain food categories and why interventions must consider the system as a whole rather than isolated nodes.

The prioritisation assessment demonstrated that, although a wide range of PFAS is detected in foods and food-relevant matrices, only a small number of analytes, and a similarly small number of food categories, account for most of the estimated dietary exposure. This concentration of exposure reflects a combination of mechanistic drivers (notably aquatic bioaccumulation, feed-mediated transfer to animal products, and retention in certain tissues) and the current analytical focus of the evidence base. Exposure estimates are dominated by PFOS, PFOA, PFHxS and PFNA, while many other PFAS are more sporadically analysed or lack sufficient occurrence data to contribute quantitatively to exposure estimates. As a result, the finding that a small number of analytes drive estimated exposure should not be interpreted as evidence that other PFAS are inconsequential for dietary exposure, but rather that they are presently under-represented in the analytical literature and hence their occurrence and potential effects are unclear.

The horizon scanning exercise indicates that shifts towards short-chain and polymeric PFAS, together with circular-economy flows, are likely to change the composition of PFAS entering the food system rather than eliminate exposure. Monitoring and risk-assessment frameworks will therefore need to be responsive to emerging PFAS profiles.

4.1. System level integration

The evidence assembled in this report depicts a connected food system in which PFAS move from persistent environmental reservoirs (soils, freshwaters, coastal waters) through agricultural inputs (bioresources,

irrigation, recycled residues, feed) and post-harvest nodes (food-contact materials and processing) to reach consumers. These flows are not isolated: circular pathways, such as packaging to compost to soil, create feedback loops that sustain background loading. The conceptual mapping and literature synthesis therefore support risk management that works across nodes (source control, on-farm measures, packaging assurance) rather than at a single point of the chain.

4.2. Population exposure profile

When dietary exposure is expressed on a per-kilogram body weight basis, toddlers (1.5 – 3 years) have the highest intake under the central-tendency (mean) scenario, followed by children aged 4 – 10 years. Adult groups show lower per-kilogram exposure, though still above the benchmark used in this assessment.

4.3. Dietary drivers of exposure

Across all age groups, overall exposure is dominated by a small set of widely consumed food categories. For adults, fish and fish dishes, meat and meat products and vegetables and vegetable products and dishes account for most PFAS-4 intake, with eggs and egg dishes and fruit contributing secondarily. This reflects a combination of high consumption volumes and the presence of high PFAS concentrations within these first tier NDNS categories.

Whilst the second tier of NDNS food categories was not systematically examined in this assessment, the available evidence indicates that PFAS occurrence within these broad categories is heterogeneous. In some cases, specific sub-groups (for example, offal within meat and meat products, or certain fish species) exhibit higher PFAS concentrations than category-level averages. However, the current evidence base was not sufficient to robustly quantify the relative contribution of individual sub-categories to overall exposure. Further disaggregation of the NDNS categories would therefore be an important next step in refining understanding of the specific drivers of dietary exposure and targeting surveillance more precisely.

4.4. Scenario framing

Dietary exposure was characterised using a central-tendency (mean) scenario intended to represent typical long-term exposure under current conditions. The scenario is based on observed occurrence data and UK consumption patterns, and do not constitute forecasts or predictions of future exposure trajectories.

The central-tendency scenario provides an indication of typical population exposure given the available evidence. Using maximum levels, i.e. a worst-case scenario, would be a significant overestimation of actual occurrence, as it is unlikely an individual would be exposed to the maximum concentration from all foods at the same time.

The exposure scenario included in this assessment is constrained by the scope and coverage of the current evidence base, including uneven analyte coverage and limited UK-specific occurrence data for some food categories. Nonetheless, it provides a proportionate framework for screening dietary exposure, highlighting consistent patterns across age groups and informing targeted surveillance and risk-management considerations.

4.5. Horizon scanning

Horizon scanning was undertaken to identify plausible emerging factors that may influence the long-term relevance of PFAS to the UK diet, recognising that quantitative evidence on future exposure is inherently limited. This assessment is therefore qualitative in nature and is intended to highlight system-level drivers rather than to estimate future risk or exposure magnitude.

Several cross-cutting trends are likely to shape future dietary exposure profiles. These include continued substitution away from legacy long-chain PFAS towards short-chain, ultra-short-chain and ether PFAS, many of which exhibit high environmental persistence and mobility and are poorly captured by existing food monitoring programmes. Substitution does not necessarily imply a reduction in long-term dietary relevance, particularly where replacement compounds are more mobile and enter the food system via water, soils or food-contact materials.

More broadly, the persistence of PFAS within environmental reservoirs, combined with circular-economy practices such as recycling of food-contact materials, use of composts and biosolids, and reliance on imported foods, is likely to sustain low-level, diffuse exposure pathways over time. Regulatory developments, including grouping approaches and increasing attention to persistent and mobile substances, may alter the analytical focus of future monitoring, but are unlikely to eliminate dietary PFAS exposure in the near term.

Collectively, these considerations reinforce the importance of adaptable, class-based surveillance approaches and periodic reassessment of analytical scope, rather than reliance on static lists of priority analytes. Horizon scanning therefore complements the scenario-based exposure assessment by placing current findings within a broader food-system and regulatory context.

4.6. Uncertainty, evidence confidence and limitations

There are several data gaps and uncertainties in this assessment, primarily arising from limitations in the underlying occurrence data. PFAS occurrence data in foods are characterised by heterogeneous analytical coverage, with most monitoring programmes focusing on a limited subset of historically used compounds, variable limits of detection and quantification, and differences in reporting practices across studies and laboratories. The heterogeneity of PFAS data across the literature is well documented (Dong et al., 2026; Megson et al., 2025; Yang et al., 2026).

A further source of uncertainty relates to the representativeness of occurrence data for the UK food system. For many food categories, UK-specific monitoring data are limited, and the harmonised dataset therefore draws on a combination of UK, European and international studies. This reflects both gaps in domestic monitoring and the structure of the UK food system, with imported foods produced under diverse environmental conditions and regulatory regimes. While international data are therefore relevant for characterising dietary exposure in the UK, differences in production practices, environmental contamination profiles and analytical approaches introduce uncertainty when extrapolating to UK supply-chain conditions.

These uncertainties are compounded by the large and diverse PFAS chemical class, the presence of precursor compounds and transformation products that are not routinely measured, and challenges related to matrix effects, background contamination and the availability of analytical reference standards. To support transparent interpretation, this assessment integrates adapted confidence ratings and presented a central-tendency exposure scenario, with conservative assumptions clearly flagged where data are sparse. A comprehensive discussion of analytical limitations, evidence gaps and UK-specific considerations is provided in Appendix C.

5. Conclusions

PFAS reach the UK foods system through interacting environmental, agricultural and post-harvest pathways. Contamination in soils, freshwaters and coastal waters can be taken up by crops, livestock and seafood. Additional inputs arise from land-applied bioresources, and irrigation influenced by wastewater discharges, while some paper- and board-based FCMs can transfer PFAS to foods under specific conditions such as use-relevant time, temperature and fat-content. Circular flows, such as packaging entering compost and subsequently being applied to

land, further sustain background inputs. As a result, effective management of dietary PFAS exposure in the UK requires action across multiple stages of the food system rather than reliance on a single control point.

For assessing potential dietary concern, PFAS-4 (PFOS, PFOA, PFHxS, PFNA) remains the most relevant group of PFAS, as these compounds are routinely measured in occurrence datasets and are covered by the EFSA TWI. Under the central-tendency (mean) dietary exposure scenario fish, meat and vegetables were principal contributors in adults, with eggs and fruit also contributing to total intake. For toddlers and young children, the pattern is similar with fish, meat and vegetables again playing a dominant role, alongside contributions from fruit. As exposure is concentrated in a limited number of food categories, surveillance and assurance activities can be targeted efficiently without imposing disproportionate analytical burdens across the entire food supply.

Based on the compiled dataset, central-tendency dietary exposures for the UK population, expressed on a body weight normalised basis, exceed the EFSA PFAS-4 TWI across all age groups. The highest relative exposures occur in toddlers and young children, driven by lower body weight rather than higher absolute food consumption. While these exceedances are of potential toxicological concern, they are subject to considerable uncertainties arising from the available database and assessment approach. Exposures are based on occurrence values from different studies from across the UK and Europe, with studies applying different analytical approaches and methods and recording different sets of PFAS. The exposure assessment, consistent with a screening-level approach, was based on the conservative assumption that PFAS are present across all food categories simultaneously, using first-tier NDNS categories only, which is likely to overestimate actual dietary exposure. Conversely, the limited data or data gaps for some food categories may lead to an underestimation of total exposure. Hence, these estimated exposures need to be considered in light of the uncertainties and, while a toxicological concern cannot be excluded, in this assessment, the estimates are intended to support the identification of foods and population groups of potential concern, rather than to characterise individual risk.

In the future, substitution away from regulated historically used PFAS towards short-chain and polymeric PFAS, together with expansion of circular economy practices such as composting of PFAS-treated paper and board materials, is likely to change the composition of PFAS entering the food system rather than eliminate exposure. Surveillance and risk-assessment frameworks should therefore adopt a class-aware approach, using PFAS-4 as a core comparator while remaining flexible to incorporate,

short-chain species and extractable organic fluorine screening, where appropriate, including future integration of other compounds, once EU authoritative health-based guidance becomes available.

Overall, pathway identification and system-level interpretation are supported by multiple converging lines of evidence. While uncertainty remains in quantitative estimates due to heterogeneous analytical coverage and limited UK-specific occurrence data, the dominant exposure pathways and priority food categories are clearly outlined. Targeted investment in UK-specific packaging-migration studies, investigation of precursor-to-PFAA transformation, longitudinal monitoring of soils and irrigation waters, and systematic alignment of new datasets with NDNS food categories would most efficiently reduce uncertainty and support proportionate, evidence-based decision-making.

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Appendices

Appendix A: Literature search, extraction and confidence assessment

A1. Sources, pathways and occurrence

Appendix Table 1. Keywords for search string relating to PFAS sources, occurrence, pathways and concentrations.

Chemical	Food	Occurrence	Sources
"PFAS"	"food"	"occurrence"	"food chain"
"perfluoroalkyl substances"	"foods"	"concentration"	"bioaccumulation"
"polyfluoroalkyl substances"	"diet"	"levels"	"accumulation"
"PFOA"	"dietary"	"contamination"	"production"
"PFOS"	"meat"	"residues"	"packaging"
PFHxS"	"fish"	"dietary exposure"	"agriculture"
"PFNA"	"seafood"	"Quantification"	"food contact material"
"PFDA"	"milk"	"matrices"	
"PFUnDA"	"dairy"		
"perfluorinated compounds"	"eggs"		
"fluorinated surfactants"	"cereals"		
"forever chemicals"	"grains"		
perfluoroalkyl	"vegetables"		
polyfluoroalkyl	"fruit"		
	"processed food"		
	"ready meals"		

Appendix Table 2. Database search strings and number of results carried forward to the full paper screen for data relating to PFAS sources, occurrence, pathways and concentrations.

Search number	Database	Search string	Total results returned	After title/ abstract screen	After removal of replicates
1	Scopus	TITLE-ABS-KEY ("PFAS sources" AND "UK food system" OR "agriculture" OR "food packaging" OR "environmental contamination")	11	3	3
2	Scopus	TITLE-ABS-KEY ("PFAS sources" OR "PFAS" OR "FOREVER CHEMICAL") AND ("UK" OR "UK food systems" OR "UK Agriculture") AND	210	13	13

Search number	Database	Search string	Total results returned	After title/ abstract screen	After removal of replicates
		PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (AFFILCOUNTRY , "United Kingdom"))			
3	Google Scholar	TITLE-ABS-KEY (“PFAS sources" AND "UK food system" OR "agriculture" OR "food packaging" OR "environmental contamination")	866 (first 200 screened)	6	6
4	Science Direct	TITLE-ABS-KEY (PFAS) (ALL="PFAS contamination pathways" AND "food chain" OR "processing" OR "retail" OR "contact materials")	5384 (first 200 screened)	7	5
5	Science Direct	TITLE-ABS-KEY("PFAS") (ALL="PFAS concentrations" AND "UK foods" OR "Total Diet Study" OR "monitoring data")	208	2	2
6	Google Scholar	TITLE-ABS-KEY("PFAS Concentration") (ALL="PFAS concentrations" AND "UK foods" OR "Total Diet Study" OR "monitoring data)	650 (first 200 screened)	3	2
7	PubMed	((("PFAS accumulation"[All Fields] AND "food system"[All Fields]) OR "processing stages"[All Fields] OR "packaging"[All Fields]) AND "PFAS"))	136	10	10
8	Google Scholar	TITLE-ABS-KEY("PFAS" AND "Diet" AND "Food") AND ("perfluoroalkyl Substances" OR "Polyfluoroalkyl substances" OR "PFOA" OR "PFOS" OR "PFHxS" OR "PFNA" OR "PFDA" OR "PFUnDA" OR "perfluorinated compounds" OR "Fluorinated surfactants" OR "Forever Chemicals")	18,000 (first 200 screened)	10	9
9	Google Scholar	("Regulation" AND "Imports" AND "Production" AND "PFAS"	4650 (first 200 screened)	8	8

Search number	Database	Search string	Total results returned	After title/ abstract screen	After removal of replicates
		AND "food" AND "UK" ("perfluoroalkyl substances" OR "Polyfluoroalkyl substances" OR "Agriculture" OR "food chain" OR "processed food" OR "dietary")			
10	PubMed	("UK"[All Fields] AND ("PFAS"[All Fields] OR "Perfluoroalkyl substances"[All Fields] OR "Polyfluoroalkyl substances"[All Fields]) AND ((("Imports"[Title/ Abstract] OR "Regulation"[Title/ Abstract] OR "Knowledge Gaps"[Title/Abstract]) AND "OR"[Title/Abstract]) OR "UK"[Title/Abstract] OR "Food Safety"[Title/ Abstract]) AND ("2015/ 12/22 00:00":"3000/01/01 05:00"[Date - Publication] AND "english"[Language])) AND ((y_10[Filter]) AND (english[Filter]))	34	3	2
11	Science Direct	("PFAS" OR "Perfluoroalkyl Substances" OR "Polyfluoroalkyl Substances") AND ("Food" OR "Agriculture" OR "Diet" OR "Vegetables" OR "Milk" OR "Fish")	1247 (first 200 screened)	17	17
12	Google Scholar	TITLE-ABS-KEY("PFAS" OR "Perfluoroalkyl Substances" OR "Polyfluoroalkyl Substances") AND ("UK" AND "Food" AND "Total Dietary Study")	8990 (first 200 screened)	4	4
13	Science Direct	('Diet' OR 'Dietary' OR 'Food') AND TITLE('PFAS' OR 'Perfluoroalkyl' OR 'Polyfluoroalkyl')	207	17	16
14	Google Scholar	TITLE-ABS-KEY (“PFAS" AND "Quantification" AND "Food" AND "Matrices")	23,500 (first 200 screened)	5	4

Appendix Table 3. Articles identified through the literature search for their relevance to PFAS occurrence, sources, pathways and/or concentrations in the UK food system. ● Denotes where an article addressed a specific theme and/or location (UK, EU, ROW = Rest of World, Global). Confidence rating relates to the score given by the adapted CREED assessment regarding the PFAS concentration data, H=high, M=moderate, L=low, n/a = study reporting concentrations, but not relevant (e.g. due to being a secondary review or non-food concentrations or based on metadata or irrelevant geography).

Article no.	Citation	UK	EU	ROW	Global	Occurrence	Accumulation points	Pathways	Evidence gaps	Concentrations	Confidence rating
1	Stecconi et al., 2024		●			●				●	H
2	Junqué et al., 2026	●	●			●				●	H
3	Susman et al., 2019			●		●	●				
4	Bonato et al., 2025		●	●		●				●	H
5	Eze et al., 2024				●	●	●	●			
6	Vázquez Loureiro et al., 2024		●			●	●	●			
7	Souza & Domingo, 2025				●	●	●			●	n/a
8	Fernandes et al., 2018		●			●				●	H
9	Nobile et al., 2024a		●			●	●			●	H
10	Schoeters et al., 2025				●	●				●	n/a
11	Beriro et al., 2025	●				●	●	●			
12	Piva et al., 2023		●			●				●	M
13	Torres et al., 2023				●	●	●			●	L
14	Nobile et al., 2024b		●			●				●	M
15	Gyllenhammar et al., 2026		●			●				●	M
16	Theurillat et al., 2023		●			●				●	M
17	Costello and Lee et al., 2024				●	●		●			
18	Genualdi et al.,			●		●	●	●			

Article no.	Citation	UK	EU	ROW	Global	Occurrence	Accumulation points	Pathways	Evidence gaps	Concentrations	Confidence rating
	2021										
19	Simonetti et al., 2024		•			•	•	•			
20	Ramírez Carnero et al., 2021				•	•	•				
21	Jeannot et al., 2025		•	•		•		•			
22	Biswas et al., 2025				•	•					
23	Melnyk et al., 2025				•	•			•	•	n/a
24	Nxumalo et al., 2024	•	•	•		•	•				
25	Jovanović et al., 2024				•	•					n/a
26	Ohoro et al., 2026				•	•	•		•		
27	Holder et al., 2024				•	•			•	•	n/a
28	Lasters et al., 2022		•			•	•			•	H
29	Consolato et al., 2024		•			•		•		•	M
30	Young et al., 2022			•		•				•	H
31	Fabregat-Palau et al., 2025		•				•	•	•		
32	Weber et al., 2019				•			•	•		
33	Gallocchio et al., 2022		•			•				•	H
34	Richterová et al., 2022		•		•	•				•	n/a
35	Papadopoulou et al., 2017		•			•				•	L
36	Aßhoff et al., 2024		•			•				•	H
37	Verley et al.,				•	•			•	•	n/a

Article no.	Citation	UK	EU	ROW	Global	Occurrence	Accumulation points	Pathways	Evidence gaps	Concentrations	Confidence rating
38	Yang et al., 2025			•		•				•	H
39	Susma et al., 2019		•			•				•	H
40	Zhang et al., 2024		•			•	•				n/a
41	D'Amore et al., 2025		•				•	•	•		n/a
42	Death et al., 2021				•	•				•	n/a
43	Hawley et al., 2025			•		•				•	H
44	Bolan et al., 2021				•		•	•			
45	Mikolajczyk et al., 2023		•			•				•	H
46	Marín-García et al., 2023		•			•	•				
47	Lerch et al., 2023				•	•		•	•		
48	Koenig et al., 2025		•			•				•	M
49	Xing et al., 2023				•		•	•			
50	Timshina et al., 2024			•		•				•	n/a
51	Rigby et al., 2021	•				•	•	•			
52	Bedi et al., 2023			•		•				•	n/a
53	Yao et al., 2025				•		•	•			
54	Sznajder-Katarzyńska et al., 2019		•			•				•	L
55	Dueñas-Mas et al., 2023		•			•	•			•	n/a
56	Di Mario et al., 2024		•			•	•				
57	Alam and Chen, 2025				•	•	•	•	•		

Article no.	Citation	UK	EU	ROW	Global	Occurrence	Accumulation points	Pathways	Evidence gaps	Concentrations	Confidence rating
58	Sapozhnikova et al., 2023				•	•				•	n/a
59	Stroski et al., 2024			•		•	•				
60	Lasters et al., 2024		•			•		•		•	L
61	Dimri et al., 2026				•			•			
62	Khanashyam et al., 2025				•	•					n/a
63	Saffari Aman et al., 2026				•	•	•			•	n/a
64	Battisti et al., 2024		•			•	•			•	H
65	Mikołajczyk et al., 2024a		•			•	•			•	H
66	Lasters et al., 2024b		•			•	•			•	H
67	Mikołajczyk et al., 2024b		•			•	•			•	H
68	Nobile et al., 2023		•			•	•			•	H
69	Zafeiraki et al., 2016		•			•	•			•	H
70	Zafeiraki et al., 2019		•			•	•			•	H
71	Van Leeuw et al., 2024		•			•				•	H

A2. Study quality assessment protocol

Study quality was assessed using a streamlined, adapted CREED framework focusing on sampling, analytical methods and reporting of PFAS concentrations. Each study was evaluated against the checklist in Appendix Table 4.

Appendix Table 4. Criteria used for study quality assessment, based on an adapted CREED framework.

Criterion	Yes	Partial	No	Notes
Study design and sampling				
Food sampling strategy clearly described				
Sampling context defined (e.g. retail, market, composite)				
Sample size reported				
Sampling period and location reported				
Food characterisation and NDNS relevance				
Food items clearly described				
Food matrices appropriate for PFAS analysis				
Sufficient detail to assign NDNS food group				
Foods relevant to UK diet or supply				
Analytical methods				
Analytical method described				
Method appropriate for PFAS analysis				
PFAS compounds analysed clearly listed				
Use of validated or established methods				
Quality control measure described				
Reporting of concentration data				
Concentration units clearly reported				
Summary statistics reported (e.g. mean median, range)				
Individual values or ranges provided				
Limits of detection / quantification reported				
Treatment of non-detects described				
PFAS coverage and relevance				
PFAS selection justified				

Based on the criteria above, the overall confidence in the PFAS occurrence data from this study was assessed as High, Moderate and Limited confidence.

A3. Horizon Scanning

Appendix Table 5. Keywords for search string relating to horizon scanning for emerging trends for PFAS that may influence the UK food system.

Chemical	Food	Location	Sources
“Per- and polyfluoroalkyl	“Packaging”	“United	“Contamination”

Chemical	Food	Location	Sources
substances"		Kingdom"	
"PFAS"	"Processing aids"	"Europe"	"Cross-sector material use"
"PFAS alternatives"	"Industrial"	"USA"	"Environmental contamination"
"Fluorinated compounds"	"Food"		"Industrial emission*"
"PFAS substitutes"			"Persistence"
"Emerging PFAS"			"Toxicity"
			"Fate"
			"Pathway*"
			"Source*"
			"Bioaccumulation"
			"Biomagnification"
			"Innovation"

Appendix Table 6. Database search strings and number of results carried forward to the full paper screen for information relating to the data horizon scanning for emerging trends for PFAS that may influence the UK food system.

Search	Database	Search string	After title/ abstract screen
1	Science Direct	(PFAS OR "per- and polyfluoroalkyl substances") AND (food OR "food chain") AND (packaging OR "food contact") AND (UK OR "United Kingdom") AND contamination	17
2	Science Direct	((PFAS) AND (Food) AND (Contamination) AND (Forecasting))	1
3	Science Direct	((PFAS) AND (Food) AND (Alternatives))	1
4	Science Direct	((PFAS) AND (Food) AND (Contamination) AND (Future))	5
5	Science Direct	((PFAS) AND (Food) AND (Emerging) AND (Application))	0

Appendix Table 7. Articles identified through the literature search for their information relating to the data horizon scanning for emerging trends for PFAS that may influence the UK food system.

Article number	Citation	Reference
A	Ohorro & Ngole-Jeme, 2026	OHORO, C. R. & NGOLE-JEME, V. M. 2026. PFAS contamination and its rising toll on food security: A hidden global threat. Food Control, 180, 111611.
B	Saffari Aman et al., 2026	SAFFARI AMAN, M., DALEY, D. J., YOU, Y., KUMAR, D. & YOO, C. G. 2026. PFAS in commercially available organic amendments and food-contact paper products. Science of The Total Environment, 1014, 181342.
C	Souza & Domingo, 2025	SOUZA, M. C. O. & DOMINGO, J. L. 2025. Levels of per- and polyfluoroalkyl substances (PFAS) in foodstuffs: a review of dietary exposure, health risks, and regulatory challenges. Food Research International, 221, 117494.
D	Timshina et al., 2024	TIMSHINA, A. S., ROBEY, N. M., OLDNETTLE, A., BARRON, S., MEHDI, Q., CERLANEK, A., TOWNSEND, T. G. & BOWDEN, J. A. 2024. Investigating the sources and fate of per- and polyfluoroalkyl substances (PFAS) in

Article number	Citation	Reference
		food waste compost. Waste Management, 180, 125-134.
E	Khanashyam et al., 2025	KHANASHYAM, A. C., KANWAL, S., LAOSAM, P., SANGSAWAD, P., THORAKKATTU, P., BANDLA, S., RATHNAKUMAR, K., OMANAKUTTAN, A. M., AL-ASMARI, F., BEKHIT, A. E.-D. A. & NIRMAL, N. 2025. Perfluoroalkyl and polyfluoroalkyl substances contamination in dairy: A global perspective. Science of The Total Environment, 1007, 180968.
F	Ali et al., 2025	ALI, A. M., BERNTSSEN, M. H. G., SELE, V. & VALDERSNES, S. 2025. Wide scope screening and target quantification of per- and polyfluoroalkyl substances (PFAS) in feed and feed ingredients to farmed salmonids. Journal of Hazardous Materials, 495, 139078.
G	Dosunmu et al., 2025	DOSUNMU, O., WHITING, R., MATHARU, A., WATSON, N. & SWEETMAN, A. J. 2025. The unintentional role of chemical regulation in regrettable substitution: The case of PFAS. Environmental Science & Policy, 174, 104275.
H	Cui et al., 2026	CUI, Y., XIAO, W., FANG, Y., LI, B., ZHENG, M. & LI, Y. 2026. PFAS bioaccumulation in food crops: Structure-informed machine learning and mechanistic evidence for priority control. Environmental Chemistry and Ecotoxicology, 8, 1043-1056.
I	Kannan et al., 2026	KANNAN, U., RAVICHANDRAN, M. K., MONISHA, M., KRISHNASAMY, S., VALLIAMMAI, PRABAKAR, P., DARSHINI, D. & SUNANTHA, G. 2026. Short-chain PFAS: A global challenge - Environmental fate, health risks, and promising removal technologies. Results in Chemistry, 20, 103000.
J	Srivastava & Srivastava, 2025	SRIVASTAVA, R. K. & SRIVASTAVA, S. 2025. Mapping PFAS behavior via meta-analysis of soil dynamics, predictive modeling and policy integration. Science of The Total Environment, 1000, 180399.
K	Polychonidou & Nag, 2025	POLYCHRONIDOU, V. & NAG, R. 2025. Data-driven predictive estimation of Per- and polyfluoroalkyl substances (PFAS) in a suite of environmental compartments. Journal of Hazardous Materials Advances, 19, 100815.

Appendix B: NDNS food categorisation

To ensure that exposure estimates reflected real UK consumption patterns, each food from the data matrix was assigned to the first-tier NDNS food categories (Appendix Table 8). Composite foods were mapped to the most relevant category by primary ingredient and typical consumption. This first-tier mapping enables direct pairing of PFAS concentrations with UK consumption rates for exposure estimation.

Appendix Table 8. NDNS food categories.

NDNS tier numbers	Primary food category	Primary food groups (subgroups included)
1-7	Cereals and cereal products	Pasta, rice, pizza and other cereals (1.1 - 1.7), Bread (2.1 - 2.4), Sandwiches (3.1), Breakfast cereals (4.1), Sweet and savoury biscuits and cereal bars (5.1 - 5.3), Buns, cakes, pastries, fruit pies (6.1 - 6.2), Puddings (7.1 - 7.2).
8-11	Milk and milk products and alternatives	Milk and milk products and alternatives (8.1 - 8.8), Cheese (9.1 - 9.2), Yogurt, fromage frais and dairy desserts (10.1 - 10.4), Ice cream (11.1 - 11.3).
12	Eggs and egg dishes	Eggs and egg dishes (12.1 - 12.2).
13	Fats and oils	Fats and oils (13.1 - 13.7).
14-24	Meat and meat products	Bacon, ham and other processed red meat (14.1 - 14.2), Beef and beef products and dishes (15.1 - 15.2), Lamb and lamb products and dishes (16.1 - 16.2), Pork and pork products and dishes (17.1 - 17.2), Poultry and poultry products and dishes (18.1 - 18.3), Offal and offal products and dishes (19.1 - 19.3), Burgers and kebabs (20.1 - 20.2), Sausages and sausage products and dishes (21.1 - 21.2), Meat pies and pastries (22.1), Game and game products and dishes (23.1 - 23.2), Mixed meat products and dishes (24.1).
25	Fish and fish dishes	Fish and fish products and dishes (25.1 - 25.5).
26-28	Vegetables and vegetable products and dishes	Vegetables and vegetable products and dishes (26.1 - 26.5), Starchy roots and potatoes (27.1 - 27.5), Plant-based meat alternatives (28.1 - 28.2).
29	Savoury snacks	Crisps and savoury snacks (29.1 - 29.2).
30	Nuts and seeds	Nuts and seeds (30.1 - 30.3).
31	Fruit	Fruits (31.1 - 31.3).
32-33	Sugar, preserves and confectionery	Sugars, preserves and sweet spreads (32.1 - 32.3), Confectionery (33.1 - 33.3).
34-37	Non-alcoholic beverages	Fruit and vegetable juices and smoothies (34.1 - 34.2), Soft drinks, with added sugar (35.1 - 35.3), Soft drinks, no added sugar (36.1 - 36.3), Tea, coffee and water (37.1 - 37.8).
38-41	Alcoholic beverages	Spirits and liqueurs (38.1 - 38.2), Wine (39.1 - 39.3), Beer, lager and cider (40.1 - 40.4), Premixed alcoholic drinks (41.1).

NDNS tier numbers	Primary food category	Primary food groups (subgroups included)
42-43	Infant and toddler foods and milks	Formula and baby milks (42.1 - 42.2), Baby and toddler foods (43.1 - 43.2).
44	Soup	Soup (44.1).
45	Savoury sauces, spices, condiments and other ingredients	Savoury sauces, spices, condiments and cooking ingredients (45.1 - 45.4).
46	Dietary supplements, meal replacements and sports foods	Dietary supplements, meal replacements and sports foods (46.1 - 46.6).
47	Tabletop sweeteners	No or low calorie sweeteners (47.1).

Appendix C: Limitations and uncertainty

C1. Analytical limitations and evidence constraints

The analysis of per- and polyfluoroalkyl substances (PFAS) in food systems presents a range of scientific, analytical and regulatory challenges. These challenges are particularly significant for the UK food system, which relies heavily on imported foods and integrates multiple environmental and industrial pathways through which PFAS may enter the food chain. Below is a structured overview of the major issues affecting PFAS analysis in foods, drawing on peer-reviewed literature and authoritative sources.

C1.1. PFAS are an extremely large and diverse chemical class

One of the most fundamental challenges is the large scale and diversity of the PFAS chemical class. PFAS encompass thousands of synthetic compounds with different chain lengths, functional groups and physicochemical properties. However, only a small subset of these compounds is routinely analysed in monitoring programmes. Most analytical methods target legacy PFAS such as the PFAS-4, largely because analytical standards and validated methods exist for these compounds. However, significant variation is observed in the range of PFAS compounds analysed and detected. This variation is often a consequence of the various methods and instruments used for PFAS analysis and can pose a challenge for comparison between studies.

Furthermore, recent analytical studies have demonstrated methods capable of quantifying larger suites of compounds (for example up to 70+ PFAS analytes in animal foods), but such approaches remain relatively specialised and are not widely implemented in routine monitoring programmes.

This situation creates several important limitations, such as many emerging PFAS or transformation products remain unmeasured, exposure estimates based on a small subset of compounds may underestimate total PFAS burden, and regulatory frameworks are based on a limited number of substances despite the existence of thousands.

C1.2. Lack of standardised analytical methods

Another major issue is the heterogeneity of analytical approaches across laboratories and studies. Methods for PFAS detection in food matrices vary widely in terms of:

- Extraction techniques (e.g., solid phase extraction, alkaline digestion, liquid-liquid extraction)
- Clean-up procedures
- Chromatographic methods
- Mass-spectrometry detection parameters.

Liquid chromatography coupled with tandem mass spectrometry (LC-MS/MS) is currently the dominant approach, but there is no single standardised method suitable for all food matrices.

Different laboratories may therefore employ different analytical protocols, detection limits, calibration strategies and compound lists. This lack of harmonisation complicates:

- Comparison of results between studies
- Compilation of occurrence datasets
- Meta-analysis and exposure modelling.

Methodological variability can also lead to differences in limits of detection (LOD) and quantification (LOQ), which directly affects reported concentrations.

C1.3. Ultra-trace concentrations

PFAS in food are typically present at very low concentrations, often at parts-per-trillion (ppt) levels. Detecting such concentrations requires highly sensitive analytical instrumentation and careful sample preparation.

C1.4. Matrix complexity and extraction efficiency

Food matrices vary greatly in composition, which can affect the efficiency of PFAS extraction and quantification. High-fat foods such as meat, eggs and fish can interfere with extraction and detection processes, requiring specialised clean-up procedures. This makes it difficult to apply a single analytical method across all food categories, increasing methodological complexity and reducing comparability between studies.

C1.5. Background contamination and laboratory artefacts

PFAS are extremely ubiquitous in modern environments and can be present in laboratory materials themselves. This creates a significant risk of background contamination during analysis. As a result, PFAS analysis requires rigorous quality assurance procedures, which are not always consistently applied across studies.

C1.6. Limited availability of reference materials and standards

Accurate quantification of PFAS requires certified analytical standards and reference materials. However, for many PFAS compounds such materials are not available. This can lead to several issues such as the inability to validate analytical methods for many PFAS, uncertainty in quantification of emerging compounds, and difficulty comparing results between laboratories and/or studies. The absence of reference materials is therefore a major barrier to expanding analytical coverage beyond the most commonly studied PFAS.

C1.7. Non-targeted and precursor PFAS

Another analytical limitation is the presence of precursor compounds and transformation products. Many PFAS precursors can degrade into persistent compounds such as PFOA or PFOS during environmental processes or even during sample preparation. Conventional targeted analysis may therefore fail to detect unknown PFAS, precursor compounds, and transformation products formed during processing or metabolism.

To address this issue, non-targeted and total fluorine approaches (e.g. total oxidisable precursor assays) are increasingly used, but these techniques remain technically challenging and are not yet widely implemented in food monitoring.

C2. Incomplete occurrence data across food categories

Despite growing interest in PFAS contamination in food, the global occurrence dataset remains incomplete and uneven. Most studies have focused on certain high-risk food groups such as fish and seafood, while many other food categories remain poorly characterised. This creates significant gaps in exposure assessment due to: PFAS contamination potentially occurring in many food categories, dietary exposure being dependent on consumption patterns and, monitoring programmes varying between countries and/or laboratories. For example, fish and seafood are widely monitored due to known PFAS bioaccumulation, but less information is available for plant-based foods, processed foods and packaged foods.

A summary of the total PFAS and PFAS-4 occurrence identified for each food category presented in Appendix Tables 9 and 10 respectively, together with the number of references from literature used for the assessment and the level of confidence assigned.

Appendix Table 9. Total PFAS occurrence for each food category including the confidence rating based on the adapted CREED assessment.

Food category (NDNS)	Mean Total PFAS, ng g^{-1}	Max Total PFAS, ng g^{-1}	No. of References	Confidence
Cereals and cereal products	0.07	0.22	1	High
Milk and milk products and alternatives	0.01 - 2.64	0.01 - 5.20	3	High
Eggs and egg dishes	0.03 - 5.03	0.11 - 31.2	9	High
Fats and oils	701.97	NA	1	Moderate
Meat and meat products	0.05 – 19.61	0.05 - 35	7	High
Fish and fish dishes	0.002 - 13.20	0.66 - 23	7	High
Vegetables and vegetable products and dishes	1.18 - 4.02	4.7 - 7.32	4	High
Nuts and seeds	2.53	NA	1	High
Fruit	0.10 - 2.85	0.21 - 2.98	2	High
Sugar, preserves and confectionery	ND	ND	1	High
Non-alcoholic beverages (soluble coffee only)	1436.79	NA	1	Moderate
Infant and toddler foods and milks	0.02-0.24	0.23	2	High
Savoury sauces, spices, condiments and other ingredients	0.67	2.05	2	High

NA = not available
ND= no PFAS detected

A high variability is observed in the data, especially for the fish and meat categories. Limited data from literature was available for some of the food categories. In the case of fats and oils and non-alcohol beverages (soluble coffee), only one publication of moderate confidence was identified, while for cereals, nuts, and sugar only one study of high confidence was available.

Appendix Table 10. PFAS-4 occurrence for each food category including the confidence rating based on the adapted CREED assessment.

Food category (NDNS)	Mean PFAS-4, ng g^{-1}	Max PFAS-4, ng g^{-1}	No. of References	Confidence
Cereals and cereal products	0.037	0.14	1	High
Milk and milk products and alternatives	0.019	0.028	3	High
Eggs and egg dishes	3.10	34.7	9	High
Fats and oils	2.04	NA	1	Moderate

Food category (NDNS)	Mean PFAS-4, ng g^{-1}	Max PFAS-4, ng g^{-1}	No. of References	Confidence
Meat and meat products	1.04	4.75	7	High
Fish and fish dishes	6.47	66.93	7	High
Vegetables and vegetable products and dishes	0.51	4.91	4	High
Nuts and seeds	0.16	0.53	1	High
Fruit	0.34	2.83	2	High
Sugar, preserves and confectionery	ND	ND	1	High
Non-alcoholic beverages (soluble coffee only)	1.38	NA	1	Moderate
Infant and toddler foods and milks	0.006	NA	2	High
Savoury sauces, spices, condiments and other ingredients	0.43	1.72	2	High

NA = not available
ND= no PFAS detected

Four categories were not included in the tables due to the lack of studies found in the literature: savoury snacks, alcoholic beverages, soup and dietary supplements, meal replacements and sports foods.

C3. Challenges related to food contact materials and processing

As discussed in section 3.2, PFAS may enter foods not only from environmental contamination but also through migration from food contact materials such as grease-resistant packaging. This introduces additional complexity in interpreting contamination sources.

C4. Regulatory and monitoring gaps

Regulatory frameworks currently focus on a small number of PFAS compounds and selected food categories with e.g. maximum levels in the EU currently being applied primarily to a small group of PFAS (e.g., PFOS, PFOA, PFNA and PFHxS) in specific foods such as fish, eggs and meat. Consequently, risk assessments may not fully capture the total PFAS exposure through diet.

C5. UK food system specific issues

C5.1. High reliance on imported foods

The UK imports a large proportion of its food supply, meaning PFAS contamination patterns may reflect environmental conditions, regulatory environments and production practices in exporting countries rather than UK-specific sources. This can introduce variability in PFAS profiles and complicate interpretation of monitoring results.

C5.2. Heterogeneous monitoring datasets

PFAS occurrence data for foods consumed in the UK are derived from a combination of UK monitoring programmes, EU datasets and international studies. These datasets differ in analytical methods, detection limits, analyte lists and reporting practices, making direct comparisons difficult and increasing uncertainty when harmonising data for exposure assessment.

C5.3. Limited UK-specific occurrence data

Compared with other environmental compartments, systematic UK-specific monitoring of PFAS in foods remains limited. Several food categories have little or no contemporary UK data, which constrains assessment of national exposure patterns and increases reliance on international datasets that may not fully represent UK supply-chain conditions.

C5.4. Representativeness of food-occurrence data and hotspot influence

An additional source of uncertainty arises from the potential influence of localised environmental contamination (“hotspots”) on reported PFAS concentrations in foods. Occurrence data drawn from targeted studies or monitoring programmes may reflect proximity to contaminated soils, waters or point sources rather than background conditions representative of wider food supply chains. When such values are used in exposure estimation, particularly in the absence of detailed contextual information, there is a risk that dietary exposure may be over- or under-estimated depending on how representative the sampled conditions are of typical production environments. Distinguishing between hotspot-driven contamination and background exposure is therefore important for interpretation of both occurrence data and resulting dietary exposure estimates.

Supplementary Materials

Supplementary Document 1 - Literature screening and review

Supplementary Document 1 presents a summary of the studies included in the assessment, including information on study geography, food or matrix type, PFAS compounds analysed, results of the study-level evidence-quality appraisal and other relevant study characteristics.

Download: https://science.food.gov.uk/article/173666-long-term-impact-of-pfas-on-food-safety-and-regulation/attachment/377092.xlsx

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Supplementary Document 2 - PFAS HBGVs

Supplementary Document 2 provides the list of PFAS health-based guidance values (HBGVs) identified during the review, including details such as source, critical health effects, uncertainty factors and confidence rating assigned by the authority.

Download: https://science.food.gov.uk/article/173666-long-term-impact-of-pfas-on-food-safety-and-regulation/attachment/377093.xlsx

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Supplementary Document 3 - PFAS and food levels matrix

Supplementary Document 3 presents the PFAS occurrence data extracted from the literature and used in the assessment and estimated PFAS dietary exposure by food category and age group.

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