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METHOD

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The Food Contact Chemicals Health effect matrix (FCChelix): protocol for a systematic evidence map

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ABSTRACT

Background: Food contact chemicals (FCCs) are known to migrate from food packaging and other food contact articles into food. This leads to human exposure to FCCs, and some FCCs have been linked to human health effects such as chronic and non-communicable diseases. However, a systematic overview of the health effects of FCCs is missing.

Objectives: The objective of this study is to systematically map the relations between exposure to FCCs and human health effects within the Population, Exposure, Comparator, Outcomes, and Study Design (PECOS) framework.

Search strategy and eligibility criteria: We will search PubMed for combinations of search terms related to the identity of the chemical and the epidemiological study design. The references will be screened at the title-and-abstract level, followed by the full-text level. Eligible references will be included according to predefined criteria, further specifying the elements of the applied PECOS framework.

Data extraction and coding: Information on human exposure to FCCs will be collected and linked to human health effects according to previously defined data categories and standardized terms. The human health effects will be classified based on the Six Clusters of Disease (SCOD) framework.

Synthesis and visualization: Results will be published in a narrative summary, and data will be made available in a freely accessible interactive dashboard, the Food Contact Chemicals Health Effect Matrix (FCChelix).

Abbreviations: CHMS: Canadian Health Measures Survey; FCA: food contact article; FCC: food contact chemical; FCM: food contact material; HBM4EU: European Human Biomonitoring Initiative; ICD: International Classification of Diseases; KONEHS: Korean National Environmental Health Survey; NHANES: National Health and Nutrition Examination Survey; PECOS: population, exposure, comparator, outcome, study design; SAB: scientific advisory group; SCOD: Six Clusters of Disease

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Food contact chemicals; human health; exposure; systematic evidence map

Introduction

Rationale

Humans are exposed to many synthetic chemicals from various sources, and exposure to some of these chemicals has been linked to the rise of non-communicable diseases (Martínez-Ibarra et al. 2021; Symeonides et al. 2024). Food packaging and other food contact articles (FCAs) contribute to this

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exposure via oral uptake because food contact chemicals (FCCs) migrate from food contact materials (FCMs) into foodstuffs (Muncke et al. 2020).

Regulating FCMs and managing the risks associated with chemical migration from FCMs is challenging. Firstly, hundreds of FCCs with hazard properties of concern are used in FCMs (Zimmermann et al. 2022), and legislation often lags far behind toxicological research (Muncke et al. 2017). Secondly, many FCCs do not have sufficient migration, hazard, and exposure data to assess their risks, and this is even more pronounced for non-intentionally added substances (NIAS), such as degradation products, contaminants, impurities, and by-products (Nerin et al. 2013; Nerín et al. 2022).

To understand which FCCs are used in the manufacture of FCMs, we previously compiled the Food Contact Chemicals Database (FCCdb), listing publicly available evidence on >12,000 intentionally used FCCs (Groh et al. 2021). However, during FCM manufacturing, many intentionally used FCCs are chemically transformed, leading to the generation of expected reaction products as well as NIAS. To better understand which chemicals are present in FCMs, we also published a systematic evidence map on FCCs that have been analyzed in migrates and/or extracts of FCMs (Geueke et al. 2023). The resulting Database on Migrating and Extractable Food Contact Chemicals (FCCmigex) is available as an interactive dashboard (Food Packaging Forum 2025). FCCmigex currently contains information on 5,295 FCCs from 1,500 references. Together, the FCCdb and FCCmigex databases include >15,000 FCCs, but the overlap between them is small, as only 28% of the FCCs detected in migrates and/or extracts are also part of the FCCdb. The remaining 72% of the chemicals in the FCCmigex database may be present as NIAS or may have been used intentionally without being listed in the sources included in the FCCdb. Migration from FCMs indicates a high probability of human exposure, albeit with some uncertainty. To understand the extent of human exposure to FCCs, we systematically compiled the Database on Food Contact Chemicals Monitored in Humans (FCChumon) (Food Packaging Forum 2024; Geueke and Parkinson 2024). In total, 25% of the known FCCs have been detected in humans. While not dismissing exposure sources other than FCMs, these data nonetheless help to link exposure from FCMs to the presence of FCCs in humans, and they also support the identification of knowledge gaps. The FCCdb, FCCmigex, and FCChumon databases provide systematically compiled information on the use of FCCs in the manufacture of FCMs as well as their presence in migrates and/or extracts of FCMs and in human samples. However, comprehensive data on human health effects exist for only a small fraction of these chemicals. For example, the Plastic Health Map summarizes human health effects of selected plastic-associated chemicals and particles, including polymers, plasticizers, flame retardants, bisphenols, and per- and polyfluoroalkyl substances (PFAS) (Minderoo Foundation 2025); Seewoo et al. 2023). Further systematic evidence maps and scoping reviews associating chemical exposure and human health outcomes have been published, such as on bisphenol A (Zhu et al. 2024), PFAS (Pelch et al. 2022; Radke et al. 2022; Zhang et al. 2023; Ricolfi et al. 2024; Shirke et al. 2024; Symeonides et al. 2024), polyethylene terephthalate (PET) oligomers (Schreier et al. 2023), and persistent organic pollutants (Yost et al. 2021; Carlson et al. 2023; Payne-Sturges et al. 2023). A recent umbrella review focused on selected plastic-related exposures to chemicals across a broad range of groups and identified at least one adverse health outcome for each group (Symeonides et al. 2024). Based on a gap analysis, the authors of the umbrella review prioritized micro- and nanoplastics, bisphenol analogues, non-phthalate plasticizers, and alternative flame retardants as key priority areas for further research. For other chemical groups broadly used in FCMs, such as synthetic phenolic antioxidants, studies on human health effects are scarce (Hao et al. 2023).

Recent regulatory actions addressed the health risks of certain chemical groups by establishing legally enforceable limits on, e.g. PFAS in food packaging waste (EU 2025) and bisphenols in FCMs (EU 2024).

However, many current regulatory approaches to chemical risk assessment for FCCs primarily emphasize evaluating the genotoxicity of chemicals used as starting substances in the production of FCMs. This neglects the presence of NIAS in FCMs and other toxicological endpoints that are also of high concern. One notable development is the recent regulatory amendment on plastic FCMs (EU 2025) that introduced more details on the required risk assessment of NIAS in the EU.

In 2023, chronic health outcomes that are highly prevalent in the human population were grouped into Six Clusters of Disease (SCOD), including cancers, cardiovascular diseases, reproductive disorders, brain-related disorders, immunological disorders, and metabolic diseases (Figure 1) (Muncke et al. 2023). To better understand the impact of FCCs on human health, the development of high-throughput

screening assays for endpoints related to these disease clusters was recommended. Such high-throughput methods would allow testing of all migrating FCCs. However, it is also essential to understand the epidemiologic data linking exposure to FCCs to diseases categorized under the SCOD framework. This knowledge can support the development of screening assays.

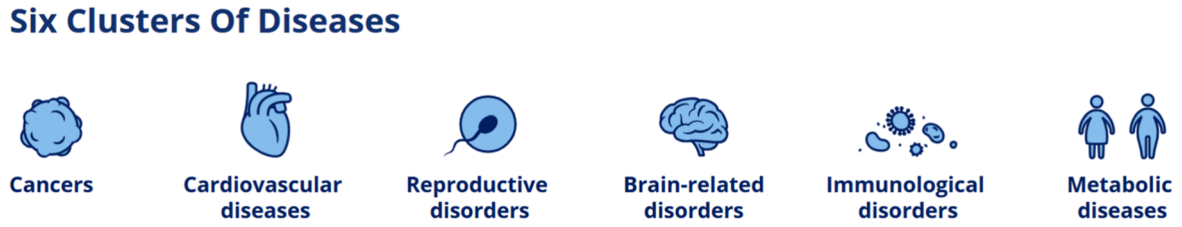

Figure 1. The Six Clusters of Disease (SCOD) concept comprises highly prevalent, non-communicable diseases that are of increasing concern and associated with hazardous chemical exposures (according to Muncke et al. 2023).

Objectives

Our aim is to systematically map the literature examining the established links between exposure to known FCCs and adverse human health outcomes. We will particularly focus on FCCs that have been detected in FCMs and in human samples (Geueke and Parkinson 2024; Geueke et al. 2023). Health outcomes will be assigned to the SCOD (Figure 1) (Muncke et al. 2023). The international classification of diseases (11th Revision, ICD-11; World Health Organisation 2022) will be used as the basis for these assignments.

The systematic evidence map will allow the identification of FCCs (i) that are associated with human health effects and (ii) for which more data on exposure and/or health effects are needed. Additionally, it aims to provide information for more specific research questions that are, for example, related to certain chemicals or chemical groups, types of FCMs, specific health outcomes, or vulnerable populations. The data will be presented in an interactive and openly accessible dashboard, the **F**ood **C**ontact **C**hemicals **He**a**l**th Effect Matr**ix** (FCChelix), and key findings will be summarized in a peer-reviewed article.

Methods

This protocol was drafted following the updated 2015 PRISMA-P guidelines (Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols; Annex 3) (Moher et al. 2015; Page et al. 2021) and giving due consideration to the recommendations for the Conduct of Systematic Reviews in Toxicology and Environmental Health Research (COSTER) (Whaley et al. 2020).

Research question

The PECOS (Population, Exposure, Comparator, Outcome, Study Design) framework will be applied to answer the research question: Which FCCs are associated with non-communicable chronic diseases in humans? (Table 1).

Table 1. Elements of the research question following the PECOS framework.

Element of the PECOS framework	Description
Population	Any human
Exposure	To FCCs or metabolites of FCCs
Comparator	Control groups or any other comparator
Outcome	Human health effects related to the Six Clusters of Disease (SCOD)
Study design	Epidemiological studies

Eligibility criteria

Inclusion and exclusion criteria are defined to facilitate decisions on the eligibility of a reference during literature screening (Table 2). They are structured according to the elements of the PECOS framework. Studies meeting one or more exclusion criteria will be excluded. Eligible studies contain primary data, have been peer-reviewed, and are published in English. There will be no general restriction regarding the publication date.

Table 2. Elements of the PECOS framework and eligibility criteria to be applied during literature screening. Studies that meet any exclusion criteria will not be considered eligible.

Element of the PECOS framework	Inclusion	Exclusion
Population	• Any human, without restriction based on age, sex, life stage, and preexisting health conditions, including the developing fetus	• Analyzed sample originates from an animal, plant, fungi, and bacteria, is an environmental sample, or is not defined • Sample is a human cell line
Exposure	• Analyzed sample originates from a human specimen (e.g. blood, urine, breast milk AND at least one analyte is an FCC that has previously been detected in extracts/migrates of FCMs (i.e. the chemical is listed in the FCCmigex database) or a specific metabolite of such an FCC (i.e. the parent compound is specifically transformed into the analyte)	• FCC or its specific metabolite is listed in the FCCdb, but has never been detected in migrates or extracts of FCMs according to the FCCmigex database • Modelling of chemical exposure • Dermal exposure, such as patch and skin-prick tests
Comparator	• All studies including a control group or any other comparator	
Outcome	• Any health outcome that can be related to the Six Clusters of Disease (SCOD) • Direct reporting of a disease • Measurement of physiological and/or biochemical changes associated with the SCOD	• Missing/incomplete assessment of health outcome • Health outcome cannot be aligned with SCOD • Modelling of health outcomes
Study design	• Epidemiological studies, including longitudinal or cross-sectional study designs	• Case study/report • Descriptive studies

The systematic evidence map will consider studies on any human *population* globally, without restrictions on age, sex, life stage, and pre-existing health conditions. Studies on animals and human cell lines will be excluded. Data from a control group are included in the study, serving as a *comparator*.

Studies are required to report the detection of FCCs in human samples (indicating *exposure*) and link them to human health effects. We will only consider epidemiological studies on FCCs that have been previously detected in migrants and/or extracts of FCMs (Food Packaging Forum 2025). For some FCCs, specific metabolites are known and routinely assessed (e.g. phthalates). If such metabolites have been detected in humans, the exposure element of the framework is fulfilled.

Only measurements of human health effects will be included. The health *outcomes* can be classified into at least one of these six disease clusters (i.e. SCOD): cancers, cardiovascular diseases, reproductive disorders, brain-related disorders, immunological disorders, and metabolic diseases (Figure 1). Studies reporting the diagnoses of a disease will be included (e.g. diabetes), as well as studies on physiological and/or biochemical measurements that are associated with changes in relevant organ systems (e.g. ovaries, brain). A longitudinal or cross-sectional *study design* is required; case reports will be excluded.

Stakeholder engagement

During the development of this protocol, we had regular meetings with the core team and the scientific advisory group (SAG) of the Food Contact Chemicals and human Health (FCCH) project (Food Packaging Forum 2025). The members of these two groups have expertise in the fields of FCMs and FCCs, toxicology, epidemiology, chemical databases, and systematic evidence mapping. Between August 2024 and January 2025, we had monthly meetings with the core team. The core team has been deeply involved in protocol development, literature screening, and data extraction of previous systematic evidence maps related to the FCCH project (i.e. FCCmigex and FCChumon) (Geueke and Parkinson 2024; Geueke et al. 2023). Therefore, its members have a detailed understanding of the

underlying data and processes and provided valuable input throughout the development of this protocol. All core team members are co-authors of this protocol. Advice was also given by Louise Goodes from Minderoo Foundation, who is the first author of the protocol of the Plastic Health Map (Goodes et al. 2022). Additionally, the SAG of the FCCH project was consulted twice during protocol development and asked for input during online meetings.

Information sources

We investigated the suitability of the databases PubMed, Medline (Ovid), Embiology®, SciFinder®, and ScienceDirect® for this project. PubMed offers the most advantages in terms of coverage of the literature, the possibility to run automated searches, and the availability of search and filter options. Furthermore, PubMed is freely available and focuses on medical/health-related topics. As the use of only one database also simplifies the workflow, data management and future updates for hundreds to thousands of individual FCCs, PubMed will be used for all literature searches.

Search strategy

The ideal search strategy identifies as many relevant published studies on FCCs and human health outcomes as reasonably feasible. However, the available evidence for individual chemicals and chemical groups varies strongly. Therefore, we developed a modular search strategy including study-related search terms, defined filter options, and chemical-related search terms that will allow us to customize the literature searches within given boundaries (Figure 2). This strategy is markedly different and less complex than the searches employed by the Plastic Health Map (Seewoo et al. 2023).

Figure 2. Modular search strategy. Study-related search terms aim at identifying epidemiological studies. Filter settings allow the selection of, e.g. the studied species (i.e. humans), publication data and type and language. Chemical-related search terms include common chemical names, synonyms and identifiers.

Scoping searches

We applied different strategies to identify search terms related to the study design of epidemiological research. First, we brainstormed study-related search terms within the core team and refined this list by running iterative searches. Then, we analyzed the word frequencies of the reference titles included in the Plastic Health Map, as this benchmark database addressed a similar research question regarding plastic-associated chemicals in general (no specific focus on FCMs) (Seewoo et al. 2023). Word frequency analysis was supported by using the Voyant tools (Sinclar and Rockwell 2024).

Iterative testing of these preliminary terms resulted in a short and a long list of study-related search terms (Table S1). We also applied different filter settings for the studied species (i.e. human) and publication types. By combining the different study-related search terms and filters, we obtained four search options and tested them for different FCCs and groups of FCCs.

A comparison of the results of our scoping searches for bisphenols, phthalates, and per- and polyfluoroalkyl substances (PFAS) with the benchmark references included in the Plastic Health Map illustrated that our search options successfully captured 80%–97% of them (see Supplementary information, Figure S1). Refining of the chemical related-search terms improved the coverage of a test search for PFAS from initially 50% to 92% (Figure S2). Importantly, in a preliminary screening of the reference list for bisphenols, we identified even more eligible references that have not been included in the Plastic Health Map (see Supplementary information, section 4). More detailed analyses showed that most of the studies missed by the scoping searches are included in PubMed but were not found because the chemical names are not mentioned in the titles, abstracts or keywords (Figure S3). This limitation may

be overcome by using additional chemical synonyms. Based on the results of these scoping searches, we considered our general search strategy to be appropriate in terms of sensitivity and specificity.

Implementing the literature searches

Automated literature searches will be conducted in PubMed using the Entrez Programming Utilities API. This approach will enable the systematic retrieval of records for each FCC.

We will use the short list of study-related search terms as default setting, since it balances sensitivity (i.e. identifying the benchmark references) and specificity (i.e. keeping the screening effort low) (search option 1, Table S1 and Table 3).

Table 3. Search terms and filters to query for 1. an individual chemical (here: melamine) and 2. a chemical group (here: PFAS).

Study-related	Filters	Chemical-related (examples)
(NHANES OR HBM4EU OR CHMS OR KONEHS OR odds OR cross-sectional OR case-control OR cohort OR incidence OR prevalence OR epidemiol* OR associat* OR prospective OR longitudinal OR urin*)	• Language: English • Publication type: "journal article" NOT "review" NOT "case report" • Species: human	(melamine OR 108-78-1 OR "2,4,6-triamino-s-triazine") (PFAS OR perfluor* OR polyfluor*)

In accordance with the eligibility criteria, the language filter for English and the publication type "journal article" will be selected, and the publication types "review" and "case report" will be excluded. The species filter for "humans" will be selected. No date limit will be set. Only for FCCs that are already included in the Plastic Health Map, we will search for references that were published after January 31, 2022 (i.e. the last update of the Plastic Health Map). This will prevent duplication of work, as the Plastic Health Map addressed a similar research question, and it is supported by the results of our scoping exercise (see Supplementary Information).

Searching the scientific literature for individual chemicals is often challenging as chemical names can have many different spellings and are often only mentioned in the full text, tables and/or figures, which makes them undetectable in most literature searches. Additionally, chemical identifiers such as CAS RN, InCHI and SMILES are rarely used in epidemiological studies. To address this and cover the chemical space more broadly, we will perform individual searches for each FCC and include names used in the FCC databases, CompTox, and CAS Common Chemistry, as well as IUPAC synonyms and CAS RNs (Groh et al. 2022; Geueke et al. 2025). Chemical synonyms and identifiers will be connected by the operator OR, as illustrated in Table 3. We will also search for groups of FCCs that have been assigned on the basis of similar functional or structural properties, because the group names may be mentioned in titles, abstracts, or keywords while individual chemical names may not. Work on the grouping of FCCs is currently ongoing at the Food Packaging Forum and will be applicable for this project.

The potential for certain chemical names to yield unspecific results (e.g. "phenol"), and the possibility of missing studies due to the omission of commonly used chemical synonyms may reduce the specificity and sensitivity of the search results, respectively. These limitations will be acknowledged in the interpretation of the findings and addressed, if possible, through iterative refinement of search terms. For example, if the literature search for an FCC (group) of particular interest will not result in any eligible references, we will consider conducting additional broader literature searches to make sure that we did not miss relevant information. For chemicals where the search results indicate many unspecific hits, searching only the titles and abstracts for the chemical names may reduce the number of irrelevant studies.

Considerations on prioritizing FCCs

Scoping searches revealed substantial variability for individual chemicals and chemical groups, ranging from zero to tens of thousands of studies found. This is mainly attributed to the differences in the

volume of existing research between chemicals. To effectively address our research question and optimize the use of available resources, we will

- focus on FCCs and groups of FCCs of particular interest (e.g. high evidence for presence in FCMs, high level of concern),
- exclude FCCs for which there is widely recognized evidence linking chemical exposure to human health effects (e.g. certain heavy metals and volatile organic compounds, and pharmaceuticals found to be present in FCMs), and
- exclude FCCs that are inorganic compounds, endogenous metabolites and/or naturally occurring constituents of food.

By applying this prioritization strategy, we aim to focus on the most relevant FCCs that are attributed to FCMs, while avoiding duplication of existing research.

Screening process

Duplicates within the search results will be identified based on their PubMed ID and removed by using Excel, optionally followed by using the deduplication function in SWIFT-Active Screener (Howard et al. 2020). For each reference, we will maintain the links to the chemicals for which the respective studies have been found because this information will facilitate data extraction.

All studies retrieved from the literature searches will be first screened in SWIFT-Active Screener at title-and-abstract level, followed by full-text screening. The screening of the titles and abstracts will be actively supported by SWIFT-Active Screener, which iteratively prioritizes all references for manual screening. A 95% recall level will be set, which defines the proportion of eligible studies to be included based on the prediction. Studies that clearly do not meet all the inclusion criteria (Table 2) will be excluded during either the title-and-abstract or the full-text screening. Initially, we will perform a consistency check on 10% of the references at the title-and-abstract level to refine the eligibility criteria, where two experts will screen in parallel. Disagreements will be recorded, inter-rater reliability scores will be determined, and conflicts will be resolved. Any learnings at this early screening stage will be included in a guidance document. If the IRR score exceeds 0.7 at this stage, indicating acceptable agreement according to Hanegraaf et al. (2024), the remaining titles and abstracts will be screened independently by one reviewer only. If the IRR is below 0.7, we will continue with parallel screening for the next 10% of studies and then re-evaluate the IRR score. This process will repeat until the IRR surpasses the threshold of 0.7, at which point single screening will start, or the recall level predicted by SWIFT-Active Screener is reached and screening can be stopped. All included references will then be screened at full-text level and for consistency, ten percent of these will be screened independently and in parallel by two team members. Any discrepancies will be resolved by bilateral discussions, with the option to ask a third team member for their opinion. The IRR score will be tracked, and we will follow the same process as described above for title-and-abstract screening. A PRISMA flow diagram will be generated that provides an overview of the studies found in the literature searches, how many of them were included/excluded at the two different screening levels, and the reasons for exclusion at full text level (Figure 3).

Data extraction

Data will be extracted from all studies included after the full-text screening. The in-house software tool SciExtract will be used to compile the data based on pre-coded options and free text. SciExtract allows us to compile the data in a highly structured way, and it supports organizing and managing the workflow, tracking changes, and storing the pdfs and extracted data. We will include relevant publication details, information on the population, chemical exposure, health outcome(s) and study design (Table 4, SI_draft data extraction code book).

After setting up data extraction templates in SciExtract, we will test the process with a defined set of references. At least two team members will independently extract data from a subset of studies and compare the results. Potential conflicts will be discussed and either resolved directly, or input from an additional team member will be called in. After this testing process, data extraction templates may be

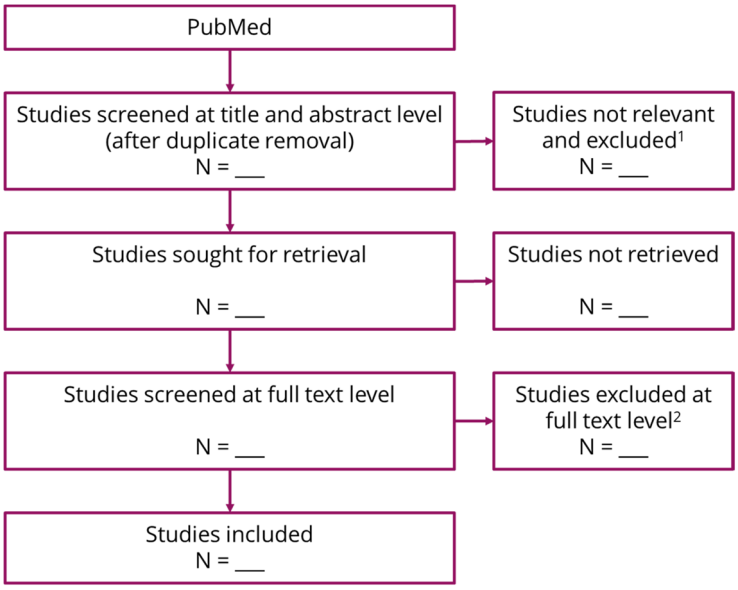

Figure 3. Example workflow based on the PRISMA flow diagram. Individual literature searches will be run for each FCC.[1] Clearly irrelevant studies will be excluded during title and abstract screening.[2] Reasons for exclusion during full text screening may be: full text not accessible, no primary data presented, exclusion criteria fulfilled.

Table 4. Data that will be reported based on pre-coded options.

Data category	Data captured
Bibliographic information	• Author(s) • Title • Year of publication • Journal • URL • Volume • Issue • Pages • DOI • Abstract
Information on studied population	• Population type • Number of participants • Biological sex • Ethnicity • Socio-economic status • Age at which exposure was measured • Age at which health outcome was measured • Country of investigated population • Special risk population and comparator group
Chemical information	• Chemical name(s) • CAS RN • Optional: Chemical group • Multiple exposures • Detection frequencies
Health outcomes	• Predefined categories based on the SCOD* (cancer, cardiovascular diseases, reproductive disorders, brain-related disorders, immunological disorders, metabolic diseases)
Study design	• Predefined categories, such as cross-sectional and longitudinal studies

*If an FCC is linked to more than one disease cluster, several database entries will be generated reflecting these multiple associations.

revised, and an additional guidance document will be prepared to facilitate consistent data extraction. The data from the remaining references will be extracted by one team member and the option to call for an additional opinion will be implemented in the task management process. If necessary, the guidance document will be refined during the data extraction process and all team members will be regularly informed about potential edits. It will be ensured that updates will not conflict with existing data (e.g. the addition of response options to a predefined selection is often possible). The option to exclude references during data extraction will be permitted to revise decisions regarding a study's eligibility

made during the full-text screening process. Such decisions will always require review by and agreement from a second team member.

In many cases, the CAS RN is not provided for a given chemical in an epidemiological study. Therefore, the chemical names will be matched to CAS RNs in a post-processing step, following a previously described process (Geueke et al. 2023). A critical appraisal of the studies and extracted data will not be included, which is in line with the methodology of systematic evidence mapping.

Data analysis and presentation

The extracted information will be linked to a chemical index of FCCs, the references, and a pre-coded overview of human health outcomes. It will be presented graphically as an interactive dashboard using PowerBI, including diagrams, heat maps, bar plots and/or tables to visualize the main outcomes. The focus will be placed on the link between human exposure to FCCs and associated health outcomes. Integrated filters will allow the selection and highlighting of specific information, e.g. in relation to study design, population types, chemical groups, and the publication year. For filtered data sets, the underlying references will always be linked. A narrative summary in the form of a peer-reviewed scientific manuscript will further explain the presented results and provide background information.

The systematic evidence map linking FCCs to human health effects will provide a comprehensive overview of the existing literature and will complement the systematic evidence map on migrating and extractable FCCs (Geueke et al. 2023), the systematic overview of the presence of FCCs in humans (Geueke and Parkinson 2024), and the systematic evidence map of human health effects of plastic chemicals (Seewoo et al. 2023). Together, these sources will provide a better understanding of the human health effects of chemical exposure from FCMs, highlight knowledge gaps and identify areas for further investigation.

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CRediT: **Birgit Geueke**: Conceptualization, Investigation, Methodology, Project administration, Validation, Writing – original draft; **Ahmed Elagali**: Conceptualization, Methodology, Validation, Writing – review & editing; **Ksenia J. Groh**: Conceptualization, Writing – review & editing; **Christopher D. Kassotis**: Conceptualization, Writing – review & editing; **Maricel V. Maffini**: Conceptualization, Writing – review & editing; **Olwenn V. Martin**: Conceptualization, Writing – review & editing; **Lindsey V. Parkinson**: Conceptualization, Data curation, Writing – review & editing; **Christos Symeonides**: Conceptualization, Writing – review & editing; **Helene Wiesinger**: Conceptualization, Data curation, Writing – review & editing; **Lisa Zimmermann**: Conceptualization, Writing – review & editing; **Jane Muncke**: Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing.

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Data availability statement

The supplementary information that supports the findings of this study are openly available in the Zenodo repository at http://doi.org/10.5281/zenodo.14943978.

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