From Evidence to Policy

THE SOUND OF CONTAMINATION

A Comprehensive Analysis of Endocrine Disruptors and Hazardous Additives in the Headphones

February 2026

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A Comprehensive Analysis of Endocrine Disruptors and Hazardous Additives in the Headphones

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ToxFree Life FOR ALL

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This paper is the second in the series of policy briefing papers (the first briefing paper "Ban Bisphenols in All Products – Policy briefing paper" by Grechko et al, 2024 is available at the project website). The policy briefing papers are issued as a result of the ToxFree LIFE for All project (**https://tudatosvasarlo.hu/tox-free-life-for-all-english**), whose aim is to raise awareness through telling stories and presenting accurate laboratory measurements about products and the harmful substances these may contain. The ToxFree LIFE for All project also supports policy changes for the restriction and phasing out of chemicals of concern thus protecting people and the planet.
Coordinating Beneficiary: Tudatos Vásárlók Egyesülete (Association of Conscious Consumers) (HU); Associated Beneficiaries: ARNIKA (CZ), dTest (CZ), Zveza Potrosnikov Slovenije Drustvo (SI), Verein Für Konsumenteninformation (AT).
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Arnika is a Czech non-governmental organisation established in 2001. Its mission is to promote environmental health, raise awareness and work toward toxic pollution reduction within the European and global context. Arnika's Toxics and Waste Programme aims to eliminate the use and releases of POPs and other toxic chemicals in the Czech Republic as well as globally. Our work is based on research, developing evidence-based inputs for use in policy dialogues and running public awareness raising campaigns for a variety of stakeholders including the general public, NGOs, media, public servants and businesses. Our science-based studies promote measures to ensure that the EU legislation becomes a flagship of a sustainable and just environmental legal framework. **www.arnika.org/en**

dTest is the largest Czech consumer organisation and has been operating in the Czech Republic since 1992. Our mission is to provide comprehensive services to consumers. We publish the dTest magazine, which publishes the results of independent and objective product tests, information on consumer rights and advice on how to exercise these rights effectively. Our comparators and calculators make it easy to choose services. Through our constantly updated database we also warn about dangerous products, deceptive business practices and educate businesses and consumers. We provide free consumer advice to consumers. dTest is part of the International Consumer Research and Testing Organisation (ICRT) and the European consumer organisation BEUC. **www.dtest.cz**

VKI, the Austrian Consumer association, was founded in 1961 as a testing organisation. Main fields of VKI´s activities comprise product testing, publishing, law enforcement and advice to consumers. VKI is located in Vienna and runs advice centers in Vienna and Innsbruck. Content-wise VKI has special expertise on topics like health and safety of products and food, sustainability and environment, financial services and consumer law. **www.vki.at**

TVE, Tudatos Vásárlók Egyesülete - in Hungarian, or the Association of Conscious Consumers (ACC) has been promoting sustainable, circular, ethical, fair and just consumption and lifestyle choices since 2001. Its main goal is to make consumers aware of the environmental, social, and ethical aspects of their consumption and to help them to live more sustainable lifestyles while making ethical choices. ACC works mainly, but not exclusively, in the following fields: food consumption, local and global supply chains, household chemicals, advertising, consumer rights, product and service testing. It delivers campaigns, educates and builds communities, conducts background research, and advocates decision makers to achieve this aim. **www.tudatosvasarlo.hu**

ZPS, the Consumers´ Association of Slovenia, is a non-profit independent non-government membership consumer organisation established in 1990 to defend, promote and advocate for the interests of consumers. We work for consumer-friendly legislation, promote good consumer choices, test products, try and evaluate services, provide advice and help in cases of consumer confusion. Currently, it has approximately 7,000 active (membership fee paying) members. More than 90% of Slovenians are aware of ZPS and the association is respected by the general public as well as businesses. Its web portal **www.zps.si** is the country's most important national web portal for consumer information and advice and has approx. 700,000 unique visitors per year. ZPS acts as the champion of individual consumers, through advice and information, research and advocacy, campaigning and policy-making and represents Slovenian consumers nationally and internationally.

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LIST OF ABBREVIATIONS

ABFRs – Aromatic Brominated Flame Retardants
ABS – Acrylonitrile Butadiene Styrene
BBP – Butyl benzyl phthalate
BDP / BPADP – Bisphenol A bis(diphenyl phosphate)
BFR – Brominated Flame Retardants
BPA – Bisphenol A
BPB – Bisphenol B
BPF – Bisphenol F
BPS – Bisphenol S
CLP – Classification, Labelling and Packaging Regulation
CMR – Carcinogenic, Mutagenic, or Reprotoxic
DBDPE – Decabromodiphenyl ethane
DBP – Dibutyl phthalate
DEHA – Diethylhydroxylamine
DEHP – Di(2-ethylhexyl) phthalate
DEP – Diethyl phthalate
DiBP – Di(isobutyl) phthalate
DINCH – Diisononyl-cyclohexane-1,2-dicarboxylate
DnBP – Di-n-butyl phthalate
DnOP – Di-n-octyl phthalate
DMP – Dimethyl phthalate
DPP – Digital Product Passport
EDC – Endocrine Disrupting Chemical
EFSA – European Food Safety Authority
ECHA – European Chemicals Agency
EVA – Ethylene Vinyl Acetate
EU – European Union
ESPR– Ecodesign for Sustainable Products Regulation
GRA – Generic Risk Approach
HFR – Halogenated Flame Retardants
LC-MS/MS – Liquid Chromatography–Mass Spectrometry/Mass Spectrometry
LOQ – Limit of Quantitation
MAF – Mixture Assessment Factor
MCCP – Medium-Chain Chlorinated Paraffins
OEKO-TEX – International Association for Research and Testing in the Field of Textile and Leather Ecology
OPFR – Organophosphate Flame Retardants
PBDE – Polybrominated Diphenyl Ethers
PC – Polycarbonate
PBT – Persistent, Bioaccumulative and Toxic
PMT – Persistent, Mobile, Toxic
POPs – Persistent Organic Pollutants
PUR – Polyurethane
PVC – Polyvinyl Chloride
RDP – Resorcinol bis(diphenyl phosphate)
REACH – Registration, Evaluation, Authorisation and Restriction of Chemicals
RoHS – Restriction of Hazardous Substances Directive

SCCP – Short-Chain Chlorinated Paraffins
SCCS – Scientific Committee on Consumer Safety
SCIP – Substances of Concern in Products Database
SSbD – Safe-and-Sustainable-by-Design
SVHC – Substances of Very High Concern
TBBPA – Tetrabromobisphenol A
TOTM – Trioctyl trimellitate
TPhP – Triphenyl phosphate
UN GHS – United Nations´ Globally Harmonized System of Classification and Labelling of Chemicals
vPvB – very Persistent and very Bioaccumulative
vPvM – very Persistent, very Mobile

To ensure clarity for international readers, this report adopts standard English numerical formatting, utilizing the full stop (.) as a decimal separator and the comma (,) to group thousands.

Foreword: Protecting the Foundation of Our Future

Safety of the products we bring into our homes is no longer merely a technical or regulatory issue. It is a fundamental matter of **protecting families and future generations, ensuring sovereign consumer choices, and common-sense transparency.**

PROTECTING THE WELL-BEING OF FUTURE GENERATIONS

The family and the safety of our children are core values shared by the vast majority of Europeans. Our findings reveal that even common everyday products like headphones have become pathways for endocrine-disrupting chemicals (EDCs). These substances do not just affect the individual; they interfere with fertility and the hormonal health of our children during their most vulnerable windows of development. Safeguarding the health of the children, the next generations is a non-negotiable duty. By demanding stricter chemical standards, we are quite literally **defending the health of current and all future generations.**

REDEFINING CONSUMER SOVEREIGNTY

True sovereignty more than the abundance of choices, it is the **freedom to choose from products that are inherently safe.** A consumer is only truly “sovereign” when they can trust that the products available on the market will not cause long-term harm to their health. As our results show, this is not yet the case.

THE DEMAND FOR SIMPLICITY AND TRANSPARENCY

Simplicity is a fundamental consumer need. An average person uses **10 to 20 products a day** that contain explicit chemical ingredients. Every year, consumers make **hundreds of other decisions** regarding clothes, toys, furniture, kitchenware, electronics — all products that contain complex chemical mixtures, yet offer no visible information about them. In an increasingly complex world, citizens want their lives to be simpler, not more complicated. We should not be required to conduct a chemical analysis every time we purchase a pair of headphones. People do not feel equipped to identify or evaluate chemical risks in the goods they use daily; they **simply want safe products.**

As consumer organisations, our role is to bridge the gap between complex industrial data and everyday needs. True simplification means ensuring that safety is built into the product from the start. Through chemical transparency, we empower the stakeholders to make informed decisions, ensuring that “simplicity” leads to higher safety standards rather than the erosion of consumer protection.

On behalf of the ToxFree LIFE for All partnership
Gulyás Emese PhD
President
Tudatos Vásárlók Egyesülete (Association of Conscious Consumers), Hungary

Executive Summary

KEY TAKEWAYS

100% Market Contamination: Hazardous substances were detected in every product tested. While individual doses may be low, the **"cocktail effect"** of daily, multi-source exposure poses severe long-term risks to endocrine health and fertility.

The Bisphenol Crisis: BPA and its substitutes—the most documented endocrine disruptors—were nearly universal, found in **177 of 180 samples.** Their high concentrations highlight a critical failure to curb toxins affecting human hormonal system in consumer structural plastics.

A Market-Wide Failure: Premium brands offer no guarantee of safety. Toxic substances, including unregulated flame retardants, are pervasive across the entire market, proving that **price is not a proxy for chemical safety.**

The "Toxic Legacy": Current regulatory gaps allow dangerous additives to poison the secondary raw material market. This makes safe recycling impossible and undermines the **EU Circular Economy** objectives. We urge EU policymakers to abandon the "substance-by-substance" approach and implement **comprehensive bans on chemical classes** to prevent regrettable substitution and ensure safety is a market standard, not a consumer burden.

PROJECT SCOPE AND METHODOLOGY

While headphones are indispensable for communication and recreation, they represent a neglected pathway for chemical exposure. An international testing campaign, funded by the **ToxFree Life for All** project, conducted a rigorous analysis of **81 headphone models** across the Central European market (Czech Republic, Slovakia, Hungary, Slovenia, and Austria) with a smaller number of samples purchased at popular online marketplaces such as Temu and Shein.

The study provided a comprehensive cross-section overview of the current market segment:

- **Product Types:** Analysis included both in-ear (inserted into the ear canal) and over-ear models.
- **Target Demographics:** Testing covered products specifically marketed to children, adults, and the gaming sector (teenagers).
- **Connectivity:** The scope included both wireless models (predominant in adult segments) and wired models (common in children's and gaming segments).

The analytical program evaluated 81 individual products, which were disassembled into 180 samples of hard and soft plastic components. These samples underwent rigorous analysis for hazardous substances, including brominated flame retardants (BFRs), organophosphate flame retardants (OPFRs), chlorinated paraffins, phthalates, and bisphenols.

OVERVIEW OF FINDINGS

Harmful substances were detected in 100% of the products tested. While many individual substances appeared in low concentrations, our findings raise concern because a significant portion of the detected substances—including bisphenols, phthalates, and new brominated flame retardants—are well-known Endocrine Disrupting Chemicals (EDCs).

THE BISPHENOL CRISIS

Our analysis identified bisphenols in all 81 distinct headphone models. These well-documented endocrine disruptors probably migrate from internal electronic components—specifically epoxy resins used for structural bonding and thermal insulation.

- **Exposure Pathways:** Bisphenol migration is accelerated by acidic environments and elevated temperatures, conditions common during daily use (e.g., sport and skin contact with sweat).
- **Prevalence:** Bisphenol A (BPA) was nearly universal, detected in 177 of 180 samples. Its common substitute, Bisphenol S (BPS), was found in 137 samples.
- **Concentration Levels:** Maximum recorded concentrations reached **351 mg/kg (0.035% by weight)**, significantly exceeding the **10 mg/kg limit** proposed by ECHA. Notably, hard plastic components— not in direct skin contact—exhibited higher concentrations than the parts touching the skin.

FLAME RETARDANTS, PHTHALATES AND CHLORINATED PARAFFINS

The study further highlights the omnipresence of both brominated and organophosphate flame retardants (OPFRs).

- **Flame retardants:** Organophosphate flame retardants have emerged as the primary substitutes for polybrominated diphenyl ethers (PBDEs) and other halogenated flame retardants (such as TBBPA and DBDPE). Halogenated FRs were detected in trace contaminations (<5 mg/kg). In case of OPFRs, four samples exceeded the **0.1% threshold** requiring notification under **REACH Article 33**, with concentrations of **Triphenyl phosphate** (**TPhP),** a known endocrine disruptor, reaching as high as **1,424 mg/kg**. An even higher concentration was detected for the currently unregulated **Resorcinol bis(diphenyl phosphate) (RDP)**. Used as a substitute for TPhP, RDP reached the highest overall concentration in the study at **3,514 mg/kg.**
- **Phthalate Contamination:** Approximately 60% of samples contained traces of CMR-classified (Carcinogenic, Mutagenic, or Reprotoxic) phthalates. While most concentrations were low, a sample from an international marketplace (Temu) reached **4,950 mg/kg of DEHP**, highlighting the severe risks associated with unregulated online markets outside of the EU legislation.
- The average concentrations of short-chain (SCCPs) and medium-chain (MCCPs) chlorinated paraffins were recorded at 45 mg/kg. This value is notably lower than levels previously reported in peer-reviewed studies concerning chlorinated paraffins in other categories of small electronics and cables. A notable exception was identified, a children's product from an online marketplace containing **1,299 mg/kg**, highlighting a narrow margin of compliance with the **1,500 mg/kg** legal limit for SCCPs derived from the POPs Regulation.
- While products marketed specifically for children showed a lower frequency of harmful chemicals, products targeting teenagers and gamers showed higher contamination values. Crucially, the data confirms that premium brand status does not guarantee a lower chemical burden, as toxic substances were identified across the entire market spectrum.

POLICY IMPLICATIONS AND RECOMMENDATIONS

The Cumulative Risk

While these products do not pose an acute or "imminent" danger, the cumulative and synergistic effects of chronic exposure to these chemical classes pose a long-term risk to public health, therefore having a negative impact on sovereign consumer choice.

Scientific consensus suggests there are **no safe levels of exposure** to Endocrine Disrupting Chemicals (EDCs) such as bisphenols or phthalates, as they trigger biological responses at minute concentrations mirroring the body's own hormones. Because EDCs effects are chronic, they may not be immediately observable, often manifesting years later or during **"critical windows of development"** like pregnancy and puberty. Furthermore, emerging research indicates that EDC exposure can have **transgenerational impacts**, affecting the health of future offspring. As science evolves, regulatory standards shift downward reflecting these systemic, long-term risks and the need for protecting the children and future generations.

The Case for Group Restriction

The continued presence of these substances—despite individual bans—demonstrates the inadequacy of the current "substance-by-substance" regulatory approach. To protect consumers and enable a safe circular economy, the European Union must move toward:

1. **Group-Based Restrictions:** Implementing comprehensive bans on entire chemical classes (e.g., all bisphenols) to prevent "regrettable substitution."
2. **Mandatory Disclosure:** Requiring full transparency regarding the chemical composition of **consumer electronics and their materials.**
3. **Safer-by-Design Standards:** Enforcing stricter ecodesign requirements that prioritise non-toxic materials, facilitating safer recycling and waste management.

The individual consumer has limited power to choose a safe product. Consumer protection is a **systemic problem** that cannot be solved by individual choice; it must be addressed at the institutional level. Currently, the EU's "competitiveness agenda" often prioritises free market over the precautionary principle, effectively endangering consumer safety and human health.

Harmonised EU-wide regulation is the only way to ensure that the secondary raw material market is not poisoned by "legacy toxins," allowing products to be safely reused and recycled within a truly circular economy. Such measures should serve as a blueprint for global legislative action, preventing the international trade of toxic consumer goods and protecting both human health and the global environment from long-term chemical burdens.

Introduction: The Hidden Chemical Burden

In the modern digital landscape, headphones have transitioned from occasional accessories to essential tools for communication, education, and recreation. Used daily for extended periods by individuals of all ages, genders, and social groups, headphones maintain intimate physical contact with the user, making their chemical composition a matter of urgent public health significance.

Electronics are complex assemblies containing a vast array of substances of concern. While many of these chemicals are subject to individual restrictions, the final product remains a sophisticated **mixture of chemicals**. Both the rigid housings and the flexible, soft-plastic components of headphones contain a variety of well-studied toxins (Darbre, 2020; Meeker et al., 2009). These products serve as a classic example of the chemical "cocktail effect" to which consumers—including highly vulnerable populations such as **children and teenagers**—are exposed to on a daily basis.

A fundamental failure in the current market is the **complete lack of transparency**. Consumers are currently unable to make well-informed decisions because chemical data is not disclosed at the point of sale. While several major manufacturers and global brands adopted extensive "Restricted Substance Lists," our research reveals that **regrettable substitutes** are prevalent across all product categories.

In light of the increasing global incidence of **paediatric cancers, infertility, and obesity**, the role of well-studied endocrine disruptors and carcinogens in everyday products cannot be ignored (Petrakis et al., 2017). To protect public health and the future of the next generation, the European Union must move beyond fragmented regulations and adopt more effective, group-wide chemical restrictions that prioritise human well-being over industrial status quo.

Toxic Effects and Regulatory Status of Analysed Chemical Groups

Headphones can be made from a wide range of plastic materials (see **Table 1**), each of which may contain different functional additives. As a result, several groups of potentially harmful chemicals may be present. The sampling campaign therefore focused on five different groups of substances:

- **Chlorinated paraffins**: These substances are used as plasticisers and softening agents in plastics and may be present in plastic components of headphones. Although short and medium-chained chlorinated paraffins are banned globally via the Stockholm Convention due to their persistency and bio-accumulation, they are still frequently detected in consumer products (Fiedler, 2010; IPEN, 2025).
- **Phthalates and alternative plasticisers**: Phthalates commonly used as plasticisers, are potent reproductive toxins that can impair fertility and disrupt foetal development by interfering with the body's natural hormones (Wang & Qian, 2021).
- **Brominated flame retardants (BFRs)**: BFRs are added to plastics to reduce flammability. They are highly persistent environmental pollutants that act as potent neurodevelopmental toxins and endocrine disruptors, often interfering with thyroid hormone function and impairing cognitive development in children (Kim et al., 2014).
- **Organophosphate flame retardants (OPFRs):** Used as alternatives to brominated flame retardants to reduce flammability, OPFRs are of concern due their potential neurotoxicity, developmental and reproductive issues and endocrine disruption (Wei et al., 2015).
- **Bisphenols:** Mostly used in the manufacturing of polycarbonate plastics and epoxy resins, bisphenols are endocrine disruptors that mimic oestrogen, potentially leading to metabolic disorders, reproductive issues, and increased cancer risk even at trace concentrations (Maffini et al., 2006; Rochester & Bolden, 2015).

CHLORINATED PARAFFINS: SCCPS AND MCCPS

Chlorinated paraffins (CPs) are complex mixtures of polychlorinated n-alkanes categorised by their carbon chain length: short-chain (SCCPs), medium-chain (MCCPs), and long-chain (LCCPs). In the electronics industry, they are primarily utilised in PVC cable coatings and plastic casings as both flame retardants and secondary plasticisers (softeners) (Fiedler, 2010).

Health and Environmental Toxicity

- **SCCPs (Short-Chain, C10–C13):** Classified as **Persistent Organic Pollutants (POPs)**, SCCPs are highly resistant to environmental degradation. Toxicological studies on laboratory animals have linked SCCP exposure to liver hypertrophy, thyroid follicle cell alterations, and renal damage. (Huang et al., 2023). International Agency for Research on Cancer (IARC) categorise them as **potentially carcinogenic** (IARC, 1990).

Table 1. Types of hard and soft plastics usually used for headphones (Schmidt et al., 2008).

Materials in contact with the ear, identified by analysis	Headphones			Hearing protection aids	
	Around-ear	On-ear	In-ear	Around-ear	In-ear
Silicone	X		X		X
PUR, soft (polyurethane)	X			X	
PUR, foam		X			
PUR, lacquer					X
ABS (acrylonitrile-butadiene-styrene)			X		
Polyester (textile)	X				
PVC, nitrile modified				X	
PVC with phthalate plasticiser					X
Other materials, identified in the survey					
Leather	X				
PC (polycarbonate)		X			
PC/PBT		X			
Acryl					X
EVA (ethylene-vinyl acetate)		X			
PP/EPDM		X			
Chloroprene-rubber		X			
Artificial leather	X				

- **MCCPs (Medium-Chain, C14-C17):** Often marketed as "safer" substitutes for SCCPs, MCCPs share many of the same hazardous traits. They are highly lipophilic and bioaccumulative, building up in the food chain and appearing globally in water, soil, human adipose tissue, and breast milk. Due to their chlorination and lipophilicity, these chemicals accumulate in aquatic organisms and have been found in fish, birds, and marine mammals in both urban and remote areas (KEMI, 2017; Zellmer et al., 2020).

Regulatory Framework and 2025/2026 Updates

The legislative landscape for these substances has tightened significantly:

- **SCCPs Regulation:** Regulated under the **Stockholm Convention** since 2018 and the **EU POPs Regulation (2019/1021)**, the current legal limit for SCCPs in consumer articles is **0.15% by weight (1,500 mg/kg)** (European Parliament and Council of the EU, 2022).
- **MCCPs Global Ban:** A major regulatory milestone was reached in **May 2025 at COP-12**, where MCCPs were officially added to **Annex A (Elimination)** of the Stockholm Convention (Stockholm Convention on POPs, 2025).

Upcoming EU Implementation: The EU is currently transiting this global ban into the **POPs Regulation**, with adoption expected in the **first half of 2026**. The proposed draft sets a stringent limit of **1,000 mg/kg (0.1%)** for MCCPs when present as an "unintentional trace contaminant."

PHTHALATES: ENDOCRINE DISRUPTORS AND PLASTICISERS

Phthalates—dialkyl or alkyl aryl esters of phthalic acid—are primarily utilised as plasticisers to impart flexibility to polyvinyl chloride (PVC). **As non-chemically bound additives,** these substances are continually released from the polymer matrix, and their high mobility results in chronic human exposure via dermal contact and the inhalation of contaminated indoor dust (Wang & Qian, 2021).

Health Impacts of Traditional Phthalates

Decades of toxicological research have identified significant health risks associated with specific phthalate ortho-esters:

- **DEHP (Di(2-ethylhexyl) phthalate):** The most extensively studied phthalate, linked to reduced testosterone levels, anti-androgenic effects, and impaired foetal development (Zarean et al., 2016).
- **BBP & DBP (Butyl benzyl / Dibutyl phthalate):** Both are classified as reprotoxic substances; animal studies demonstrate they cause severe malformations in male offspring (Roy et al., 2017; EFSA, 2019).
- **DiBP (Diisobutyl phthalate):** Frequently used as a substitute for DBP, DiBP exhibits nearly identical endocrine-disrupting profiles, representing a classic case of "regrettable substitution" (Yost et al., 2019).

Non-Phthalate Alternatives: DINCH, TOTM, and DEHA

As regulations tighten, manufacturers have transitioned to alternative plasticisers. Our analysis included **DINCH, TOTM, and DEHA**. While these are generally viewed as less potent than phthalates, emerging research indicates they are not biologically inert. Recent studies suggest potential impacts on **thyroid function, reproductive hormones, and metabolic health**, warranting continued scientific scrutiny (Jung et al., 2024).

Regulatory Framework: RoHS Directive 2011/65/EU

In the European Union, phthalates in consumer electronics are governed by the **RoHS (Restriction of Hazardous Substances) Directive** also known as Directive 2011/65/EU. Since **July 22, 2019**, four specific phthalates (DEHP, BBP, DBP, and DiBP) have been restricted in headphones.

The 0.1% Threshold: The maximum allowable concentration is **0.1% by weight (1,000 mg/kg) in homogeneous materials** (European Commission, 2015). Unlike the REACH regulation for other consumer goods, which often applies a cumulative limit (the sum of phthalates), the RoHS directive applies the 0.1% limit to **each individual substance** within any single material (e.g., a specific cable coating or plastic casing).

FLAME RETARDANTS: BROMINATED AND ORGANOPHOSPHATE COMPOUNDS

Flame retardants are synthetic chemicals added to consumer products to minimise fire-related injuries and damage. Since the 1970s, flame retardants have been incorporated into various consumer products, including electronics, furniture, and building insulation (Pearce & Liepins, 1975). The electrical and electronic engineering industry is a major user of flame retardants, as they are used to reduce flammability in plastic housings for consumer and office electronics (Morgan & Gilman, 2013).
Since flame retardants are added rather than chemically bonded to the plastic polymer, they are released throughout the product's lifecycle, including during incineration or waste deposition (Sakai et al., 2001).

Organophosphate Flame Retardants (OPFRs)

As the industry shifts away from halogenated substances, organophosphate flame retardants (OPFRs) —**organic esters of phosphoric acid containing carbon-phosphorus-oxygen bonds** have emerged as the dominant substitutes in electronics thermoplastics. While frequently marketed as "safer" alternatives, many OPFRs exhibit endocrine-disrupting properties, as their chemical structures often incorporate well-studied EDCs like bisphenol A or resorcinol (Wei et al., 2015).

- **TPhP (Triphenyl phosphate):** The most prevalent OPFR in our samples, TPhP is a confirmed **endocrine disruptor** (Hu et al., 2023; Li et al., 2025). It interferes with oestrogen and thyroid hormone axes (Ji et al., 2022) and is linked to obesity and metabolic changes (Wang et al., 2019).
- **BDP / BPADP (Bisphenol A bis(diphenyl phosphate)):** Often used in high-temperature engineering plastics, BDP is synthesised using **Bisphenol A (BPA)**. It has been shown in experimental studies to disrupt gut microbiota and damage intestinal function (Lyu et al., 2025).
- **RDP (Resorcinol bis(diphenyl phosphate)):** Used as a substitute to TPhP, RDP is an emerging neurotoxin and acts as an endocrine disruptor that interferes with thyroid and oestrogen pathways. It has been linked to metabolic imbalances in animal studies (Xie et al., 2023). Scientists report stronger oestrogenic effects than TPhP and RDP´s exposure showing metabolic disorders in rats and their offspring (Liu et al., 2023).

Regulatory Framework: REACH Regulation (EC) No 1907/2006

OPFRs are not yet regulated as a group. However, substances like **TPhP** are on the **REACH SVHC Candidate List** (ECHA, 2024). If present above **0.1%**, manufacturers must notify ECHA and communicate this to customers (European Parliament and Council of the EU, 2006). The EU is considering broader group restrictions for OPFRs to prevent "regrettable substitution."

BROMINATED FLAME RETARDANTS (BFRS)

BFRs are highly effective but notorious for their persistence and toxicity. While older generations like **PBDEs** are largely banned, they are being replaced by "novel" BFRs that share similar hazardous profiles.

- **PBDEs (Polybrominated Diphenyl Ethers):** Globally banned under the Stockholm Convention, PBDEs (like DecaBDE) are still found in trace amounts in modern electronics, often originating from **recycled**

plastic streams. They are linked to neurodevelopmental toxicity and reproductive harm (McDonald, 2002; Renzelli et al., 2023).
- **TBBPA (Tetrabromobisphenol A)** is a common reactive flame retardant that can cross the placental barrier, exposing foetuses during critical windows of brain development (Yin et al., 2018). It is resistant to degradation and bioaccumulates in the food chain (Okeke et al., 2022).

Regulatory Framework: RoHS Directive 2011/65/EU and POPs Regulation (EU) 2019/1021
- The EU has restricted PBDEs via the **Restriction of Hazardous Substances (RoHS) Directive 2011/65/EU with the limit of 0.1% by weight (1,000 ppm) in each homogeneous material** (European Commission, 2015).
- As these substances were gradually adopted for global ban via the Stockholm Convention, they are currently also regulated through the **POPs Regulation** (EU) 2019/1021. For Polybrominated Diphenyl Ethers (PBDEs) (Tetra-, Penta-, Hexa-, Hepta-, and DecaBDE) there is an Unintentional Trace Contamination limit of 10 mg/kg for general articles with certain exemptions for recycled plastics (350 ppm) (European Parliament and Council of the EU, 2022).
- In December 2024, ECHA published a landmark proposal to restrict **Aromatic Brominated Flame Retardants (ABFRs)** as a group. The proposal targets non-polymeric ABFRs due to their **PBT (Persistent, Bioaccumulative, and Toxic)** and **vPvB (very Persistent, very Bioaccumulative)** properties. The proposal targets non-polymeric ABFRs, which are identified as posing the highest environmental risks while opening space for extending the restriction to other hazardous properties and broadening the scope to other brominated as well as organophosphate flame retardants (ECHA, 2024).

BISPHENOLS
Bisphenols are a group of chemicals that have a similar structure, typically featuring two hydroxyphenyl functional groups. The most prevalent Bisphenol A is used primarily for polycarbonate and epoxy resins manufacturing. They are likely found in electronics, including headphones, due to the use of BPA-derived epoxy resins. These materials provide critical insulation and heat resistance for printed circuit boards, battery components, and the structural bonding of internal plastic and metal parts (Dallaev et al., 2023). Bisphenols are structurally similar to oestrogen and are well known for their endocrine-disrupting properties.

- **BPA (Bisphenol A):** Binds to oestrogen receptors and alters gene expression and hormone activity (Alonso-Magdalena et al., 2012). BPA has been detected in amniotic fluid, placental tissue, and umbilical cord blood, indicating transplacental transfer. Studies have confirmed that BPA can migrate from synthetic materials into artificial sweat (Wang et al., 2019), and dermal absorption is well established (Toner et al., 2018). These findings led to the EU ban of BPA in thermal receipt paper in 2020, although it has been widely substituted with BPS (ECHA, 2020).
- **BPF (Bisphenol F) and BPS (Bisphenol S):** Common BPA replacements that exhibit nearly identical endocrine-disrupting mechanisms (Eladak et al., 2015). BPS has been shown to impair embryonic development and induce oxidative stress in animal models (Wu et al., 2018).
- **BPAF (Bisphenol AF):** Demonstrates stronger oestrogenic activity than BPA and is increasingly used in thermal paper and plastic applications (Moreman et al., 2017).

Given the **prolonged skin** contact associated with headphone use, dermal exposure represents a relevant pathway, and it is reasonable to assume that similar migration of BPA and its substitutes may occur from headphone components directly to the user’s skin.

Regulatory Framework: REACH and Product-Specific EU Regulations

There are **no specific bans** or concentration limits for BPA or other bisphenols in electronic devices.

- **BPA, BPB and BPS** are included on the **REACH SVHC (Substances of Very High Concern) Candidate List** (ECHA, 2017; ECHA, 2021; ECHA, 2023).
- **Food Contact Materials**: The EU's Regulation 2024/3190, effective as of January 2025, bans Bisphenol A (BPA) and other hazardous bisphenols (BPS and BPAF) prohibiting their use in plastics, coatings, inks and more (European Commission, 2024).
- **Thermal Paper:** BPA has been banned in thermal receipts (concentration > 200 mg/kg) since **January 2020**. BPS is the most common replacement, but it is also under evaluation for similar restrictions (European Commission, 2016).
- **Toys:** Under the **Toy Safety Regulation** (updated late 2025), a "group restriction" approach is used. BPA and other bisphenols classified as CMRs are prohibited in toys for children under 3 or toys intended to be placed in the mouth. (European Parliament and the Council of the EU, 2025).

Table 2 presents a comparative overview of regulatory requirements and voluntary corporate standards for five key substance groups found in consumer electronics. While EU legislation sets mandatory minimum thresholds, leading manufacturers often implement stricter internal policies, particularly for substances in direct contact with skin or those identified as emerging concerns. Notably, companies like Apple have adopted near-zero tolerance limits (≤10 ppm) for several substance classes, significantly exceeding legal requirements and effectively driving market-wide improvements in product safety.

Table 2. A summary of legislative restrictions and company specific rules sorted by substance groups.

	OPFRs	BFRs (PBDEs)	SCCPs	Phthalates (DEHP, BBP, DBP, DIBP)	Bisphenols (BPA/ BPF/BPS)
EU-Wide Limits	No restrictions REACH SVHCs list e.g. TCEP, TEP and TPhP ≥0.1% triggers SCIP and supply chain info	RoHS limit: ≤ 0.1% (1000 ppm) POPs: ≤0.035% total PBDEs in recycled plastics	POPs Regulation: ≤ 0.15% by weight in articles	RoHS limit: ≤ 0.1% in homogeneous materials	No restrictions REACH SVHC list for BPA, BPB, BPS: ≥0.1% triggers SCIP reporting and supply chain info
Apple (Apple Inc., (2025)	≤0,1% for TPhP, TCEP, TCPP and other SVHC substances	10 ppm individually and 500 ppm for sum of total PBDEs	SCCP + MCCPs ≤ 0.1%	Covers all orthophthalates ≤0,1%	≤100 ppm bisphenol chemicals
Sony (Sony Group Corporation, 2025)	REACH SVHCs compliance	RoHS compliance ≤ 0.1% (1000 ppm)	SCCP ≤ 0.1%	≤0,1%	No limit

Product Test Sample Selection and Exposure Categorisation

To ensure a representative assessment for a broad consumer base, our study included products designed for **adults, teenagers, and children**. Teenagers were included in the adult product category, as their usage patterns align more closely with that demographic. Furthermore, a dedicated segment of the sampling campaign focused on **gaming headsets** to address the specific exposure profiles of the gaming community.

Our market research indicates that the adult market is dominated by **wireless technology**, across both in-ear and over-ear form factors. The children's market consists primarily of **over-ear designs**, featuring a mix of wired and wireless configurations. While child-branded in-ear products exist, they currently represent a marginal share of the market.

EXPOSURE ASSESSMENT METHODOLOGY

To provide a scientifically grounded risk assessment, our methodology distinguished between materials based on their **proximity to the user** and the likelihood of **dermal absorption**. We categorised headphone components into two primary exposure levels:

- **Direct Skin Contact:** This category prioritises components in constant contact with the user, such as **silicone ear tips** (in-ear), **synthetic leather or foam ear cushions** (over-ear), and **hard plastic housings** that rest against the ear canal.
- **Indirect Contact:** This includes structural elements such as **hard plastic headbands, the hard casing of in-ear products not touching the skin,** and **connection cables**. While these components have less frequent skin contact, they are included in the assessment as they contribute to the total chemical burden and potential environmental migration within the user's immediate breathing zone.

Table 3. Types of headphones for consumer groups.

Consumer group	Type of product	wires
Adults	Over-ear and in-ear	Wireless
Young adults / teenagers	Adult products and gaming headphones	Both with and without wires
Children	Over-ear and in-ear	Both with and without wires

Table 4. Distribution of samples among the various age groups.

	product group	Number of samples
Adult – 40 products	in-ear wireless	18
	in-ear with wires	2
	over ear adult	20
Gaming over ear headphones – 8 products	gaming with wires	6
	gaming wireless	2
Children – 33 products	in-ear wireless	1
	in-ear with wires	2
	over ear child	30
Total number of products		**81**

The full list of products including substances tested per product part can be found in **Annex 2**.

ANALYSIS PROTOCOL

The analytical approach was tailored to the construction and materials used in different headphone types. Each product was disassembled into distinct components—soft materials (ear cushions, cables), hard plastics (housings, structural parts), and cables—with targeted chemical analyses assigned based on the most likely sources of contamination. The analysis protocol does not distinguish between children's and adult products; grouping is based solely on headphone construction and material composition.

Table 5. Overview of chemical analyses by headphone type and component.

Type of product	analysis of soft parts	analysis of hard parts	analysis of the wire
Over ear – wireless	SCCPs/MCCPs phthalates bisphenols	bisphenols flame retardants	none
Over ear with wires	SCCPs/MCCPs phthalates bisphenols	bisphenols flame retardants	SCCPs/MCCPs phthalates bisphenols
In-ear with wires, hard and soft plastic	SCCPs/MCCPs phthalates bisphenols	bisphenols flame retardants	SCCPs/MCCPs phthalates bisphenols
In-ear wireless, only hard plastic	none	bisphenols flame retardants	none
In-ear wireless, hard plastic and soft plastic	SCCPs/MCCPs phthalates bisphenols	bisphenols flame retardants	none

Results and Evaluation

EVALUATION CRITERIA

Chemical substances were classified using a “traffic light” system: **green** indicates the lowest risk (meeting the most protective standards), **yellow** signals moderate concern (legally compliant but exceeding stricter voluntary limits), and **red** marks high concern (non-compliant with legal limits or containing multiple hazardous substances).

The classification is based on legally binding limits, ecolabel threshold values such as OEKOTEX 100 or Blue Angel, and health-based guidance values for different groups of chemicals. Substances with higher health concern (e.g., CMRs and SVHCs) are assessed more strictly, and the combined presence of multiple chemicals is also taken into account.

Different evaluation thresholds are applied depending on the function and exposure potential of individual product parts. In case of bisphenols, components in direct contact with the skin are assessed using lower, more protective limits, while parts with indirect or no skin contact are evaluated using higher thresholds reflecting reduced exposure.

Detailed evaluation criteria including limits can be seen in **Annex 5**.

OVERALL PRODUCT EVALUATION

The final product rating integrates results from two exposure categories: **primary exposure** (components in direct skin contact, such as ear cushions and in-ear tips) and **secondary exposure** (structural parts with minimal skin contact, such as headbands and cables).

The evaluation prioritises components with direct dermal contact, as these pose the highest risk of chemical migration. A “worst-case” principle is applied: **if any component is rated red, the entire product receives a red rating**, regardless of other parts’ performance. The detailed evaluation methodology is provided in **Annex 5**.

Figure 1 presents the distribution of evaluation results across all tested products:

- **Total evaluation:** Shows the final rating for complete products. **Only about one-third of headphones received a green rating**, meeting the most protective standards. Nearly half were rated red due to exceeding legal limits or containing multiple hazardous substances.
- **Parts touching the skin:** Components in direct contact with ears show notably better performance, with **a clear majority rated green**. This reflects manufacturers’ increasing attention to materials that contact the skin directly.
- **Parts not touching the skin** show significantly worse results, with **a substantial proportion rated red** signalling less regulatory and commercial scrutiny.

The stark difference between skin-contact and non-contact components reveals that manufacturers prioritise chemical safety only for soft plastic, touch-sensitive parts, while other components often contain concerning levels of harmful substances. This practice creates a “toxic legacy” within the materials, forming a major barrier to the safe recycling and reuse essential for achieving true circular economy objective.

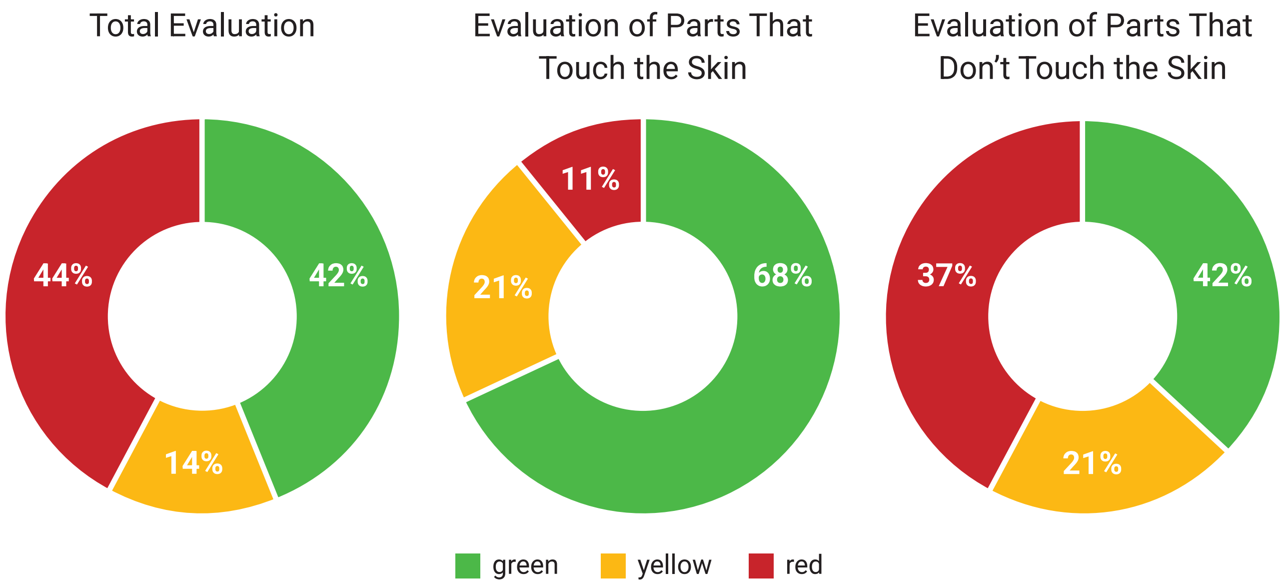

Figure 1. Chemical safety evaluation of complete products and individual components (skin-contact vs. non-contact parts).

EVALUATION BASED ON COMPONENT

This evaluation breaks down the results by material type, revealing distinct patterns of chemical contamination across different headphone components:

- **Soft plastic parts:** Components like ear cushions, silicone tips, and foam padding show the best performance, with **a clear majority rated green**. Very few received a red rating, reflecting manufacturers' awareness that these materials have prolonged skin contact.
- **Hard plastic parts:** The rigid plastic components forming the headphone structure show significantly worse results, with **about one-third rated red**—the highest failure rate among all component types. This indicates that problematic chemicals, particularly flame retardants and bisphenols, are concentrated in hard structural plastics rather than in materials that contact the skin.
- **Wires:** Cable insulation shows a mixed picture, with **over half rated green but a substantial proportion in the yellow category**. While very few cables exceeded legal limits, a notable share contained moderate levels of chlorinated paraffins and phthalates used as PVC plasticisers.

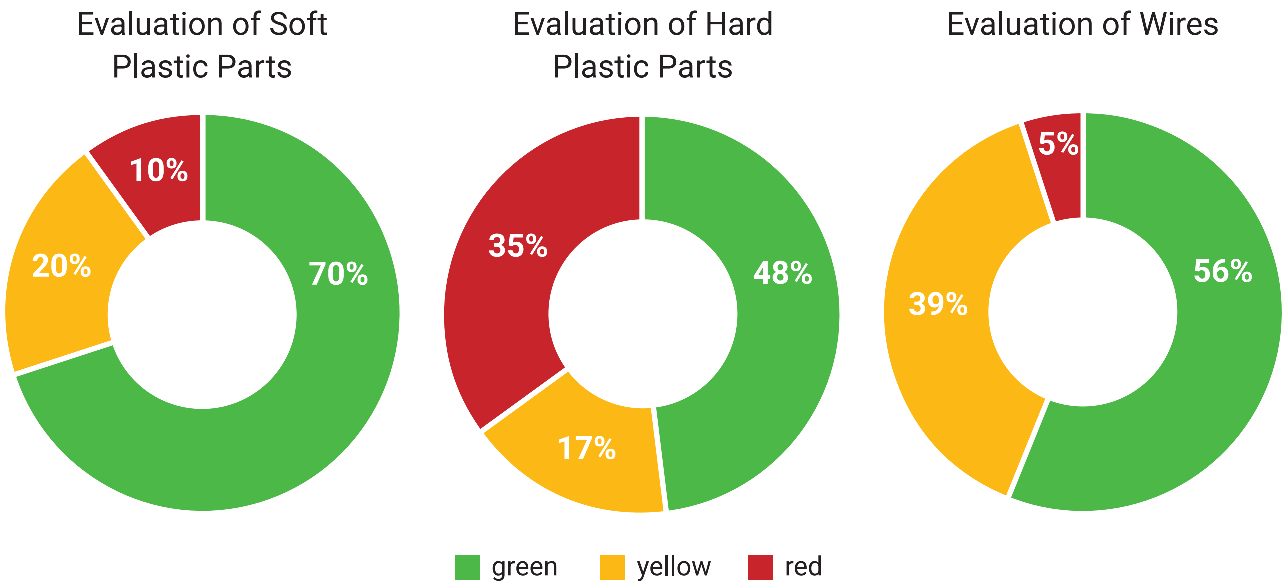

Figure 2. Chemical safety evaluation by component type. Soft plastic components analysed in 80, hard plastic parts in 83 and wires analysed in 18 samples.

EVALUATION BASED ON CHEMICAL GROUP

A review of current scientific literature reveals a significant research gap, as existing studies on harmful substances in headphones are limited primarily to wire insulation. **Our investigation is therefore unique, as it provides the first recent data determining the concentrations of phthalates and bisphenols within the structural and contact components of small electronic devices.**

Chlorinated Paraffins

The majority of products **contained less than 50 mg/kg** of chlorinated paraffins, which is the threshold limit value established for **OEKO-TEX® STANDARD 100** certified textiles (OEKO-TEX, 2025). Given the frequent and prolonged skin contact required for headphone use, our study adopted this same benchmark as a safety performance indicator for all soft plastic components. The **average sum value of SCCP+MCCP was 45 mg/kg**.

The highest amount detected in a sample a children's product bought from Temu was **1,299 mg/kg, mainly due to the SCCP content of 0.12%.** None of the samples exceeded the legal limit of 1,500 mg/kg of SCCPs.

The second highest amount of SCCP+ MCCP was detected in a retail-brand Qlive product. It contained over 800 mg/kg SCCP+MCCP.

Existing scientific literature has frequently identified **chlorinated paraffins** in electronic components, particularly within the flexible plastic coatings of wiring. **Kutarna et al. (2023)** reported elevated concentrations in the plastic sheathing of computer and headphone cables sourced from the Canadian market, with peak levels reaching **9,340 mg/kg** for SCCPs and **18,700 mg/kg** for MCCPs. These findings align with **Guida et al. (2022)**, who detected MCCP concentrations as high as **59,000 mg/kg** in electrical cables from the Japanese market. Similarly, **McGrath et al. (2020)** analysed small consumer goods in Belgium—including electric shavers and speakers—finding total SCCP concentrations in cables ranging from **1,100 to 47,000 mg/kg**. In contrast, our findings indicate that SCCP and MCCP levels in soft plastics and wiring of the tested headphones are notably lower than those reported in these previous electronic device analyses.

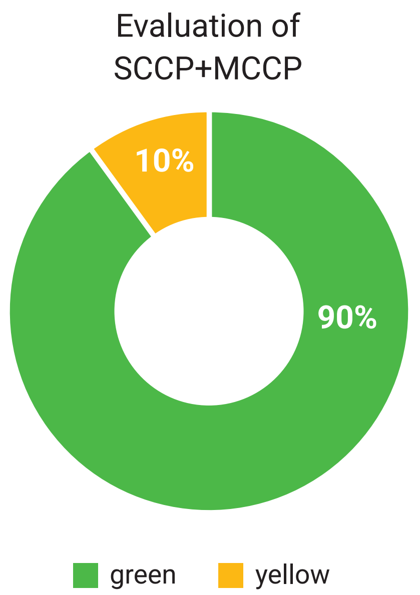

Figure 3. Evaluation of chlorinated paraffins (100 analysed components).

Flame retardants

Although many samples achieved a "green" rating, flame retardants (FRs) remain omnipresent in very small concentrations across the tested products. **Halogenated FRs (including brominated flame retardants)** were generally limited to unintentional trace contaminations, with maximum levels reaching **5 mg/kg** (primarily **TBBPA** and **DBDPE**), suggesting that the transition to unregulated halogenated substitutes remains minimal in this sector.

The presence of organophosphate flame retardants was significantly higher: **72% of all samples contained five or more distinct OPFRs**, while **10% contained 10 or more**, with cumulative concentrations reaching as high as **1,424 mg/kg**.

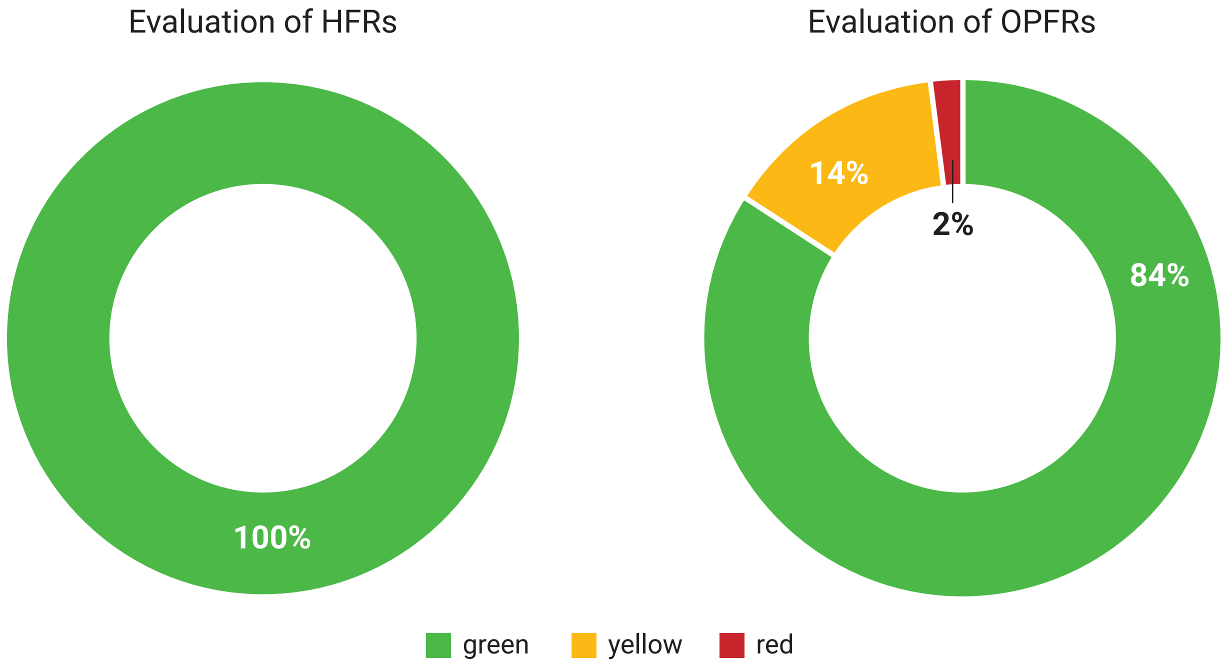

Figure 4. Evaluation of organophosphate flame retardants (86 analysed components).

Table 6. Overview of detected flame retardants (FRs).

	HFRs	OPFRs
Total number of samples tested for FRs	86	86
Highest number of FRs detected in a sample	9	12
Number of samples with no FRs present	65	0
Number of samples with 1 or more FRs present	22	86
Number of samples with 5 or more FRs present	2	62
Number of samples with 10 or more OPFRs present	0	9

Two samples - **Marshall, Motif II ANC and Skullcandy, Grom Kids Bluetootth** - received a "red" rating due to the presence of **Triphenyl phosphate (TPhP)** at concentrations exceeding the **0.1% (1,000 mg/kg)** threshold for SVHCs.

Our findings align with **Zhang et al. (2019)**, who identified TPhP as the primary organophosphate flame retardant in smartphones. Copper wire plastic contained from ‚non-detected' up to **956 mg/kg TPhP.** These levels are lower than the concentrations detected in our **"red-rated" headphone samples (1,424 mg/kg and 1,004 mg/kg)**. Furthermore, we observed evidence of a shift toward **RDP (Resorcinol bis(diphenyl phosphate))** as a substitute for TPhP. RDP was detected at the **highest overall concentration in our study**, reaching **3,514 mg/kg** in the **Haylou Bluetooth over-ear headphones**.

Phthalates

Phthalates were only tested in soft plastics and wires. At least small amounts of phthalates or other softener substitutes including TOTM or DINCH were detected in all 98 samples tested.

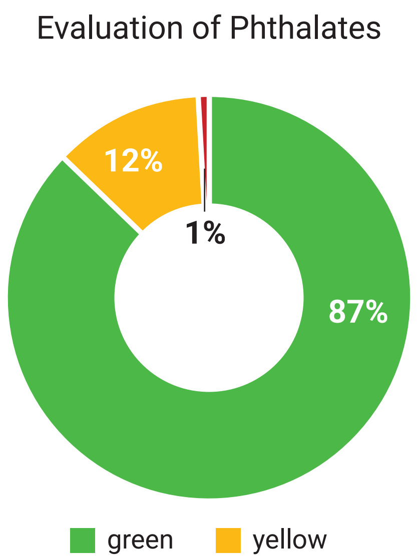

Figure 5. **Evaluation of phthalates (98 analysed components).**

Given the ubiquitous presence of phthalates in manufacturing processes, even stringent ecolabel Blue Angel permits trace amounts of known CMRs; for instance, a threshold of **0.15 mg/kg** is generally accepted as evidence of non-intentional use in toys (Blue Angel, 2017)

Consequently, we conducted a dual-tier evaluation of phthalate content. First, all detected phthalates were analysed using the laboratory's **Limit of Quantitation (LOQ)** to differentiate between "no content" and the presence of phthalates. Second, a specific assessment was performed for phthalates classified as **CMR substances** exceeding the **0.15 mg/kg threshold**. The comprehensive results of these analyses are presented in the following tables.

Table 7. Evaluation of all phthalates detected.

Total number of samples tested for phthalates	98
Average phthalate concentration mg/kg	5.1
Highest number of phthalates detected in a sample	8
Number of samples with no phthalates present	0
Number of samples with 1 or more phthalates present	98
Number of samples with 5 or more phthalates present	69

Table 8. Evaluation of CMR phthalates detected above 0.15 mg/kg.

Total number of samples tested for phthalates	98
Average phthalate concentration mg/kg	2.4
Highest number of CMR phthalates detected in a sample	4
Number of samples with no CMRs above 0.15 mg/kg present	4
Number of samples with 1 CMR above 0.15 mg/kg present	17
Number of samples with 2 CMRs above 0.15 mg/kg present	17
Number of samples with 3 or more CMRs above 0.15 mg/kg present	60
Maximum concentration of a single CMR phthalate	4,950 mg/kg

Our analysis revealed a significant prevalence of phthalate mixtures across the sample set. The highest variety detected in a single sample reached **eight distinct phthalates**, with **61% of all analysed samples containing three or more CMR classified phthalates.** Notably, only four samples maintained concentrations of CMR-classified substances below the **0.15 mg/kg** threshold for non-intentional use.

The most severe contamination was identified in a children's headphone sourced from **TEMU,** which contained **4,950 mg/kg of DEHP** in the plastic headband. The second-highest cumulative concentration of CMR phthalates was **115 mg/kg**, detected in the Buddyphones sample, which is another product marketed specifically for children.

Beyond the primary CMR substances, the study identified a wide array of phthalates and alternative plasticisers, including:

- **Phthalates:** DnOP, DnBP, DMP, DiBP, DEP, and BBP.
- **Alternative Softeners:** DINCH, DEHA, and TOTM.

Bisphenols

To our knowledge, no peer-reviewed studies have yet quantified specific concentrations of bisphenols across the diverse structural components of small electronic devices. Given that these substances are not chemically bound to the polymer matrix, they can migrate to the surface of plastic materials, posing a risk of dermal uptake during consumer use (Wang et al., 2019; Toner et al., 2018).

Our analysis of 180 samples revealed detectable levels of bisphenols in every single specimen, with **78% of samples containing a mixture of two or more analogs**. Notably, the majority of identified compounds—including **BPA, BPB and BPS**—are officially classified as **Substances of Very High Concern (SVHCs)** due to their well-documented endocrine-disrupting properties (ECHA, 2017; ECHA, 2021; ECHA, 2023).

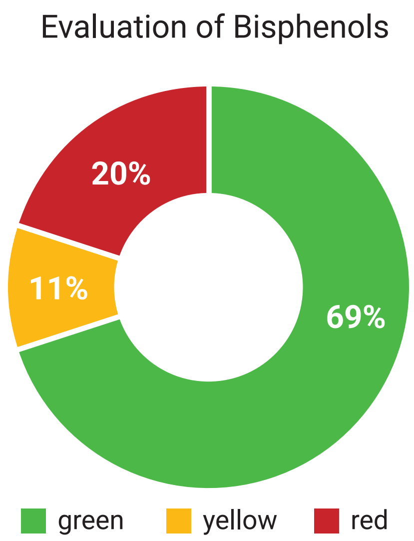

Figure 6. Evaluation of bisphenols (180 analysed components).

Bisphenol A (BPA) was the most prevalent substance, detected in 177 of the 180 samples tested. **Bisphenol S (BPS)**—a common substitute for BPA—was identified in 137 samples, followed by **BPF** in 36 samples and **BPE** in 7. The maximum concentration recorded for a single bisphenol was 351 mg/kg (0.035% by weight). These high concentrations are well above the limit of 10 mg/kg suggested in the ECHA proposal and align

closely with findings from our previous study on underwear textiles, demonstrating consistent levels of contamination across different consumer product categories (Grechko et al.,2025).

The highest concentration of bisphenols was detected in the hard plastic sample **of My First Care by Care Buds, Blue**. This finding is particularly striking given that the product is marketed specifically for children under a brand name that explicitly evokes a sense of safety and "special care."

Table 9. Overview of bisphenols in all samples.

	total
Substances found	BPA, BPE, BPF, BPS
Average sum of all bisphenols/sample (mg/kg)	15.9
Average sum of bisphenols of high concern/sample (mg/kg)	15.9
Lowest sum of all bisphenols/sample (mg/kg)	0.0003
Highest sum of all bisphenols/sample (mg/kg)	351
Number of samples with bisphenols	All 180
Number of samples with bisphenols of high concern	All 180
Number of „red" samples	36
Number of „yellow" samples	20
Number of „green" samples	124
Total number of samples	180

EVALUATION BASED ON PRODUCT CATEGORY

Figure 7 compares overall product ratings between over-ear and in-ear headphones. Both categories show similar results, with 42 and 44 % of products receiving green ratings and roughly half rated red due to hazardous chemical content.

In-ear headphones show a more polarised pattern, with products predominantly falling into either green or red categories and very few in the moderate (yellow) range. This indicates a stark divide between manufacturers prioritising chemical safety and those who do not.

The similar failure rates across both product types suggest systemic issues in the electronics supply chain rather than design-specific problems.

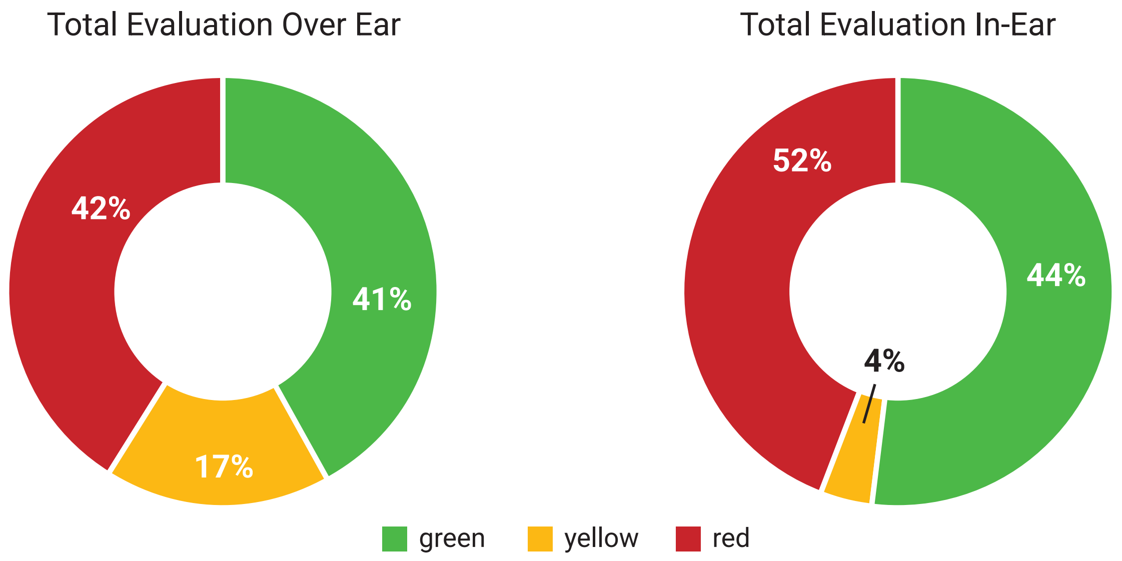

Figure 7. Evaluation based on product category – in over and in-ear samples.

EVALUATION BASED ON CONSUMER GROUP

While adult and gaming headphones exhibit similar contamination profiles, products marketed specifically for children generally contain lower concentrations of hazardous chemicals.

Among the adult and gaming segments, nearly **60% of samples received a "red" rating**, with only approximately one-third achieving a "green" status. In contrast, the children's category showed significantly better performance, with more than **half of the tested products rated "green."**

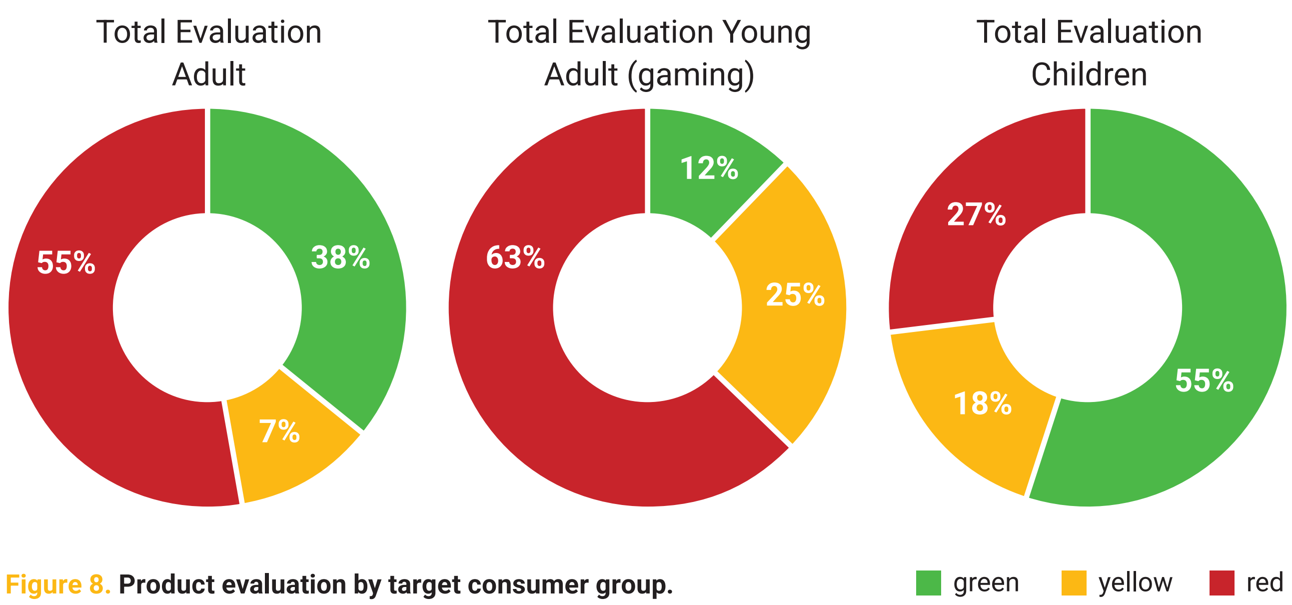

Figure 8. Product evaluation by target consumer group.

EVALUATION BASED ON BRAND

One of the major findings of this study is that products bought from well-known brands do not guarantee greater safety of the product itself.

Table 10. Categories of brands.

Category	Description	Number of samples
Brand	Well-known brands such as Apple, Sennheiser, JBL, Sony.	58
Retail brand	Brands from: Claire's, HEMA, Lidl, Mediamarkt, Auchan or Pepco	8
No-name	Bought from Shein, TEMU, Action, Smyth Toys, emag.hu or babycenter.si	16

While approximately half of the products from well-known and retail brands received a "red" rating, this was true for only 31% of unbranded ("no-name") products, which were significantly more likely to achieve a "green" status. These results underscore that a brand name does not serve as a guarantee for the absence of harmful chemicals.

Table 11. Evaluation based on category of brand.

Category	red	yellow	green
Brand	48%	16%	36%
Retail brand	50%	12%	38%
No-name	27%	7%	67%

Contrary to common assumptions, our analysis of 7 samples sourced from Chinese online retailers revealed that these products did not pose a higher risk of containing toxic chemicals compared to those from established local or global markets.

Table 12. Summary of results from Chinese marketplaces.

TEMU			Shein			Chinese Online shops		
Total number of samples	5	%	Total number of samples	2	%	Total number of samples	7	%
green	3	60	green	2	100	green	5	71
yellow	1	20	yellow	0	0	yellow	1	14
red	1	20	red	0	0	red	1	14

In summary, while manufacturers gradually phase out substances once restricted by **RoHS** or **REACH**, these are frequently replaced by structural analogs that carry similar health concerns. Our survey indicates that **phthalates, chlorinated paraffins, and halogenated flame retardants** are increasingly appearing in lower concentrations; however, in certain samples, halogenated flame retardants have been replaced by **organophosphate esters (OPFRs)**. This trend of reduction does not extend to **bisphenols**, which exhibited a ubiquitous presence across all analysed samples, with approximately **20% of products receiving a "red" rating** due to high bisphenol content.

POLICY RECOMMENDATIONS

As civil society organisations dedicated to consumer safety and the protection of European citizens from toxic substances, we call upon national and European policymakers to adopt the following stringent EU and global chemical policies:

FOLLOWING UPON THE CHEMICAL STRATEGY FOR SUSTAINABILITY (CSS)

Our study confirms that while targeted restrictions are effective at phasing out substances from production, the current regulatory system is prohibitively slow and reactive. The existing substance-by-substance risk assessment approach inadvertently promotes "regrettable substitution," taking decades to address chemicals that remain prevalent in our sampling. To fulfil the commitment from CSS, the REACH regulation shall:

- **Ban Aromatic Brominated Flame Retardants:** Support the submission to ban this group via REACH, specifically including **TBBPA** due to its carcinogenicity. This ban should include a "dynamic link" to encompass other BFRs beyond PBT and vPvB substances and should eventually be extended to include **OPFRs**.
- **A Comprehensive Bisphenol Ban:** We urgently call for an EU-wide restriction on the production and use of the **entire bisphenol family** in all consumer products. Restricting only individual bisphenol substances allows manufacturers to pivot to equally harmful substitutes.
- **Broaden Regulatory Scope:** Restrictions must automatically apply to all bisphenol-containing products and include a dynamic link to ban any newly identified CMR or EDC bisphenols.
- **Resubmit and Strengthen the 2022 German Proposal:** Following its 2023 withdrawal, we urge the resubmission of Germany's bisphenol restriction proposal with a wider scope, stricter concentration limits, and shorter transition deadlines, particularly for recycled materials.
- **Restrict Phthalates via the PVC Additives Ban:** Initiate a group-based phthalate restriction as part of the broader proposed ban on harmful PVC additives.

REACH REVISION

The upcoming REACH revision must pivot toward proactive safety by adopting two core principles:

- **The Generic Risk Approach (GRA):** Move from individual substance testing to a generic ban on the most harmful chemicals (CMRs and EDCs) in all consumer products. Hazardous substance groups should be banned by default in electronics without requiring years of case-by-case assessment.
- **Address the "Cocktail Effect":** Implement a **Mixture Assessment Factor (MAF)**. Safety limits must account for cumulative exposure, recognising that consumers encounter the same chemicals through food, water, and various consumer products simultaneously.

CLP REGULATION

We strongly advocate for the swift implementation of the new **CLP hazard classes** for **Endocrine Disruptors (EDCs)**, **PBT/vPvB**, and **PMT/vPvM** substances is essential for protecting human health and ensuring a toxic-free environment.

- **Dual-Category EDC System:** We endorse the distinction between **Category 1 (Known/Presumed)** and **Category 2 (Suspected)**. This two-tier approach is vital to address current data gaps and ensure that „suspected" chemicals are not left unregulated while long-term testing continues.
- **Global Leadership:** By integrating these classes into the **UN Globally Harmonized System of Classification and Labelling of Chemicals (GHS)**, the EU can set a global benchmark for chemical safety and harmonised labelling.

CIRCULAR ECONOMY & ECODESIGN (ESPR)

For a circular economy to be viable, the material cycle must remain uncontaminated:

- **Safe-and-Sustainable-by-Design (SSbD):** Chemical safety must be integrated at the earliest design phase to eliminate the "toxic cocktail" effect identified in our research. Our findings—showing as many as **12 different OPFRs** and multiple bisphenols in a single product—demonstrate that headphones are currently designed as complex mixtures of hazardous additives. Materials from discarded products may be recyclable if they are free of these legacy toxins; otherwise, recycling simply circulates hazardous substances into the secondary raw material market, "poisoning" the circular economy.
- **Digital Product Passport (DPP):** To bridge the significant transparency gap between manufacturers, retailers, and consumers, the Digital Product Passport must include full disclosure and traceability of the chemicals of concern (not only SVHCs but all chemicals classified on the basis of CLP classification). Currently, consumers and recyclers have no way of knowing if a product contains SVHCs like **TPhP** or **bisphenols**.

INTERNATIONAL POLICY

As the most critical tool for addressing the 100% detection rate of harmful substances in our tests, the Global Plastics Treaty must secure:

- **Mandatory Transparency:** Implement a global "no data, no market" rule, ensuring full chemical disclosure for all imported goods.
- **Global Group-Based Bans:** The treaty should implement global, class-based bans on EDCs, flame retardants, and CMRs in all plastic consumer goods to prevent the global trade of toxic products.
- To ensure clean material cycles in the global economy, it is crucial to set environment- and health-**protective limits for POPs wastes** under the **Basel Convention and the EU POPs Regulation**.

MANUFACTURERS

Manufacturers and retailers of electronic devices should proactively demonstrate their commitment to consumer safety by adopting the following measures:

- **Implement Stringent Chemical Policies:** Adopt or strengthen a **Restricted Substances List (RSL)** applying the most protective limit values. This ensures maximum safety beyond the current minimum legal requirements.
- **Establish Supply Chain Transparency:** Clearly communicate these chemical policies to all suppliers and sub-contractors. Simultaneously, provide transparent information to consumers regarding the chemical composition and safety of products.
- **Prioritise Independent Certification:** Seek third-party **ecolabels** (such as TCO Certified, EU Ecolabel, or Blue Angel) to verify that products meet rigorous environmental and health standards throughout their lifecycle.

CONSUMERS

While individual consumers face significant challenges in identifying truly safe and toxics-free products, the following recommendations empower citizens to minimise personal risk while driving the systemic change necessary for a healthier future.

- **Support Policy Change:** Use your voice as a consumer to demand transparency. Ask brands for their **List of Restricted Substances (RSL)** to ensure they use safe materials and chemicals. Use your vote to support candidates and parties that prioritise **public health and environmental protection** over radical deregulation.
- **Demand Stricter Regulation:** Sign the **ToxFreeProductsNow.eu** petition to demand that the European Union implements group-based restrictions on toxic chemicals and holds manufacturers responsible for the safety of their products.
- **When Purchasing for Children:** Select products designed specifically for their age group. Our testing confirmed that **children's models are generally a safer choice**, as they typically contain fewer hazardous chemicals compared to adult or gaming versions.
- **Limit Duration and Avoid Prolonged Contact:** To reduce the cumulative absorption of chemicals, limit your daily headphone use. Specifically, **do not fall asleep with headphones on**; prolonged skin contact combined with body heat and sweat can significantly increase the migration of toxins into your body.

Annexes

ANNEX 1 – EVALUATION OF INDIVIDUAL PRODUCTS

Manufacturer	Model	Product type	Evaluation of parts touching the skin	Evaluation of parts NOT touching the skin	Total product evaluation
LifeBee	Digital Pro 40	in-ear wireless	green	yellow	green
Picun	B8 Wireless Over ear Headphones	over ear adult	green	green	green
Enjoy Music	M6pop cat ear	over ear child	yellow	red	red
JMMO	Kabellose Ohrhörer mit Premium-Klang, 5.3 Auto-Pairing Ohrhörer mit 14 Stunden Spielzeit, leicht, IPX4	in-ear wireless	green	**there are no such parts**	green
DONG QUAN SHUNXIN ELECTRONIC	Kinder Kabel Kopfhörer 3.5MM Hafen Einhorn Dekor	over ear child	green	yellow	green
Dongguan Yuanze Acoustics Technology	KZ EDX Pro In Ear Monitor Headphones Wired IEM Headphones Dual DD HiFi Stereo Sound	in-ear with wires	green	yellow	green
Shenzhen Weiqi Technology	Cool Black In-Ear Headphones with Type-C Plug	in-ear with wires	yellow	yellow	yellow
Niceboy	Hive Prodigy 4	over ear adult	green	red	red
Marshall	Major V	over ear adult	green	green	green
AirPods	Max -2024	over ear adult	green	yellow	green
Sony	WH-1000XM5	over ear adult	green	green	green
JBL	Tune 720BT	over ear adult	green	green	green
Sony	Ult Wear	over ear adult	yellow	yellow	yellow
Beats	Solo 4	over ear adult	green	red	red
Sony	WH-CH720N	over ear adult	green	green	green
Jlab	Jbuds Lux ANC WIRELESS	over ear adult	green	red	red
Sennheiser	Momentum Wireless 4	over ear adult	red	green	red
Apple	AirPods Pro 2. Gen. USB-C	in-ear wireless	green	green	green
Samsung	Galaxy Buds3 Pro	in-ear wireless	yellow	red	red
JBL	Tour Pro 3	in-ear wireless	green	yellow	green
Sony	Noise Cancelling WF-1000XM5	in-ear wireless	yellow	red	red

Manufacturer	Model	Product type	Evaluation of parts touching the skin	Evalua-tion of parts NOT touching the skin	Total product evaluation
Sennheiser	Accentum True Wireless	in-ear wireless	green	red	red
Sony	LinkBuds Fit	in-ear wireless	green	yellow	green
JBL	Wave Beam	in-ear wireless	green	red	red
Silvercrest	True Wireless Bluetooth In-Ear	in-ear wireless	yellow	red	red
Xiaomi	Redmi Buds 5 Pro	in-ear wireless	green	red	red
Jlab	Jbuds Mini	in-ear wireless	green	red	red
Sony	WF-C510	in-ear wireless	green	yellow	green
Jabra	Elite 10 Gen 2	in-ear wireless	green	red	red
Marshall	Motif II ANC	in-ear wireless	green	red	red
Tonies	Lauscher 2.gen	over ear child	yellow	green	yellow
Tigermedia	tigerbuddies	over ear child	yellow	green	yellow
JBL	JR310BT	over ear child	green	red	red
JLab	JBuddies Studio	over ear child	green	yellow	green
ISY	IHP-1001-BL für Kinder, Blau	over ear child	green	green	green
Hama	184112 Bluetooth®-Kinder-kopfhörer „Teens Guard“	over ear child	green	yellow	green
JVC	HA-KD7	over ear child	green	yellow	green
Skullcandy	Grom Kids Bluetooth Kopf-hörer, Over-Ear, Black	over ear child	green	red	red
Fesh'n rebel	Clam Junior, Over-ear Kopfhörer für Kinder, Lucky Lizard	over ear child	green	red	red
My first care	Care Buds blue	in-ear wireless	green	red	red
Bose	QuietComfort Headphones	over ear adult	red	green	red
Sennheiser	Accentum wireless	in-ear wireless	green	red	red
Bose	QuietComfort Ultra Earbuds	in-ear wireless	green	yellow	green
Beats	Solo Buds	in-ear wireless	green	red	red
Lisciani	Barbie fashion Bluetooth headphones	over ear child	yellow	green	yellow
Buddyphones	Connect Foldbar wired headphones	over ear child	yellow	green	yellow
Lexibook	kids headphones Squads 200 - blue	in-ear wireless	green	**there are no such parts**	green
Gjby	Forever Wireless kids headphones Gjby CATEAR CA-028	over ear child	green	green	green
Lexibook	Foldable wireless head-phones Harry Potter	over ear child	green	green	green

Manufacturer	Model	Product type	Evaluation of parts touching the skin	Evaluation of parts NOT touching the skin	Total product evaluation
Huawei	Free Buds Pro 3 or 4	in-ear wireless	green	green	green
Philips	TAK4206	over ear child	green	green	green
Philips	SHD8850	over ear adult	green	red	red
Panasonic	RB-HX220BDEK black, wireless headphone	over ear adult	yellow	red	red
Logitech	G733 LIGHTSPEED wireless RGB Gaming Headset, black (981-000864)	gaming wireless	red	green	red
SteelSeries	Arctis Nova 5 gaming headset	gaming wireless	red	green	red
Haylou	S35 ANC Bluetooth headphone	over ear adult	green	red	red
Hama	Freedom Lit wireless Bluetooth headphone with microphone, pink (184199)	over ear child	green	green	green
Maxell	HP-BT350	over ear child	yellow	green	yellow
Nextly	NEXTLY wireless headphone with cat ears, foldable, adjustable, LED lights, Bluetooth 5.0, pink	over ear child	yellow	red	red
Onikuma	B90 With Cat Ears Pink	over ear child	green	green	green
Xinxu	Wireless stereo over ear headphone, Xinxu, Bluetooth, graffiti, white	over ear child	green	green	green
Qilive	136030 Bluetooth headphone black (Auchan)	over ear adult	green	red	red
Qilive	Kids 600168061 Bluetooth headphone for kids 2in1 pink (Auchan)	over ear child	yellow	green	yellow
Qilive	600181408 gaming headset with wires (Auchan)	gaming with wires	red	yellow	red
Corsair	HS80 RGB USB Carbon gamer headset	gaming with wires	green	green	green
HyperX	Cloud III gaming headset	gaming with wires	red	red	red
Onikuma	X26 gaming headset with wires pink (X26P)	gaming with wires	yellow	yellow	yellow
Razer	Kraken V3	gaming with wires	red	red	red
Smyths Toys / eKids	Disney Die Eiskönigin Bluetooth Kinder-Kopfhörer lila	over ear child	green	green	green
Smyths Toys	Marvel Spider-Man Kinderkopfhörer mit Bluetooth	over ear child	green	green	green
claire's	Earbuds & winder caticorn	in-ear with wires	green	green	green

Manufacturer	Model	Product type	Evaluation of parts touching the skin	Evaluation of parts NOT touching the skin	Total product evaluation
Action / OTL Technologies	Super Mario earphones with Zip Case	in-ear with wires	red	yellow	red
Action / OTL Technologies	Pokémon Kids Headphones	over ear child	green	green	green
Stealth	C6 100 Light up Gaming Headset	gaming with wires	yellow	green	yellow
Kodak	Wireless Headphones Max 400+	over ear adult	yellow	green	yellow
kekz	blue headphones for audio-chips	over ear child	green	yellow	green
Oceania Trading	Paw Patrol kids headphones	over ear child	red	green	red
Hema nijntje / miffy	noise cancelling	over ear adult	green	red	red
Guess	Wireless headphones	over ear adult	green	red	red
Pepco Dasounds	Kids headphones basic	over ear child	green	green	green
GoGen	MAXISLECHY - white/blue	over ear child	green	red	red

ANNEX 2 – OVERVIEW OVER ANALYSED SUBSTANCES PER PRODUCT PART

Manufacturer	Model	Sample type	Soft plastic (leather imitation) touching the ear	Hard plastic	Wire
LifeBee	Digital Pro 40	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Picun	B8 Wireless Over ear Headphones	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Enjoy Music	M6pop cat ear	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates
JMMO	Kabellose Ohrhörer mit Premium-Klang, 5.3 Auto-Pairing Ohrhörer mit 14 Stunden Spielzeit, leicht, IPX4	in-ear wireless	none	bisphenols, brominated and organophosphate flame retardants	No
DONG QUAN SHUNXIN ELECTRONIC	Kinder Kabel Kopfhörer 3.5MM Hafen Einhorn Dekor	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates
Dongguan Yuanze Acoustics Technology	KZ EDX Pro In Ear Monitor Headphones Wired IEM Headphones Dual DD HiFi Stereo Sound	in-ear with wires	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates
Shenzhen Weiqi Technology	Cool Black In-Ear Headphones with Type-C Plug	in-ear with wires	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates
Niceboy	Hive Prodigy 4	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates
Marshall	Major V	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
AirPods	Max -2024	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Sony	WH-1000XM5	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
JBL	Tune 720BT	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No

Manufacturer	Model	Sample type	Soft plastic (leather imitation) touching the ear	Hard plastic	Wire
Sony	Ult Wear	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Beats	Solo 4	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Sony	WH-CH720N	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Jlab	Jbuds Lux ANC WIRELESS	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Sennheiser	Momentum Wireless 4	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Apple	AirPods Pro 2. Gen. USB-C	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Samsung	Galaxy Buds3 Pro	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
JBL	Tour Pro 3	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Sony	Noise Cancelling WF-1000XM5	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Sennheiser	Accentum True Wireless	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Sony	LinkBuds Fit	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
JBL	Wave Beam	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Silvercrest	True Wireless Bluetooth In-Ear	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Xiaomi	Redmi Buds 5 Pro	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Jlab	Jbuds Mini	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No

Manufacturer	Model	Sample type	Soft plastic (leather imitation) touching the ear	Hard plastic	Wire
Sony	WF-C510	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Jabra	Elite 10 Gen 2	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Marshall	Motif II ANC	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Tonies	Lauscher 2.gen	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates
Tigermedia	tigerbuddies	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
JBL	JR310BT	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
JLab	JBuddies Studio	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
ISY	IHP-1001-BL für Kinder, Blau	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates
Hama	184112 Bluetooth®-Kinderkopfhörer „Teens Guard“	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	
JVC	HA-KD7	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates
Skullcandy	Grom Kids Bluetooth Kopfhörer, Over-Ear, Black	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Fesh’n rebel	Clam Junior, Over-ear Kopfhörer für Kinder, Lucky Lizard	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
My first care	Care Buds blue	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Bose	QuietComfort Headphones	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Sennheiser	Accentum wireless	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No

Manufacturer	Model	Sample type	Soft plastic (leather imitation) touching the ear	Hard plastic	Wire
Bose	QuietComfort Ultra Earbuds	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Beats	Solo Buds	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Lisciani	Barbie fashion bluetooth headphones	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Buddyphones	Connect Foldbar wired headphones	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Lexibook	kids headphones Squads 200 - blue	in-ear wireless	none	bisphenols, brominated and organophosphate flame retardants	No
Gjby	Forever Wireless kids headphones Gjby CATEAR CA-028	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Lexibook	Foldable wireless headphones Harry Potter	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates
Huawei	Free Buds Pro 3 or 4	in-ear wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Philips	TAK4206	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Philips	SHD8850	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Panasonic	RB-HX220BDEK black, wireless headphone	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Logitech	G733 LIGHTSPEED wireless RGB Gaming Headset, black (981-000864)	gaming wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
SteelSeries	Arctis Nova 5 gaming headset	gaming wireless	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Haylou	S35 ANC Bluetooth headphone	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No

Manufacturer	Model	Sample type	Soft plastic (leather imitation) touching the ear	Hard plastic	Wire
Hama	Freedom Lit wireless Bluetooth headphone with microphone, pink (184199)	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Maxell	HP-BT350	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Nextly	NEXTLY wireless headphone with cat ears, foldable, adjustable, LED lights, Bluetooth 5.0, pink	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Onikuma	B90 With Cat Ears Pink	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Xinxu	Wireless stereo over ear headphone, Xinxu, Bluetooth, graffiti, white	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Qilive	136030 bluetooth headphone black (Auchan)	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Qilive	Kids 600168061 bluetooth headphone for kids 2in1 pink (Auchan)	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Qilive	600181408 gaming headset with wires (Auchan)	gaming with wires	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates
Corsair	HS80 RGB USB Carbon gamer headset	gaming with wires	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates
HyperX	Cloud III gaming headset	gaming with wires	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates
Onikuma	X26 gaming headset with wires pink (X26P)	gaming with wires	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates
Razer	Kraken V3	gaming with wires	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates

Manufacturer	Model	Sample type	Soft plastic (leather imitation) touching the ear	Hard plastic	Wire
Smyths Toys / eKids	Disney Die Eiskönigin Bluetooth Kinder-Kopfhörer lila	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Smyths Toys	Marvel Spider-Man Kinderkopfhörer mit Bluetooth	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
clair's	Earbuds & winder caticorn	in-ear with wires	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates
Action / OTL Technologies	Super Mario earphones with Zip Case	in-ear with wires	none	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates
Action / OTL Technologies	Pokéman Kids Headphones	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Stealth	C6 100 Light up Gaming Headset	gaming with wires	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates
Kodak	Wireless Headphones Max 400+	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
kekz	blue headphones for audio-chips	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Oceania Trading	Paw Patrol kids headphones	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Hema nijntje / miffy	noise cancelling	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Guess	Wireless headphones	over ear adult	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	No
Pepco Dasounds	Kids headphones basic	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates
GoGen	MAXISLECHY - white/blue	over ear child	bisphenols, SCCPs+MCCPs, phthalates	bisphenols, brominated and organophosphate flame retardants	bisphenols, SCCPs+MCCPs, phthalates

ANNEX 3 – LIST OF ANALYSED SUBSTANCES, METHODOLOGY ANALYSIS AND LOQ

Substance group	Group; method	Analyte	CAS number	LOQ (ng/g)
organophosphate flame retardants	aliphatic OPFRs; UHPLC-MS/MS (ESI+)1	TEP	78-40-0	<10
		TPrP	513-08-6	<0.025
		TiBP	126-71-6	<0.5
		TnBP	126-73-8	<0.5
		TBOEP	78-51-3	<0.25
		TEHP	78-42-2	<0.025
	aromatic OPFRs; UHPLC-MS/MS (ESI+)1	TPhP	115-86-6	<0.1
		CDPP	26444-49-5	<0.025
		∑TCP	1330-78-5	<0.025
		EHDPhP	115-88-8	<0.5
		iDDPP	29761-21-5	<0.25
		TIPPP	64532-95-2	<0.025
		TtBPP	78-33-1	<0.025
		TXP	25653-16-1	<0.025
	chlorinated OPFRs; UHPLC-MS/MS (ESI+)1	TCEP	115-96-8	<0.025
		∑TClPP	13674-84-5	<25
		∑TDClPP	13674-87-8	<0.05
		TTBNPP	19186-97-1	<0.25
	oligomeric OPFRs; UHPLC-MS/MS (ESI+)1	V6	38051-10-4	<0.05
		RDP	57583-54-7	<0.05
		BPA-BDPP	5945-33-5	<0.05
bisphenols	bisphenols; UHPLC-MS/MS (ESI-)2	BPA	80-05-7	<0.05
		BPB	77-40-7	<0.05
		BPC	79-97-0	<0.50
		BPE	66328	<0.50
		BPF	620-92-8	<0.25
		BPP	2167-51-3	<0.05
		BPS	80-09-1	<0.05
		BPZ	843-55-0	<0.05
		BPAF	1478-61-1	<0.05
		BPAP	1571-75-1	<0.05

Substance group	Group; method	Analyte	CAS number	LOQ (ng/g)
phthalates	phthalates and their alternatives; GC-MS/MS (EI)1	DMP	131-11-3	<5
		DEP	84-66-2	<50
		DiBP	84-69-5	<100
		DnBP	84-74-2	<0.25
		BBP	85-68-7	<5
		DMEP	117-82-8	<0.5
		DnPP	131-18-0	<0.25
		nPiPP	776297-69-9	<0.25
		DiPP	605-50-5	<0.25
		DnHP	84-75-3	<0.25
		DEHP	117-81-7	<150
		DcHP	84-61-7	<5
		DnOP	117-84-0	<100
alternatives to phthalates		DINCH	166412-78-8	<50
		TOTM	3319-31-1	<10
		DEHA	103-23-1	<100
chlorinated paraffins	chlorinated paraffins; GC-HRMS (NCI)3	SCCP	85535-84-8	<300
		MCCP	85535-85-9	<750

Substance group	Group; method	Analyte	CAS number	LOQ (ng/g)
brominated flame retardants	halogenated flame retardants; GC-MS (NCI)1 UHPLC-MS/MS (ESI-)1	PBDE 28	41318-75-6	<0.5
		PBDE 47	5436-43-1	<0.5
		PBDE 49	243982-82-3	<0.5
		PBDE 66	189084-61-5	<0.5
		PBDE 85	182346-21-0	<0.5
		PBDE 99	60348-60-9	<0.5
		PBDE 100	189084-64-8	<0.5
		PBDE 153	68631-49-2	<0.5
		PBDE 154	207122-15-4	<0.5
		PBDE 183	207122-16-5	<0.5
		PBDE 196	446255-39-6	<0.5
		PBDE 197	117964-21-3	<0.5
		PBDE 203	337513-72-1	<0.5
		PBDE 206	63387-28-0	<2.5
		PBDE 207	437701-79-6	<2.5
		PBDE 209	1163-19-5	<2.5
		BTBPE	37853-59-1	<1.0
		DBDPE	84852-53-9	<10
		Dec-602	31107-44-5	<0.5
		Dec-603	13560-92-4	<0.5
		anti-DP	135821-74-8	<0.5
		syn-DP	135821-03-3	<0.5
		DPTE	35109-60-5	<0.5
		EH-TBB	183658-27-7	<0.5
		HBBz	87-82-1	<0.5
		HCDBCO	1068659-48-2	<0.5
		OBIND	155613-93-7	<5.0
		PBEB	85-22-3	<0.5
		PBT	87-83-2	<0.5
		TBCO	3194-57-8	<0.5
		TBECH	3322-93-8	<0.5
		α-HBCD	134237-50-6	<2.5
		β-HBCD	134237-51-7	<2.5
		γ-HBCD	134237-52-8	<2.5
		TBBPA	79-94-7	<10

ANNEX 4 – METHODOLOGY

Methodology

- OPFRs (aliphatic, aromatic, oligomeric and chlorinated): liquid chromatography coupled with tandem mass spectrometry detection (UHPLC-MS/MS (ESI+))
- phthalates and their alternatives: gas chromatography coupled with tandem mass spectrometry detection (GC-MS/MS (EI))
- chlorinated paraffins: gas chromatography coupled with high-resolution mass spectrometry (GC-HRMS (NCI))
- halogenated flame retardants: chromatography coupled with mass spectrometry (GC-MS (NCI)) and liquid chromatography coupled with tandem mass spectrometry detection (UHPLC-MS/MS (ESI-)

Analytical methods: GC-MS (NCI)[1]
GC-HRMS (NCI)[3]
UHPLC-MS/MS (ESI-)[1,2]
GC-MS/MS (EI)[1]
UHPLC-MS/MS (ESI+)[1]

Sample preparation

1. For GC-MS (NCI), GC-MS/MS (EI), UHPLC-MS/MS (ESI+)
The target compounds were extracted three times using a mixture of n-hexane:dichloromethane (4:1, v/v), each extraction facilitated by ultrasonication for 30 min. The extract was evaporated, and the residue was dissolved in hexane. The sample was split into two parts. The first portion was transferred into methanol and analysed by ultra-high-performance liquid chromatography coupled with tandem mass spectrometry (UHPLC-MS/MS).

The second one was purified using a silica-based solid phase extraction (SPE) method, followed by evaporation and reconstitution in isooctane. This fraction was analysed using gas chromatography coupled with either single or tandem mass spectrometry (GC-MS, GC-MS/MS).

2. For UHPLC-MS/MS (ESI-)
The target compounds were extracted three times using a methanol:ethyl acetate mixture (1:1, v/v), with each extraction enhanced by ultrasonication for 30 min. Following solvent evaporation, the sample was analysed by UHPLC-MS/MS.

3. For GC-HRMS
The target compounds were extracted three times using a mixture of n-hexane:dichloromethane (4:1, v/v), with ultrasonication to each extraction step with the solvent exchange for 60 min. The extract was evaporated, dissolved in isooctane, and analysed using gas chromatography coupled with high-resolution mass spectrometry (GC-HRMS).

ANNEX 5 – DETAILED EVALUATION CRITERIA AND CONCENTRATION LIMITS

1. Substance-Specific Evaluation Criteria

A “traffic light” system was applied to evaluate each substance group.

Chlorinated paraffins

For the cumulative SCCPs and MCCPs concentrations, the limits applied are derived from RoHS as well as OEKO-TEX® 100 Standard. The legal limit (0.15% = 1,500 mg/kg) is used as a cut-off between red and yellow samples, green rating must meet the OEKO-TEX® 100 standard for textiles (European Parliament and the Council of the EU, 2022; OEKO-TEX®, 2025).

Table 13. Evaluation of SCCPs and MCCPs.

Concentration of SCCP + MCCP above 1,500 mg/kg (POPs regulation limit for SCCPs)
Concentration of SCCP + MCCP between 50–1,500 mg/kg
no content or concentration below 50 mg/kg (OEKO-TEX® 100 limit)

Phthalates

Phthalates are evaluated differently depending on their classification as CMRs.

Table 14. Evaluation of phthalates.

Concentration of a single phthalate is above 1,000 mg/kg (limit applied in RoHS)
contains phthalates classified as CMRs between 10–500 mg/kg, concentration of other phthalates between 10–1,000 mg/kg
no content or concentration below 10 mg/kg

Halogenated flame retardants (including brominated flame retardants)

Samples were evaluated based on their **CMR substance content** and the potential cumulative effects of chemical mixtures. The methodology accounted for the high chemical complexity found in certain products, where up to 10 distinct HFRs were identified, including several substances known for their carcinogenic, mutagenic, or reprotoxic risks.

Table 15. Evaluation of brominated flame retardants.

SVHC or substance classified as CMR present above 0.1% OR 5 or more SVHCs present (at least one above 5 mg/kg)
5–1,000 mg/kg of SVHCs or substances classified as CMRs
no content of SVHCs or substances classified as CMRs above 5 mg/kg, no other HFRs above 0.1% (1,000 mg/kg)

Organophosphate flame retardants (OPFRs)

Similarly, **OPFRs** were evaluated based on the presence of **CMR substances** and the cumulative ‘mixture factor’ because of the high chemical complexity observed in several products, which contained as many as **12 distinct OPFRs**, including substances with established carcinogenic, mutagenic, or reprotoxic (CMR) classifications.

Table 16. Evaluation of OPFRs.

SVHC or substance classified as CMR above 0.1% OR 5 or more SVHCs present (at least one above 5 mg/kg)
5 - 1,000 mg/kg of SVHCs or substances classified as CMRs
no content of SVHCs or substances classified as CMRs or concentrations above 5mg/kg, no other OPFRs above 0.1% (1,000 mg/kg)

Bisphenols

For components in **direct contact with the skin**, the assessment utilized the **Scientific Committee on Consumer Safety (SCCS)** safety limit of **0.8 mg/kg**, a benchmark originally established for textiles (SCCS, 2021). However, a **correction factor of 10** was applied to this threshold to account for the significantly smaller skin surface area covered by headphones compared to full-body garments.

In contrast, components categorised as having **indirect skin contact** were assessed using a higher concentration threshold. This evaluation was based on the **10 mg/kg limit** originally outlined in the ECHA restriction proposal for bisphenols (ECHA, 2022). Notably, this 10 mg/kg value remains the current standard for bisphenol concentrations in textiles under the **OEKO-TEX® Standard 100** (OEKO-TEX®, 2025).

Table 17. Evaluation criteria for bisphenols.

bisphenols in parts touching the skin	bisphenols in parts NOT touching the skin
Content of bisphenols above 8 mg/kg (10 times above the maximum concentration of BPA in textiles calculated by SCCS)	Content of bisphenols above 10 mg/kg (the limit suggested by the ECHA restriction proposal)
Concentrations between 0.8–8 mg/kg	Concentrations between 0.8–10 mg/kg
No content or concentration below 0.8 mg/kg	No content or concentration below 0.8 mg/kg

2. Overall Evaluation

The final, consolidated product rating was derived by integrating the results from two distinct exposure categories:

- **Primary Exposure (Direct Contact):** This includes components in constant or prolonged contact with the skin, such as the **ear cushions** of over-ear models and the **entirety of the housing and tips** for in-ear models.
- **Secondary Exposure (Indirect Contact):** This includes structural elements that typically do not maintain direct skin contact, such as **hard plastic headbands** and **external wiring**.

The following scheme was applied to receive a single rating for the entire product.

Table 18. Evaluation scheme for the entire product – final product evaluation.

Evaluation of parts touching the skin	Evaluation of parts NOT touching the skin	Total product evaluation
green	green	green
green	yellow	green
green	red	red
yellow	green	yellow
yellow	yellow	yellow
yellow	red	red
red	green	red
red	yellow	red
red	red	red

The final product rating is heavily weighted toward components with **direct dermal interface**, as these pose the highest risk of chemical migration and uptake. Consequently, materials in contact with the ear exert a significantly greater influence on the overall score than external wiring or outer structural parts.

To ensure consumer safety, a **"worst-case" override** was applied to the scoring logic: if any single component is rated **"red"** due to hazardous chemical concentrations, the entire product automatically receives a **"red"** rating, regardless of the performance of its other parts.

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