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Restricted but Still Present: Scope and Transparency of RoHS Exemptions for Hazardous Substances in Electrical and Electronic Equipment

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Abstract

The SCIP database currently lists nearly 18 million articles associated with electrical and electronic equipment (EEE) containing RoHS-restricted substances above the applicable threshold, raising fundamental questions about the overall effectiveness of the RoHS Directive. While the restriction applies to nearly all EEE categories, exemptions permit the continued use of restricted substances where substitution is not yet feasible. However, the continued high prevalence of RoHS-restricted substances in SCIP may indicate that exemption use remains widespread. This study provides a systematic analysis of the RoHS exemption process. The median time between submission and decision is at least 6.1 years, substantially exceeding the intended time frame. Three hotspot exemptions (Nos. 6(c), 7(a), and 7(c)-I) were identified, all material- rather than application-specific, associated with large estimated lead quantities entering the EU market, and characterized by an insufficiently specified scope. Transparency regarding these exemption use remains critically low, making it impossible to estimate total quantities of restricted substances entering the EU market and leaving market surveillance authorities, waste operators, and customers without the information needed to verify legitimate use. Mandatory disclosure of exemption use would improve market surveillance, accelerate exemption specification, and create competitive pressure to phase out exemption use in favor of sustainable alternatives.

Keywords: RoHS directive; hazardous substances; exemption process; electronic and electrical equipment; lead; sustainable electronics; information transparency; market surveillance; SCIP database; sustainable industrial development

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1. Introduction

Electrical and electronic equipment (EEE) is one of the key product value chains in the European Circular Economy Action Plan (CEAP) [1]. However, the EU recycling rate for E-waste reached only 31.7% in 2023 (calculation based on indicator 6d according to [2] and data from [3]), which reflects persistent deficiencies in waste management, particularly regarding E-Waste collection, and the absence of sound material cycles. EU regulations such as Directive 2011/65/EU on the restriction of the use of certain hazardous substances (RoHS) in electrical and electronic equipment [4] directly address this by restricting the use of hazardous substances in EEE placed on the EU market, thereby making recycling safer, cleaner and more cost-efficient and contributing in a broader sense to the United Nations Sustainable Development Goals 3 (good health and well-being) and 12 (responsible

consumption and production). Furthermore, as the sister to Directive 2012/19/EU on waste electrical and electronic equipment (WEEE) [5], RoHS directly targets hazardous substances in EEE, based on the premise that end-of-life collection and treatment processes are insufficient to fully mitigate the environmental and health risks associated with these substances [6].

The ten restricted substances under RoHS comprise lead (Pb), cadmium (Cd), mercury (Hg), hexavalent chromium (Cr^{VI}), two groups of brominated flame retardants (PBB and PBDE), and four phthalates (DEHP, BBP, DBP and DIBP). Maximum tolerated concentration by weight in homogenous materials of EEE are 0.01% for Cd and 0.1% for all other substances (Annex II). Even though only Pb, Cd, and Hg are listed as restricted substances, the restriction also includes compounds of these materials, e.g., cadmium oxide (CdO), lead sulphide (PbS), or mercury chloride ($HgCl_2$). However, the 0.1/0.01% (*w*/*w*) threshold applies to the elemental content of the restricted substance within the homogeneous material, not to the concentration of the compound itself.

The directive covers nearly all EEE classified into 11 product categories as listed in Annex I (see also Supplementary Materials, Table S1). However, certain equipment is explicitly excluded from the directive's scope, including EEE designed exclusively for military or space applications, large-scale stationary industrial tools and fixed installations and equipment that is itself a component of another excluded product (for a complete list of exclusions, see Article 2(4)(a–k)).

The manufacturer guarantees that the EEE complies with the RoHS requirements by providing an EU declaration of conformity (Article 13) and a visible CE marking on the product (Article 14 and 15). If a company is based outside of the EU and wants to sell on the EU market, a responsible economic operator established within the EU is required (Article 4(1), Regulation (EU) 2019/1020) [7]. Further, importers have to verify that the EEE bears the CE marking and that the EEE fulfil the requirements of the directive, e.g., that the conformity assessment procedure has been carried out by the manufacturer, and that the manufacturer has drawn up the technical documentation. To some extent, these obligations also apply to the distributors (Article 7(b), 9 and 10).

The directive enables the temporary allowance of restricted substances in specific applications where substitution is not feasible yet. Exemptions can be granted by the commission according to Article 5 and are listed in Annex III (for all categories) and IV (for categories 8 and 9, i.e., medical devices and monitoring and control instruments). The validity period is up to 5 years for categories 1–7, 10 and 11 and 7 years for the categories 8 and 9. However, the validity period is to be decided on a case-by-case basis (Article 5(2)). Application for renewal of an exemption should be submitted no later than 18 months before the exemption expires, whereby existing exemptions remain valid until an evaluation of a renewal request is conducted (Article 5(5)). In case of rejection, a transition period between 12 and 18 months is granted before the exemption expires (Article 5(6)).

For a renewal request, detailed administrative, technical, and regulatory information to justify why a restricted substance should remain permitted is necessary. The applicant should clearly define the scope and wording of the exemption including a technical description of the application, the relevant EEE categories, the substance concerned, its function, concentration, and the estimated annual amount entering the EU market. Applicants are also expected to describe the material or component in which the substance is used and the particular characteristics and functions of the restricted substances in this material or component. Applicants should further outline ongoing efforts to develop substitutions, actions that have been taken, steps that are necessary for the establishment, and a respective time frame needed to complete these steps [8].

The European Commission conducted a general review of the RoHS Directive in 2023, as required under Article 24(2), supported by two complementary studies. The review of EU rules on the restrictions of hazardous substances in EEE together with the provision of guidance to improve coherence with relevant legislation, including the Regulation (EC) No 1907/2006 on the registration, evaluation, authorization and restriction of chemicals (REACH) [9] and the Regulation (EU) 2024/1781) establishing a framework for the setting of ecodesign requirements for sustainable products (ESPR) [10], is also one of the actions outlined in the CEAP [1]. The first study to support the general review, published in 2021, assessed the Directive's general effectiveness, efficiency, and relevance, while the second, published in 2023, built on these findings to, among other aims, identify and analyze policy options for the areas of improvement identified [11,12].

The review found that the use of hazardous substances restricted under the RoHS Directive in EEE had been reduced by approximately 67% since the Directive's initial introduction in 2003, with Pb in WEEE decreasing by 20% between 2011 and 2015 [12]. However, this estimate should be seen as an indication of reduction, as limited baseline data exists on the amounts of hazardous substances present in EEE either prior to or following the introduction of RoHS, and it therefore relies on scenario estimations [12].

At the same time, the exemption process was characterized as complex, insufficiently transparent, and slow, with a large number of renewal applications accumulating since 2016 alongside increasing technical complexity. To address these shortcomings, a revision of the exemption process was recommended, including the introduction of individual validity periods, standard evaluation timelines, and a transfer of the exemption request evaluations to the European Chemicals Agency (ECHA) in line with the 'one substance, one assessment' principle of the Chemicals Strategy for Sustainability [11–13].

While the evaluation of exemption requests will be transferred to ECHA starting on 13 August 2027 [14], apart from the inclusion of new exemptions from the restrictions, no further changes have been conducted after the RoHS revision. Moreover, in its Report on the review of the RoHS Directive the EU Commission stated that "Given the above and in view of other prioritized initiatives under the CEAP, at this stage this general review of the RoHS Directive, as required by Article 24(2), will not be accompanied by a revision of the Directive but by a targeted amendment as regards the re-attribution of scientific and technical tasks to ECHA" [15].

A previous study regarding the RoHS Directive by Deubzer [16] estimated the changes in quantities of Pb, Cd, Cr^{VI}, and Hg in EEE between 2006 and 2019 across the most relevant Annex III exemptions. While some exemptions showed only a minor reduction over this period, as in the case of exemptions 6(a/b/c) and 7(a), other exemptions that had been further specified, such as No. 8(b), showed a measurable decrease following their specification. However, these figures represent rough estimations, and quantifying the amount of hazardous substances in EEE placed on the market was identified as one of the central challenges in assessing the RoHS Directive's effectiveness [11,12].

An indirect source of information on hazardous substance use in EEE is provided by the Substance of Concern in Products (SCIP) database [17], which requires suppliers to notify to ECHA when articles contain Substances of Very High Concern (SVHCs) above 0.1% (*w*/*w*). As several RoHS-restricted substances are simultaneously classified as SVHCs, SCIP notifications may offer complementary insights into the presence of these substances in EEE on the EU market. Recent analysis of this database found that 17,567,988 notified articles corresponding to EEE include substances which fall under the RoHS Directive, while 17,299,684 of these articles (98.5%) contain Pb in concentrations above 0.1% (*w*/*w*) [18].

Assuming that the high number of articles reported through SCIP containing RoHS-restricted SVHCs are not illegally placed on the EU market, it is hypothesized that a

wide range of these articles fall under a valid RoHS exemption. However, as the SCIP database does not provide further information about the specific products containing SVHCs restricted under RoHS nor about the quantity of these substances entering the EU market, the dimension of the RoHS exemptions has been further evaluated in this work. Moreover, examining both instruments together may reveal structural problems or data gaps in the information availability along the product chain, from the use of RoHS exemptions at the product design stage through to the hazardous substance information reaching end-of-life operators, market surveillance and consumers.

This study therefore provides a systematic quantitative analysis of the RoHS exemption process, examining the scope, duration, and transparency of currently valid exemptions. The findings contribute to a better understanding of the extent to which exemption use limits the overall effectiveness of the RoHS Directive in reducing hazardous substances in EEE, and provide a basis for improving both the exemption process and the transparency of hazardous substance information along the supply chain.

2. Materials and Methods

2.1. Evaluation of the SCIP Database

The SCIP data used in the present study were based on the results reported by Schulze, Hess and Sperlich [18]. In that study, 1653 TARIC codes considered relevant to EEE were submitted to the ECHA, which subsequently provided an extract of the corresponding SCIP notifications. The resulting dataset comprised 160,033 records corresponding to 22,663,018 notified articles potentially related to EEE. Filtering for substance identities corresponding to substances restricted under Annex II of the RoHS Directive identified 17,567,988 notified articles, of which 17,299,684 were associated with Pb and its compounds at concentrations above 0.1% (w/w). These notified articles formed the basis for the present study. As the substance information in the ECHA extract was linked to the bottom-level article category, only bottom-level articles, i.e., the lowest level of a notified complex object at which the substance of concern was reported, were considered.

For example, in a laptop containing a lead-soldered circuit board, the circuit board (not the laptop) constitutes the bottom-level article. The complete selection of TARIC codes, data-filtering procedure, and assignment of substance identities to the respective regulatory requirements are documented in the Supplementary Information provided by Schulze, Hess and Sperlich [18].

2.2. Evaluation of RoHS Exemptions

To evaluate the effectiveness of the RoHS Directive and the scope of its exemptions, a comprehensive analysis of the exemption process was conducted. For the purposes of this study, an exemption is defined as an individual entry under Annex III or Annex IV, with further specified sub-exemptions counted as separate exemptions. In Annex III for example, 6(a), 6(a)-I, and 6(a)-II are treated as three distinct exemptions. This approach is justified as sub-exemptions are subject to independent evaluation, require a separate renewal request, have their own validity period, and may outlive their original broader-scoped exemption.

The analysis focused on publicly available data sources, in order to assess the extent to which information on RoHS exemptions and their scope is accessible to the general public. Therefore, for the quantitative analysis of exemptions, including processing time and distribution of exemptions across substances and EEE categories, the ‘Validity and Rolling Plan’ published by the European Commission on 28 February 2026 was used as the primary data source [19]. This publication date was adopted as the study reference date and all references to ‘valid’ exemptions throughout this study refer to the status recorded on 28 February 2026.

The Validity and Rolling Plan is an Excel spreadsheet, which lists all exemptions, alongside additional information on applicable EEE categories, start and end dates, the last permissible dates for the submission of renewal requests, and the dates of existing requests. The validity status of each exemption is categorized as follows: 'valid' (exemption within its normal operational period); 'no longer valid' (exemption past its end date); 'valid—requested for renewal' (renewal request was submitted in time, 18 months before exemption expired); 'valid—no longer renewable' (an exemption for which no application for renewal was submitted in time. The exemption remains valid until the end date); 'not applicable—request under assessment'; 'request withdrawn'; and 'decision included in another exemption'.

Within the dataset, individual exemptions are frequently listed multiple times, typically between one and five entries, as start dates or renewal request dates may differ across EEE categories (see Table 1 for an illustrative example). To capture the full scope of the exemptions across all relevant EEE categories, the analyses in this study were based on the number of final exemptions (e.g., 13(a)) and on the number of submitted exemption requests (e.g., five times exemption 13(a)). However, the analyses were restricted to exemptions that are valid, either because their end date has not yet passed or because a renewal request was submitted in time, maintaining the exemption's validity until a decision by the Commission is reached eventually.

Table 1. Example of multiple exemption requests associated with a single exemption in the EU Validity and Rolling Plan [19].

Exemption	Applicable to Categories:	Start	End	(Renewal) Request	Validity Status
Annex III n. 13(a)	1 to 7 and 10	22 July 2011	21 July 2021	28 November 2019	Valid—requested for renewal
Annex III n. 13(a)	8 and 9 other than in vitro and industrial	22 July 2014	21 July 2021	28 July 2019	Valid—requested for renewal
Annex III n. 13(a)	8 in vitro	22 July 2016	21 July 2023	28 July 2019	Valid—requested for renewal
Annex III n. 13(a)	9 industrial	22 July 2017	21 July 2024	28 July 2019	Valid—requested for renewal
Annex III n. 13(a)	11 other EEE	22 July 2019	21 July 2024	28 July 2019	Valid—requested for renewal

Decision times for exemption requests were calculated for exemptions with the validity status: 'Valid—requested for renewal'. As these decisions remained pending at the study reference date (28 February 2026), the calculations presented in this study represent the already required but not yet finalized processing time.

As Pb is the substance with the highest number of notified articles in the SCIP database, a more detailed evaluation of exemptions covering Pb was conducted to quantify their scope and estimate the amount of Pb entering the European market through their use. This analysis focused on EEE of categories 1–7, 10, and 11, as category 8 (medical devices) and category 9 (monitoring and control instruments) hold a special position within the RoHS framework since they are subject to different validity periods, and additional exemptions explicitly concerning category 8 and 9 are listed in Annex IV, while all other exemptions are listed in Annex III.

However, as these EEE are only produced in low numbers compared to other categories, they only add a negligible amount to the total volume of EEE [16].

Recent exemption requests were evaluated in consolidated, thematic packages by, among others, the Oeko-Institut, Fraunhofer Institut for Reliability and Microintegration

(IZM), the United Nations Institute for Training and Research (UNITAR), and BIO Innovation Services (Bio IS) [20]. The reports on these exemption request packages are extensive documents that summarize applicant responses, both from the initial exemption application and subsequent clarification rounds, and subject them to critical review. This critical review includes the availability of substitutes, environmental and health impacts, and the scope of the exemption. Each report concludes with an explicit recommendation, including a proposed exemption wording and duration.

In detail, information on the scope of Pb-related exemptions, including possible applications, exemption history, applying companies, and estimated amounts of Pb entering the market, report Packages 22, 23, 24, and 28 of the Oeko-Institut, Fraunhofer IZM, UNITAR, and Bio IS [21–24] were evaluated, covering the majority of valid Pb-related exemptions.

Where Pb quantities were reported as 'less than x', the value x was used as a conservative upper bound. For exemptions with substantially diverging estimates, both the minimum and maximum values are included in the manuscript. Exemptions for which no quantitative estimate was available were excluded from the quantity-based analysis.

3. Results

3.1. Review of RoHS Exemptions

Based on the Exemptions Validity and Rolling Plan dated 28 February 2026, a total of 85 valid exemptions and 138 exemption requests are listed as valid. By EEE category, the highest number of exemption requests relates to Category 9 (monitoring and control instruments) and Category 8 (medical devices), followed by Category 5 (lighting equipment) and Category 1 (large household appliances) (Figure 1a). Most exemptions cover more than one category, with 18 requests covering all EEE categories and 17 covering eight categories. Exemption requests covering only a single category predominantly relate to Categories 8, 9 or 11 (81%), while those covering two categories are mostly confined to Categories 8 and 9 (97%). In total, 74 of the 138 exemption requests cover Categories 8 and 9 exclusively (Figure 1b).

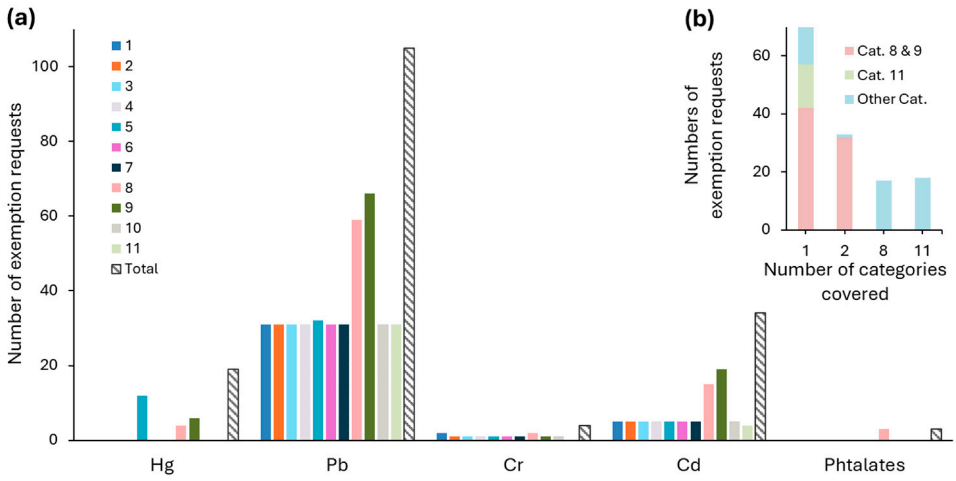


Figure 1. (**a**) Number of valid RoHS exemption requests per equipment category for categories 1 to 11, grouped by restricted substance. The hatched bar represents the total number of exemption requests covering that substance, irrespective of category. Note that individual exemption requests may cover more than one substance and typically more than one category and totals across substances and categories therefore exceed the overall number of exemption requests. (**b**) Exemption requests and the number of categories they cover. Exemption requests covering 3–7 or 10 categories do not exist and are therefore absent from the figure.

The majority of current exemptions concern the use of Pb above the 0.1% (w/w) threshold, accounting for 71% of all valid exemptions and covered by 105 exemption

requests. Cd and Hg are the next most frequently restricted substances, each accounting for 19% of all exemptions and covered by 34 and 19 exemption requests, respectively. Cr^{VI} and phthalates are addressed only rarely, each contributing to 4% of all exemptions and covered by 4 and 3 exemption requests, respectively (hatched bars in Figure 1a). It should be noted that individual exemptions may cover more than one restricted substance and consequently, the sum of percentages across substances exceeds 100%.

Renewal requests for RoHS exemptions must be submitted at least 18 months before the expiry date of the respective exemption. Figure 2a illustrates the number of days between this 18-month submission threshold and the actual dates on which requests were submitted. While 25% of requests were submitted within five days and 75% within 737 days before the 18-month deadline, some requests were submitted more than three years ahead of this threshold. Notably, in minimum 8 cases, a renewal request was filed within just 10 days after the corresponding exemption had entered into force.

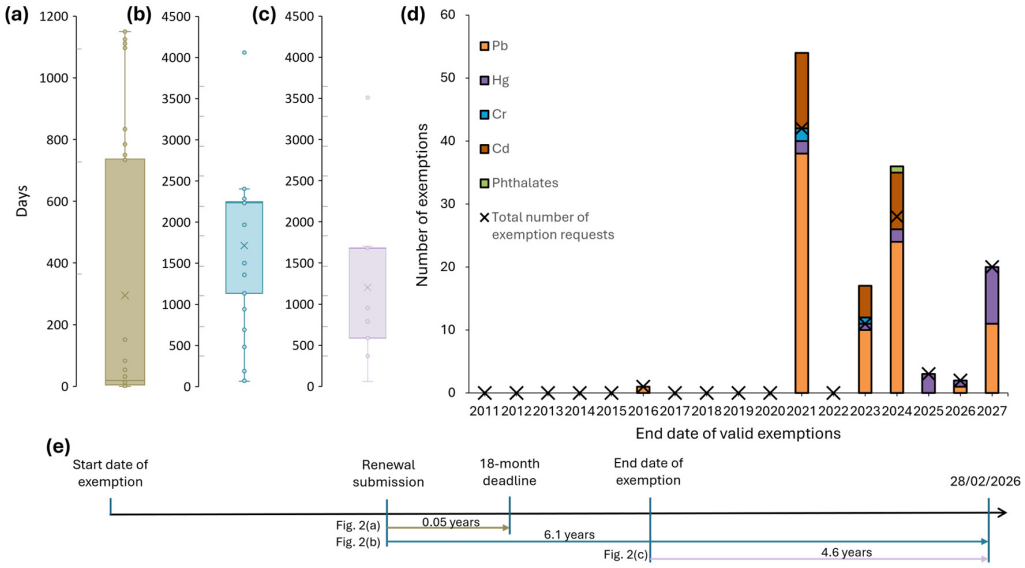


Figure 2. Temporal characteristics of valid RoHS exemptions for which a renewal request has already been submitted as of the reference date of this study (28 February 2026). (**a**) Number of days between the actual date of submission and the regulatory deadline for submitting a renewal request (18 months before the exemption's expiry date); positive values indicate submission ahead of the deadline. (**b**) Number of days between the date of submission and the study reference date. (**c**) Number of days between the exemption's end date and the study reference date. (**d**) Temporal distribution of these exemptions' end dates, broken down by restricted substance with crosses (×) indicating the total number of exemption requests. As individual exemption requests may cover more than one substance, the sum of values across substances exceeds the total number of exemption requests as they are, for example, double counted once under Pb and once under Cd. (**e**) Schematic overview of time horizons calculated in (**a**–**c**) with median values of the respective time period. In panels (**a**–**c**), grey horizontal lines indicate full-year intervals to aid orientation. The data frequency distributions for (**a**–**c**) have been added to the Supplementary Materials (Figure S1).

To assess the duration of the Commission's decision-making process, valid exemptions with open renewal requests were analyzed using the exemption overview provided by the European Commission. As only those exemptions for which the decision was still open by the threshold date of this study (28 February 2026) are included, this calculation only represents the already required but not yet finalized processing time. The median time for requests that remained undecided is 6.1 years (mean: 4.7 years) (Figure 2b).

However, since many companies submit renewal requests significantly earlier than the 18-month deadline, and it is unlikely that the Commission processes these requests

substantially ahead of that deadline, the time between submission date and decision may overestimate the actual processing time. Figure 2c therefore presents the days between expiry dates of exemptions and the threshold date of this study (for a graphical explanation see also Figure 2e).

In median, 4.6 years lay between the expiry date of these exemptions and the study threshold date (mean: 3.3 years), with one exemption requested for renewal already expired in 2016, 42 in 2021, 11 in 2023 and 28 in 2024 (crosses in Figure 2d). Most recent expired exemptions covered Pb and Hg, while previous expired exemptions also covered Cd and Cr^{VI} (Figure 2d).

3.2. Lead Exemptions in RoHS

The focus on exemptions covering Pb and categories 1–7, 10 and 11 in Annex III, involves 44 exemption requests and 37 exemptions (Figure 3a), similarly distributed over the categories. 23 out of 44 exemption requests are applicable to all categories, while 7 exemptions cover all categories except category 11. One exemption simply includes category 5 (No. 18(b) I) and 6 exemptions simply include category 11 (Figure 3b).

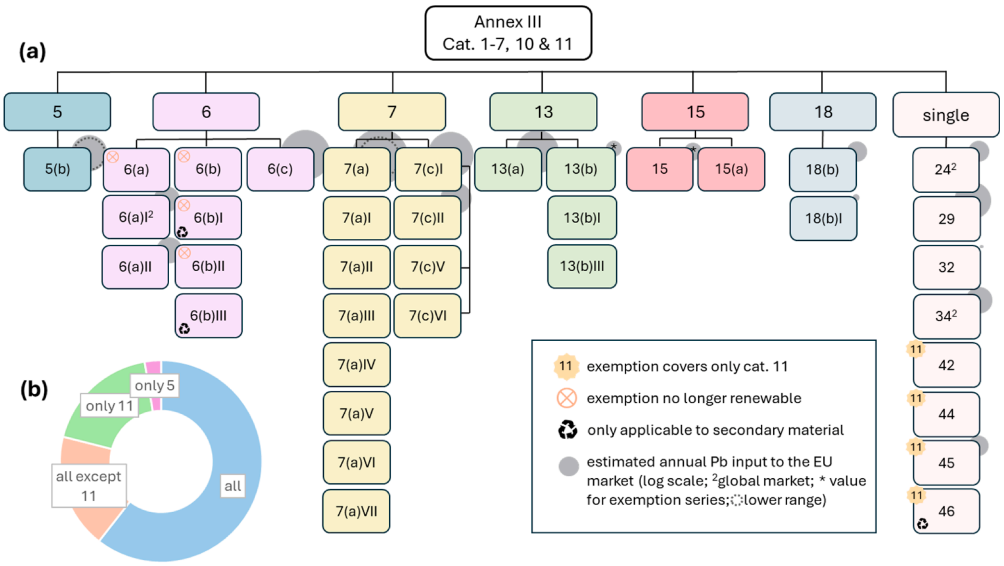


Figure 3. Overview of exemptions in Annex III for categories 1–7, 10 and 11 in (**a**) symbols within the graph are estimations based on the information from technical assessment reports [21–25] and delegated acts published by the European Union. (**b**) Distribution of exemptions according to their category coverage.

Analyses of the technical assessment reports [21–24] provided detailed insight into the scope of individual exemption requests. The majority of requests are submitted by the RoHS Umbrella Industry Project, a consortium of companies from across the globe, while others are submitted by specific companies, such as Lumentum or Roehm GmbH, or by European industry associations such as LightingEurope. In some cases, individual applications are described in detail making it possible to define the specific scope and the influenced categories falling under the exemption (examples No. 29, Pack 24 [22]; No. 13(a), Pack 7 [25]). Other exemptions, however, are material- rather than application-specific, covering a broad and partly unknown range of applications (e.g., Nos. 7(a) and 6(b)). Please note, a detailed overview of the exemptions including their scope, expire date and additional information is provided in the Supplementary Table S2.

Where sufficient information on specific use cases is available, the technical assessment reports occasionally propose a structural refinement of broadly formulated exemptions through specialization. For exemption No. 7(a), for instance, distinct application groups

were identified and proposed as individual sub-exemptions No. 7(a)-I through 7(a)-VII (Table S2) [21]. Concurrently, a short-term extension of the general exemption until 21 July 2024 was recommended, providing a transitional period during which stakeholders could submit applications for the inclusion of additional application groups. While the proposed sub-exemptions were subsequently adopted by the European Commission, the general exemption under No. 7(a) remains valid [26] and, according to the Commission's official exemption validity and rolling plan [19], continues to be eligible for renewal upon application. A comparable approach is reflected in exemptions No. 7(c)-I through 7(c)-V and 7(c)-VI, which similarly delineate specific functional applications within a broader exemption category [27].

Finally, it is noted that the recommended expiry dates proposed in the technical assessment reports partly fall before a final decision is made by the Commission. For example, Annex III No. 34 was recommended to expire on 21 July 2024 for all equipment categories [22]. However, at the time of this analysis, no Commission decision had yet been made. A similar situation applies to No. 6(a)-I, which was also recommended to expire on 21 July 2024 [21]. The corresponding delegated directive was ultimately published by the Commission in September 2025, after the recommended expiry date had passed, resulting in a delay of approximately two years and a revised deadline of 2027 [28].

3.2.1. Amount of Lead per Year Entering the European Market

The exemption request form requires applicants to specify the annual quantity of the restricted substance entering the EU market through the application in question. However, the level of detail varies considerably across submissions. For narrowly defined exemptions, such as No. 18(b) (lead as activator in fluorescent powder used in sun-tanning lamps), explicit quantitative data are provided: the relevant assessment report states that sun-tanning lamps account for 190 kg of Pb a^{-1} [22]. In contrast, many requests with a broader scope provide no quantitative estimates, while others rely on extrapolations associated with considerable uncertainty.

The highest annual quantities of lead entering the European market were identified for No. 7(a) (lead in high-melting temperature solders (LHMPSs) (i.e., lead-based alloys containing 85% by weight or more lead)). However, estimates of Pb amounts entering the EU market per year for this exemption diverge substantially: the RoHS Umbrella Project reported approximately 150 t a^{-1}, whereas the consultant estimated up to 20,000 t a^{-1} [21] and the first-place ranking holds only when adopting the consultant's estimates. Given the considerable uncertainty inherent in both estimates, these numbers cannot be regarded as definitive totals. Nevertheless, as the consultant notes, "one issue is clear, i.e., the amount of lead used under this exemption is not negligible" [21] (p. 122).

The second- and third-highest quantities were identified for No. 6(c) (copper alloys containing up to 4% lead by weight) and No. 7(c)-I (lead in glass and ceramics other than dielectric ceramics in capacitors), with approximately 2500 t a^{-1} and up to 750 t a^{-1}, respectively [21]. At the lower end smallest amounts were found for exemption No. 32 (lead oxide [...] for Argon and Krypton laser tubes) with less than 1 kg lead a^{-1} and No. 18(b)-I (Lead as activator in the fluorescent powder [...] in medical phototherapy equipment) with 2.5 kg a^{-1} [22]. All available quantity estimates extracted from the technical assessment reports are represented as circles in Figure 3, with circle diameter scaled proportionally to the logarithm of the estimated annual quantity. However, it should be noted that most values carry substantial uncertainty, and the visualization is intended to provide an approximate comparative overview of the relative magnitudes across exemptions in Annex III considering Pb and the categories 1–7, 10 and 11.

3.2.2. Exemptions Permitting Lead from Secondary Materials

Certain exemptions permit Pb concentrations above the 0.1% threshold as a consequence of secondary material use. Exemptions Nos. 6(b)-I, -III ([. . .] from lead-bearing aluminium scrap recycling), and No. 46 (Cadmium and lead in plastic profiles containing mixtures produced from polyvinyl chloride waste [. . .]) explicitly permit Pb above the threshold solely due to the use of secondary material and are therefore indicated with a recycling symbol in Figure 3.

3.3. Combining SCIP Notifications and RoHS Exemptions

The idea of analyzing the RoHS Directive and its exemptions in greater depth arose from a SCIP article analysis conducted by Schulze, Hess and Sperlich [18], which revealed a large number of articles on the European market containing substances restricted under the RoHS Directive. As non-compliant articles are not expected to be intentionally notified in SCIP, these substances are likely present under valid RoHS exemptions. This suggests that SCIP notifications of RoHS-restricted substances could, in principle, serve as a proxy indicator for RoHS exemption use in different applications. However, a direct comparison between SCIP notifications and RoHS exemption use is not straightforward and limited by several structural differences between the two instruments, which can lead to both an over- and underestimation of the number of articles relying on a RoHS exemption (Figure 4). These differences are outlined in the following section.

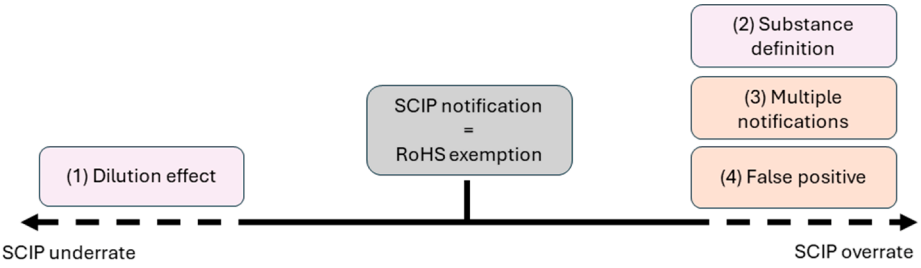


Figure 4. Schematic illustration of structural factors causing discrepancies between SCIP notifications and actual RoHS exemption use. Factor (1) leads to an underestimation of RoHS exemption use when SCIP notifications are used as a proxy, while factors (2), (3), and (4) lead to an overestimation. Factors (1) and (2) arise from fundamental differences in substance definitions and reference levels (shown in pink); factors (3) and (4) result from limitations inherent to the SCIP reporting system (shown in orange).

First, the RoHS Directive applies substance restrictions to homogeneous materials (Appendix A.1), whereas SCIP notifications refer to articles (Appendix A.2). Second, RoHS restricts the elemental content (e.g., Pb, Cd and so one) in homogeneous materials above 0.1%, or in the case of Cd above 0.01% (*w*/*w*), while REACH, and by extension SCIP, includes provisions on the notification of elementary substances as well as of specific compounds (e.g., lead oxide) above 0.1% (*w*/*w*). These differences can lead to the following two discrepancies:

1. Dilution effect: The reference level of SCIP notifications, the article, may lead to a dilution effect, whereby the SVHC concentration falls below the 0.1% (*w*/*w*) notification threshold, even though the homogeneous material within the article exceeds this threshold. For example, lead-containing solder is a homogeneous material in which Pb may exceed 0.1% (*w*/*w*) when covered by a valid RoHS exemption (e.g., Annex III, exemption 7(a)). When this solder is now used to join two articles it becomes part of the resulting complex item (after definition an article by itself) and would require a SCIP notification, if the Pb concentration in the complex item exceeds 0.1% (*w*/*w*).

However, due to the dilution of Pb within the total mass of the complex item, the concentration may fall below this threshold and therefore no SCIP notification would be required even if the solder contains an SVHC substance above 0.1%.

2. Substance definition mismatch: An article may require SCIP notification due to a Pb compound listed as an SVHC in the candidate list exceeding 0.1% (*w*/*w*), while remaining fully RoHS-compliant because elemental Pb does not exceed 0.1% (*w*/*w*). For example, if an article consists of a single homogeneous material containing lead oxide (PbO) at slightly above 0.1% (*w*/*w*), the article is subject to a SCIP notification. However, since elemental lead constitutes only approximately 0.09% by weight of that homogeneous material, and RoHS applies its threshold to the elemental substance in the homogeneous material, the article remains RoHS-compliant without the use of an exemption.

Beyond these conceptual differences, two additional limitations inherent to the SCIP reporting system itself further complicate a direct comparison:

3. Multiple notifications of the same article: Any EU-based manufacturer, importer or distributor placing an article on the market which contains an SVHC above 0.1% (*w*/*w*) is required to submit a SCIP notification, regardless of whether the article is a single inseparable component or a complex item such as a laptop comprising numerous sub-components. Following this structure, the same article may be notified multiple times across the supply chain of a product. The same applies where two companies incorporate the same SVHC-containing article into their respective complex items, both are independently obliged to report it. To avoid such duplicate notifications, SCIP provides a referencing mechanism which allows obligated operators to reference already notified articles. However, the communication of the SCIP number along the supply chain is not mandatory, and it cannot be assumed that all operators make use of this option, meaning that the extent of multiple notifications of the same article remains unquantifiable.
4. False positive notification: Obligated operators may submit SCIP notifications even if the SVHC concentration does not strictly exceed the 0.1% (*w*/*w*) threshold, for example, when uncertainty exists regarding the usage of a RoHS exemption in the previous supply chain and operators hence prefer to follow a conservative approach to ensure compliance with REACH. In contrast, suppliers knowingly placing non-compliant products on the market are unlikely to submit a SCIP notification voluntarily, suggesting that SCIP-notified articles predominantly represent precautionary notifications rather than non-compliance.

In summary, a direct quantitative comparison between SCIP notifications and the use of RoHS exemptions is difficult. Point (1) suggest that the number of SCIP-notified articles containing RoHS-restricted substances may underestimate the true prevalence of exemption use, while in contrast, points (2), (3) and (4) suggest that the number of SCIP notifications may overestimate the number of distinct articles on the European market using a RoHS exemption. However, it should be noted that the relative contribution of each factor to the overall discrepancy cannot be quantified, only the direction of the effect, towards over- or underestimation. The four factors described above should therefore be understood as conceptual explanations of structural differences between the SCIP and RoHS framework rather than empirical findings.

4. Discussion

Since the RoHS Directive entered into force in 2003 [29], the use of restricted substances in EEE has decreased by approximately two thirds [11,12]. However, this figure should

be interpreted with caution as no quantitative baseline data exists on the amounts of hazardous substances present either prior to or following the introduction of RoHS.

The international effect of the RoHS Directive is even more difficult to quantify. Following its entry into force in Europe, numerous RoHS or RoHS-like restrictions have been developed across the globe. While, for example, Iceland, Norway and Liechtenstein adopted the European RoHS Directive largely unchanged, other countries developed adapted versions [30]. Beyond the direct effect of RoHS-like initiatives, it is reasonable to expect that substitutions and technological innovations driven by RoHS requirements are also implemented outside the EU. Hence, although the RoHS Directive is legally binding only within the European market, its practical effect on the phase-out of restricted substances extended to EEE production globally [16].

This global dimension is of particular relevance given the growing WEEE challenge in countries of the Global South. Significant volumes of WEEE continue to be exported from high- to middle and low-income countries where adequate treatment infrastructure is often lacking. Critically, even independent of such imports, domestically generated WEEE is rising sharply in rapidly growing economies, while WEEE management capacities have not kept pace [31]. The restriction of hazardous substances within the product, as implemented by RoHS, therefore remains a critical instrument for reducing SVHC burdens globally, an effect commonly referred to as the 'Brussels Effect' [32], whereby EU regulations drive environmental and human health improvements well beyond their jurisdictional boundaries.

4.1. RoHS Exemptions

With 85 valid exemptions and 138 open exemption requests, the administrative burden associated with the exemption process is considerable. According to the Commission's exemption timeline, a decision on a RoHS exemption takes 18 to 24 months from the application date to the official publication of the Commission's decision [20].

However, processing delays in the exemption evaluation process have become increasingly common [11] and this study now demonstrates, that the decision time from the application date of undecided applications is at least in median 6.1 years and therefore substantially longer than the announced 18-to-24-month time frame. Companies submit renewal requests on average 9.7 months (median: 0.6 month, maximum 38 months) prior to the 18-month submission deadline, and since it is unlikely that the Commission processes renewal requests substantially before this deadline, the time between submission and decision is likely to overestimate the actual processing time. To provide a more conservative estimate, this study therefore analyzed the time between the expiry date of exemptions that had already been submitted for renewal but remained undecided at the threshold date of this study (28 February 2026). Under this approach, the estimated decision time is at least in median 4.6 years and still considerably exceeds the officially announced time frame. However, it should be noted that both values represent the already required but not yet finalized processing time, as they are derived exclusively from requests unresolved at the study reference date.

The delay in processing exemption requests has several distinct practical implications. First, the time lag between initial application and final decision means that the technical basis on which a request was originally submitted, including the state of substitution technology, production processes, and the quantities of restricted substances entering the European market, may have changed substantially by the time a decision is reached. This concern is explicitly acknowledged in recent delegated acts, where the European Commission noted that for several exemptions, future evaluations might conclude that the criteria of Article 5(1)(a) are no longer met, given the time elapsed since the original technical

assessments and the emergence of promising substitutes [33]. Short validity periods were therefore assigned to give applicants the opportunity to provide updated evidence.

Second, although Article 5(2) of the RoHS Directive limits the validity of exemptions for categories 1–7 and 10–11 to a maximum of five years (seven years for categories 8 and 9), exemptions remain in force until the Commission has reached a decision on a submitted renewal request (Article 5(5)). Due to the delay in the process this means in practice, that the actual duration of an exemption is considerably longer than the originally intended maximum validity period.

Third, companies developing innovations that require a new RoHS exemption may face years of legal uncertainty before they can bring their product to the EU market. New exemption requests offer no legal coverage during the evaluation period making long-term product planning extremely difficult.

And finally, in more than 8 cases, a renewal request was submitted within 10 days of the exemption entering into force. This pattern may reflect the structural uncertainty inherent to the long exemption process: companies having waited several years for a decision and may be unwilling to risk another prolonged evaluation period and therefore submit a follow-up request immediately. However, it cannot be excluded that in some cases this also reflects a lack of active substitution efforts.

In direct response to these challenges, the European Commission has recently transferred the scientific and technical assessment of RoHS exemptions to ECHA [14], with the explicit aim of improving the transparency, efficiency, and consistency of the exemption evaluation process in line with the 'one substance, one assessment' principle. Whether this institutional transfer will substantially reduce the time required for evaluation and address the structural uncertainties identified in this study remains to be seen, but it represents an important step towards a more streamlined exemption process.

Lead Exemptions

Among the lead-specific exemptions analyzed, three were identified as hotspots: exemptions No. 6(c), 7(a), and 7(c)-I. Unlike application-specific exemptions, these are material-specific, resulting in a broad scope and a wide diversity of potential applications covered. As a consequence, the potential for misuse is higher and market surveillance more difficult.

For exemptions No. 7(a) and 7(c)-I, the consultants already recommended the introduction of application-specific sub-exemptions as a step towards greater regulatory precision [21]. Sub-exemptions have since then been introduced for both but with the risk that these application-specific exemptions do not capture all relevant applications. This situation reflects a structural dilemma: specifying exemption scopes via sub-exemptions may leave companies without a legal basis to use the substance even though substitution or elimination of the substance is scientifically and technically impracticable. Additionally, the various uses of the substances in such exemptions may be highly complex and difficult to describe in a way that the exemption scope is clear and unambiguous. However, leaving such broad exemptions with more material- than application-specific scopes may allow misuse of the exemptions.

Regarding the long-term management of these exemptions this raises an important open question: when companies submit new requests under the broad-scope exemption for applications not yet covered by sub-exemptions, will the Commission treat these as candidates for new sub-exemptions to gradually narrow the material-specific exemption until it can ultimately be closed? The answer to this question will determine whether the current approach represents a transitional phase towards full application-specific scoping, or whether broad exemptions will persist. Full application-specific scoping would

thereby represent an effective mechanism to ensure that exemptions are applied only where substitution is not yet feasible, but achieving this will require both a clear regulatory strategy for handling new requests under broad-scope exemptions and greater transparency on which specific applications currently invoke these exemptions.

4.2. Information Gaps

Neither the specific products nor the quantities of substances entering the European market through RoHS exemptions are systematically and publicly reported under the current regulatory framework. The information on whether an exemption is used, or what quantities of the substance are present within the product, is therefore not directly available to market surveillance authorities, customers, and waste operators [22]. In fact, such information may not even be consistently transmitted within the supply chain itself. According to Article 7(b) of the RoHS Directive manufacturers have to draw up technical documentations and carry out an internal production control procedure in line with Decision No 768/2008/EC [34] on a common framework for the marketing of products (module A of Annex II). While the requirements for the technical documentation as specified in this Decision do not give instructions concerning how to describe the use of exemptions, the harmonized standard EN IEC 63000 [35] that specifies the technical documentation explicitly requires that any exemptions invoked are mentioned.

When market surveillance authorities identify a potential breach, they request the technical documentation from the relevant manufacturer to assess whether the exceedance of a RoHS threshold is covered by a valid exemption. However, it is not always possible to establish with certainty whether an exemption legitimately applies or whether a breach has occurred [36], raising questions about the practical informative value of technical documentation. This challenge is particularly relevant for material-specific exemptions such as Nos. 6(c), 7(a), and 7(c)-I. Exemption No. 7(a) illustrates this well: neither market surveillance authorities nor supply chain actors agree on its scope, creating enforcement difficulties and leaving room for potential misuse [21]. A further practical obstacle is that the technical documentation might not always be accessible in the first place. Market surveillance authorities have reported difficulties in contacting manufacturers or authorized representatives, particularly for products sold through online marketplaces [37].

In addition to the missing information about exemption use in the technical documentation, also the mandatory EU Declaration of Conformity, as specified in Annex VI of the RoHS Directive, does not explicitly require manufacturers to disclose whether a RoHS exemption is invoked, which exemption applies, or for what application it is used. In practice, declarations often provide no information on exemption use, or include only generic statements, such as that restricted substances 'may be present under an applicable exemption', without specifying which exemption is invoked or for what application.

In the absence of mandatory disclosure requirements, one might expect that the relationship between RoHS exemptions and EEE categories could at least provide an indirect means of identifying which product types are more dependent on exemptions than others. However, the present analysis shows that the majority of Pb specific exemptions cover nearly all EEE categories (23 out of 44 cover all categories and a further 7 cover all categories except Category 11), making it impossible to identify which specific products fall under a given exemption based on category information alone.

Given these limitations, this study further examined whether SCIP notifications could serve as a quantitative source of information on RoHS exemption use, since most RoHS-restricted substances are listed as SVHCs on the REACH Candidate List and therefore trigger a mandatory SCIP notification [38]. However, as shown in Section 3.3, SCIP notifications cannot be used as a quantitative proxy for RoHS exemption use, since structural

differences between the two instruments, including differences in substance and reference definitions, as well as limitations inherent to the SCIP reporting system, can lead to both an over- and underestimation of exemption use.

Nonetheless, the high number of notified articles (>17,500,000) containing RoHS-restricted substances in EEE [18], serves as a qualitative indicator of widespread exemption use across a broad range of EEE applications and products. This is further supported by the study of Deubzer [16], who demonstrated that Pb is present in almost all types of EEE due to exemptions 7(a), 7(c) and 15, and by the extensive lists of applications documented in some exemption requests, which illustrate the diversity of potential products and uses covered by individual exemptions [21].

However, beyond their implications for the specific analysis of RoHS exemption usage and SCIP notifications, the structural differences between RoHS and SCIP illustrate a broader challenge. When regulatory instruments use different reference definitions, consistent information transfer between them becomes inherently difficult. This is a challenge that may also be relevant to ongoing discussions about future information transfer instruments, where analogous definitional mismatches may arise and should be carefully considered in their design.

In addition to the missing transparency of exemption usage, most quantities of restricted substances entering the European market through RoHS exemptions are either missing or they are affected by big uncertainties. This is particularly evident in the case of exemption No. 7(a), where estimates of annual Pb quantities entering the EU market vary by more than two orders of magnitude (from ~150 tones reported by the applicant to up to 20,000 tones estimated by the consultant), reflecting that neither the applicant nor the consultant had a sufficient data basis to provide a reliable quantitative estimate. Moreover, even in cases where an applicant requesting an exemption has provided detailed information on the quantities of, e.g., Pb placed on the European market through that specific exemption, it is unknown how many other companies invoke the same exemption or what their respective contributions are. The evaluation of SCIP notifications does not add to the clarification of substance quantities either, even though SCIP notifications require declaring a concentration range of the SVHC in the article [39]. However, the possibility to declare broad concentration ranges, e.g., spanning from above 0.1% to below 100% (w/w), as illustrated in Figure S2, provides no actionable information. Hence future approaches on data transparency should focus on narrow concentration ranges to open the possibility to quantify substance amounts. However, beyond the imprecision of concentration data, SCIP notifications also do not include information on the quantity of the respective product placed on the market, further limiting their utility for estimating the total amount of restricted substances entering the European market.

A comparison with the RoHS like regulations in, e.g., Taiwan and China shows that a stronger focus in data transparency is possible. Regulations in both countries have a requirement for a hazardous substance table which informs consumers of the presence of a regulated substance in the product including part or unit. Next to that, the Taiwan RoHS mark includes information of hazardous substances integrated in the product [30].

However, while this study primarily focused on the legally used substances in EEE, it should nevertheless be noted that non-RoHS-compliant EEE are still being placed on the European market and that only a proportion of such products are detected through market surveillance. Identified breaches of the requirements of the RoHS Directive are published in reports by EU Member States or joint projects [36,37,40,41] and on the Safety Gate portal [42], but no estimation exists on the total quantity of restricted substances that have been placed on the market illegally.

4.3. Information Transfer and Data Transparency

Addressing the identified information and data gaps requires action with two distinct levels of transparency. First, information about exemption use must be clearly communicated along the supply chain as a mandatory requirement.

Although information relevant to exemption use may be documented in manufacturers' technical documentation, this documentation is not designed as a standardized mechanism for communicating exemption use throughout the supply chain. Where an exemption is invoked, a meaningful supply chain disclosure should include the specific exemption number, the application for which it is used, and a technical justification.

Second, exemption use and its justification should be made transparent beyond the supply chain to market surveillance authorities, waste operators, and the public. A simple label requirement, as applied in regulatory frameworks such as those in Taiwan and China, may be insufficient given the broad scope of material-specific exemptions, where a declaration of exemption use could apply to almost all types of EEE [16]. A more informative instrument would be a technical datasheet specifying the component containing the restricted substance, its location within the product, the concentration, the exemption invoked, and the reason for its use. Such transparency would serve multiple complementary purposes. On one hand, it would enable market surveillance authorities to verify whether exemptions are applied legitimately and to identify misuse in applications where substitution is already available, but without the need to invest great effort to obtain the technical documentation which may not even clarify exactly which exemption is being used in which component. Furthermore, quantitative information on substance amounts placed on the market through individual exemptions would provide an empirical basis for assessing the actual effectiveness of the RoHS Directive, a data gap that neither SCIP nor the current exemption process has been able to close. On the other hand, empirical data collected on which specific applications currently rely on broad-scope exemptions could lead to the development of new, clearly targeted sub-exemptions, supporting the gradual closure of broad scope exemptions as discussed in Section 4.1.

Finally, by making exemption use visible to customers and competitors, transparency may create competitive pressure on manufacturers to discontinue invoking exemptions where substitution has become technically feasible. An effect that, given the global reach of EU product regulation demonstrated by the Brussels Effect, could extend well beyond the European market.

5. Conclusions

This study demonstrates that the overall effectiveness of the RoHS Directive in reducing hazardous substances in EEE is substantially constrained by the current exemption system. The high number of SCIP notified EEE articles containing substances that are also restricted under RoHS serves as a qualitative indicator for widespread exemption use. This, combined with a median decision time of at least 6.1 years for still-unresolved requests, points to a system under considerable strain: some exemptions originally conceived as temporary instruments show signs of becoming long term approaches, while the technical basis for exemption decisions risks becoming outdated before decisions are even reached.

The lack of transparency on material-specific exemption use, both within the supply chain and towards regulators, market surveillance authorities, and end-of-life operators, together with considerable uncertainties in the estimated amount of restricted substances entering the EU market, limits the ability to assess the true extent of hazardous substance use in EEE. Mandatory disclosure of exemption use, including application-specific technical justification, could improve market surveillance, accelerate the specification of narrow-scope exemptions, and create competitive pressure to phase out exemption use where

substitution is already feasible. The recent transfer of the RoHS exemption process to ECHA through Directive (EU) 2025/2456 represents an important institutional step towards greater efficiency and consistency. However, institutional reform of the exemption process alone will not address the transparency gaps identified in this study.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su182010481/s1, Table S1: EEE categories in Annex I of the RoHS Directive [4]; Figure S1: Frequency distribution of days between (a) actual submission date and the 18-month deadline prior exemption expire date, (b) submission date and threshold date of this study (28 February 2026), and (c) expiring date and the threshold date of this study; Table S2: Exemptions covering Pb and categories 1–7, 10 and 11 in Annex III [19]; Figure S2: Exemplary SCIP notification providing the concentration range of lead in a diode of a circuit board [43].

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Abbreviations

The following abbreviations are used in this manuscript:

EEE	Electrical and Electronic Equipment
WEEE	Waste Electrical and Electronic Equipment
SVHC	Substance of Very High Concern
Pb	Lead
Cd	Cadmium
Hg	Mercury
Cr^{VI}	Hexavalent chromium
CEAP	Circular Economy Action Plan
SCIP	Substances of Concern in Products

Appendix A

Appendix A.1

'homogeneous material' means one material of uniform composition throughout or a material, consisting of a combination of materials, that cannot be disjointed or separated into

different materials by mechanical actions such as unscrewing, cutting, crushing, grinding and abrasive processes" (Directive 2011/65/EU Article 3 (20)).

Appendix A.2

"Article: means an object which during production is given a special shape, surface or design which determines its function to a greater degree than does its chemical composition;" (Regulation 1907/2006, Article 3 (3)). After the principle "once an article—always and article" all components, subcomponents or complex items which fulfil the article definition are in fact articles and need to be reported in SCIP, in case the concentration of SVHCs (on the REACH Candidate List) exceeds the 0.1% (*w*/*w*) in that article.

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