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A RISK-BASED APPROACH FOR WASTE MANAGEMENT IN THE MODERN CIRCULAR ECONOMY: PROPOSITIONS FROM THE EU RECYCLING INDUSTRIES

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ABSTRACT

EuRIC, the European Recycling Industries' Confederation, proposes five regulatory actions to enhance material circularity: i) Set stable regulations based on the principle of "one substance - one assessment" along with realistic, evidence-based scientific risk assessments; ii) Prioritise increasing waste collection for a better elimination of substances of concern to reducing the concentration limit in recycled products; iii) Strict enforcement of an Extended Producer Responsibility (EPR) scheme for all restricted or banned substances, where exemptions should be carefully considered by evidence-based science; iv) Align the classification hazard systems used for waste materials with those used for products; v) Grant an end-of-waste status (EoW) at the output of a controlled, certified industrial loop. Those propositions create a level playing field for collection, sorting, and waste preparation within EU and an improved waste shipment. The underlying question is striking the right balance between the precautionary and responsibility principles in the circular economy. Given the presence of hazardous "legacy" substances and the prolonged life of certain products within an evolving regulatory framework, the recycling industry proposes controlled-risk solutions aligned with the intended use or recycled materials for products not yet ecodesigned. The recommendations suggest a shift in the waste definition, considering the fate of matter within the waste hierarchy – emphasizing prevention, management, and policy alignment with the principles of the circular economy. So, materials that can be prepared for reuse or recycling are categorized as pre-materials, while those suitable only for other recovery methods such as energy recovery or landfilling are considered wastes.

1. INTRODUCTION

Is garden biomass matter brought by citizens to civic amenity centers a waste (which can only be transported and managed at waste licensed facilities with strict and costly administrative control) or is it a resource that can be used (after some preparation) as mulch, energy, or soil amendment? The situation may appear straightforward, but this question frequently arises in the day-to-day management of circular economy affairs in a recent case in France (Public debate about Hynovera project in 2023, personal communication), the biomass, possessing a waste status, would be prohibited from undergoing pyrolysis for synthetic fuel production. This limitation arises as the planned facility is not intended to function as a waste management facility.

Waste should be managed by risk in the modern circular economy, like products. Risk is the probability (amount, frequency) of effective harmful exposure to a hazard: risk = hazard x exposure of a target (Figure 1). A no-risk situation is more easily achieved by reducing exposure to the hazard than by reducing or removing a hazard. Risk reduction is easier than hazard reduction. Hazardous substances, while deemed or considered harmful, have or had utility owing to their physical, chemical, or biological properties. For instance, lead compounds function as UV stabilizers in PVC window frames, enhancing their durability, and brominated flame retardants serve as essential safeguards against fire hazards. If these substances face prohibition, achieving zero concentration in recycled material may not always be feasible today due to their legacy presence in the waste.

The debate on hazard versus risk has become prominent in legislative discussions concerning both products and waste, as evident in EuRIC (2023) examples. In this context, "products" refers to articles or preparations (mix-

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FIGURE 1: Illustrating the concept of "no exposure" signifies the absence of risk, emphasizing a hazard-free approach. (Madelung, 2023).

tures) classified under the Classification, Labelling, and Packaging of Substances and Mixtures (CLP) regulation (EC, 2008). The central question revolves around how to reasonably (finding a balance between advantages and disadvantages) control the risks associated with the presence of hazardous substances (toxic/ecotoxic) in products, whether sourced from virgin materials or recycled materials, and waste (which serves as the raw material for products).

Increasingly, there is a trend toward reducing concentration limits for numerous substances in products, independent of their intended use. Some substances are outright prohibited due to their classification as persistent organic pollutants (POPs). In practice, a considerable number of substances will need to have concentrations reduced to zero or below the detection limits of chemical analyses, which themselves are continuously decreasing.

This approach is essentially a "no hazard" strategy rather than a risk-oriented one, aligning with a societal inclination toward the welfare state and a political tendency to safeguard public opinion by increasingly protecting citizens against any potential hazard.

The adoption of "absolute risk," "no risk," or "worst-case" approaches essentially translates to a "hazard-only equals no hazard" strategy. For the circular economy, this poses considerable challenges, reaching the point of making it impractical to sort waste fractions with very low concentrations. Consequently, there are material losses in the recycling loop and increased costs for recycling processes, including downcycling, incineration, or landfilling of now non-recyclable fractions.

While the European Commission's Eco-design for Sustainable Products Regulation (ESPR) and the Chemical Strategy for Sustainability (CSS) aim for a "toxic-free" approach, addressing most hazardous substances in products, there are complexities introduced by legacy substances and the extended lifespan of certain products. Given the evolving regulatory landscape, the recycling industry suggests promoting controlled risk solutions for both the intended use and recycled materials in the interim.

This paper is a contribution to the discussion identified by the European Commission (EC) in 2018 (EC, 2018a): "*reflection on the appropriate balance between the overall long-term benefits from circular use of these materials and the overall long-term health and environmental concerns relating to substances present in that material*." and in 2020 (EC, 2020a): "*As a principle, the same limit value for hazardous substances should apply for virgin and recycled material. However, there may be exceptional circumstances where a derogation to this principle may be necessary. This would be under the condition that the use of the recycled material is limited to clearly defined applications where there is no negative impact on consumer health and the environment, and where the use of recycled material compared to virgin material is justified on the basis of a case-by-case analysis*." EuRIC supports that approach and pledges for its complete and evidence-based scientific implementation.

The paper is structured around five propositions (sections 1 to 6), offering solutions to enhance material circularity from the perspective of recycling organizations. These propositions also yield additional benefits for waste shipment and contribute to a level playing field within the EU (section 7). As a natural outcome, there is a suggestion to reevaluate the definition of waste in alignment with the waste hierarchy (section 8). The conclusion underscores the necessity for a comprehensive societal debate (section 9).

The reader will find in EuRIC (2023) detailed citations, examples, numerical data and discussions that are presented only shortly here.

2. PROPOSITION 1: STABLE REGULATIONS BASED ON "ONE SUBSTANCE – ONE ASSESSMENT" AND REALISTIC SCIENCE-BASED RISK ASSESSMENTS

The foundation of the waste management proposal, whether hazardous or not, based on risk in the intended use, is outlined in the Introduction section. This section delves into critical aspects, including (i) transitioning multiple substance regulations, (ii) reassessing substances, (iii) realistically evaluating risk in intended use rather than hazard, and (iv) emphasizing the necessity for a responsible, science-based policy rather than a political, conservative, precautionary-based approach, all from the standpoint of the recycling industry. The utilization of the SCIP (Substances of Concern In Products) database and the potential to mitigate certain hazard properties of materials are subsequently explored.

2.1 Recyclers have to face multiple and moving regulations of substances and materials

Waste legislations, including specific Directives or Regulations, persistent organic pollutant (POP) legislation, and product legislations, undergo revisions every five years. Typically, these revisions involve the introduction of new substances and a reduction in concentration limits or a ban on hazardous substances in products and recycled materials.

To address the challenge of substances regulated across multiple pieces of legislation (while not necessarily addressing the continuously decreasing concentration limits), the European Commission has introduced the "one substance – one assessment" method (EC, 2019; EC, 2020a), which is discussed further below.

2.2 Many substances are currently not accurately assessed by their producers, and a significant number undergo re-assessment by the European Chemicals Agency – ECHA

An example is found in the brominated substitutes for regulated brominated flame retardants (BFRs) in plastics used in electrical and electronic equipment (Hennebert, 2021). The comprehensive status of the 34 substances in producers' catalogs and in the ECHA and industry list of plastics additives is as follows: 12 substances lack a dossier, 10 substances lack hazard statement(s) (6 are under reassessment by ECHA as "persistent, bioaccumulative, and toxic" - PBT, future persistent organic pollutants (POPs), and as "endocrine disruptor" - ED), and 12 substances have complete dossiers (2 are under reassessment as PBT or ED). Among the 7 substitutes on the ECHA-industry list of plastic additives (non-POPs, non-regulated BFRs), all but one have no declared hazard statement(s), and all are currently being re-evaluated by ECHA (3 as PBT, 2 as ED, and 2 as PBT + ED).

As the premise for reassessment is based on potential hazard (due to chemical similarity), these 7 substances could likely be assessed in the future as PBT (POP) and/or ED, potentially leading to restrictions. Plastics produced today with these additives will likely face challenges in recyclability, resulting in "regrettable substitution" and the creation of new "legacy" substances. Proposition 3 could address this issue.

Chemicals are initially assessed as pure substances, first for hazard, and then hazardous chemicals are either banned or evaluated for risk in their intended use (with a given concentration in "mixtures or preparations") for authorization, potentially with limiting concentrations.

In addressing concerns related to the inaccurate assessment of chemical substances, the European Chemicals Agency (ECHA) has implemented a "generic approach to risk management" (EC, 2020a). This approach initiates predefined risk management measures, such as packaging requirements, restrictions, and bans, based on the hazardous properties of the chemical and general considerations of their exposure. Initially focused on carcinogenic substances, it has seen limited exemptions defined by law. The intention is to expand its application to include other harmful chemicals, such as those impacting the immune, neurological, or respiratory systems, as well as chemicals toxic to specific organs (EC, 2020a).

However, experts like Bridges et al. (2023) express concern that this approach may overemphasize hazard assessment without sufficiently considering exposure estimates and risks to both humans and the environment. They argue that a sustainable chemical assessment should encompass both hazard and exposure estimate and express reservations about relying solely on qualitative hazard assessments. They emphasize the importance of evaluating potency, a critical aspect of hazard assessment. Furthermore, they underscore the significance of adopting a weight-of-evidence approach and suggest the necessity for a more comprehensive and practical strategy for chemical risk assessment.

The data utilized for risk assessments must reflect realism, considering factors such as ingestion rate and transfer rate. A discussion on a practical assessment of carcinogenic polycyclic aromatic hydrocarbons (PAHs) in tyre granules is presented in (EuRIC, 2023). The substantial benefits of reducing social costs and environmental burdens through a realistic risk assessment are noteworthy (EuRIC, 2023).

The position of the recycling industry is that the "One substance – one assessment" principle should not be oversimplified and reduced to merely assessing "hazard to humans." Instead, it should remain a scientifically realistic risk approach tailored to the intended use(s). The Chemical Strategy for Sustainability (EC, 2020a) should not alter this perspective, and recovered material should adhere to this method.

2.3 The circular economy must be a science-based policy

A risk-based approach is grounded in science and should rely solely on scientific data. The emerging social science question is... "*How to reconcile scientific evidence with other forms of evidence, and with the various political, societal and other non-scientific factors that inform the process of governance?... In order to strengthen the role of science in European governance, the creation of a pro-science climate at all levels of the institutions, business circles and civil society is urgently needed… A conservative, precaution-based approach to assessment has taken hold, hindering access to innovative products and techniques… Science is becoming increasingly subjective and politicised, a trend that risks eroding public trust in the EU, undermining its legitimacy as well as its capacity to address the challenges…*" (Guégen and Marissen, 2022). The authors discuss "*how evidence-based and science-based decision-making can be further integrated into the EU decision-making process*", in particular that scientific assessment conducted at EU level (frequently by the Joint Research Centre) should be validated by policy-makers and published before decision. To promote science in the management of substances, the same authors propose a dialogue between the professional circles and the NGOs. The dialogue is nevertheless open: in the European Green Deal (EC, 2019), section 2.1.8 "*A zero pollution ambition for a toxic-free environment: The Commission will review how to use better*

the EU's agencies and scientific bodies to move towards a process of 'one substance – one assessment' and to provide greater transparency when prioritising action to deal with chemicals.". In the communication "Chemicals Strategy for Sustainability Towards a Toxic-Free Environment" (EC, 2020a), it is stated that a different limit value could apply for recycled material in clearly defined applications where there is no negative impact on consumer health and the environment (full citation in the Introduction).

EuRIC, or recyclers at large, shall not conduct risk assessments. The responsibility for assessing the risk of substances in articles or materials that eventually become waste or pre-material lies with the producers. EuRIC relies on the risk assessments conducted by producers for their specific uses. In cases where waste or pre-material comprises a mixture of different origins, recyclers shall provide data on the total concentration of substances and their distribution in the material streams for a given use. Some distributions of contaminants are presented in Section 3.1.

The EU Waste Framework Directive mandates producers to document the presence of substances of very high concern (SVHCs) in articles or complex objects (products) in a new database called SCIP, launched online in January 2021. Articles containing SVHCs from the Candidate List at concentrations above 0.1% w/w, placed on the EU market, must be recorded. Unfortunately, for the recycling industry, this database is of limited use (Friege et al., 2021). Composition data in SCIP is available by item parts, making it challenging to convert to the composition of an unsorted or sorted waste stream. To be valuable for the recycling industry, an extraction tool based on product categories and materials (typically polymers) should be developed.

2.4 Proposition #1

Regulating substances in products and waste through a risk-based approach involves establishing concentration limits for the use of substances in products and recycled materials. This is achieved through a realistic scientific assessment of the risks associated with the intended use, considering not only the hazard of toxicity to humans but also considering the climate and energy balance in the circularity of materials.

Recycled materials containing (legacy) substances of concern should be authorized for use with concentrations that may be higher than those permitted for virgin products, particularly in controlled loops. This approach aligns with a balanced risk-based and circularity perspective, encompassing the savings of virgin materials and reduction of CO2 emissions.

3. PROPOSITION 2: A MORE EFFECTIVE ELIMINATION OF SUBSTANCES OF CONCERN (SOC) CAN BE ACHIEVED BY INCREASING THE COLLECTION RATE OF MATERIALS RATHER THAN BY LOWERING THE SOC CONCENTRATION IN RECYCLED MATERIALS

This section demonstrates that increasing the collection rate sorts out more banned or controlled substances than reducing the concentration limits in recycled products, due to the distribution of contaminants skewed by some large "nugget" values. Such distributions are first illustrated. The effect of reducing the concentration limit and of increasing the collection rate depends on this distribution and are then presented.

3.1 To eliminate substances in material loops: Is it more effective to increase the collection of materials (i.e., waste) or lower the concentration in recycled material?

Twenty histograms depict the distribution of characteristics in (potentially contaminated) natural media such as soil and sediments, as well as (unprocessed and processed) waste (EuRIC, 2023, with references to additional published examples). These distributions are often skewed by some high values that prove critical for the mean concentration or value. Non-normal distributions are observed in natural media, but human activities contribute to the creation of highly concentrated portions (hot spots), significantly increasing the spatial, temporal, or batch variability of many characteristics. This situation is further exacerbated in waste, where many parts frequently have low or zero concentration, and a few parts exhibit high concentrations (Figure 2).

An important initiative within the recycling industry involves developing and implementing methods to identify and separate components with undesired substances that exceed concentration limits. It is evident from the data that, because of these skewed or asymmetric distributions, removing the last percentiles from a population significantly reduces the average concentration. Determining the relative impact of increasing material collection versus decreasing the concentration limit in recycled material on the removal of substances of concern from the material loop is not straightforward. The response depends on the distribution of concentrations of legacy contaminants in different particles of waste. A theoretical calculation illustrating the relative effects of lowering the concentration allowed in recycled products or increasing the collection rate is presented. Assuming a realistic distribution where 90% weight/weight have 0 mg/kg and 10% w/w have a 10% concentration of a substance of concern (SoC), equivalent to 100,000 mg/kg, the mean concentration of the batch is 1% or 10,000 mg/kg. The initial collection rate is 50%, and the initial concentration allowed in recycled material (concentration limit – CL) is 1,000 mg/kg. The effects of reducing the SoC concentration allowed in recycled material by 50% and increasing the collection rate of the waste by 50% are detailed in the Supplementary Information and presented in Figure 3.

The persistence of Substances of Concern (SoC) comprises the SoC in the recycled fraction (green) and the SoC in the "other fate" fraction (grey). Reducing the SoC concentration limit by 50% results in a 0.5% decrease in the mass of recycled waste (from 455 kg to 452.5 kg/tonne of waste) and a 4.5% reduction in SoC persistence (from (0.5+5) to (0.25+5) kg SoC/ton of waste). Increasing the collection rate by 50% leads to a 50% increase in the mass

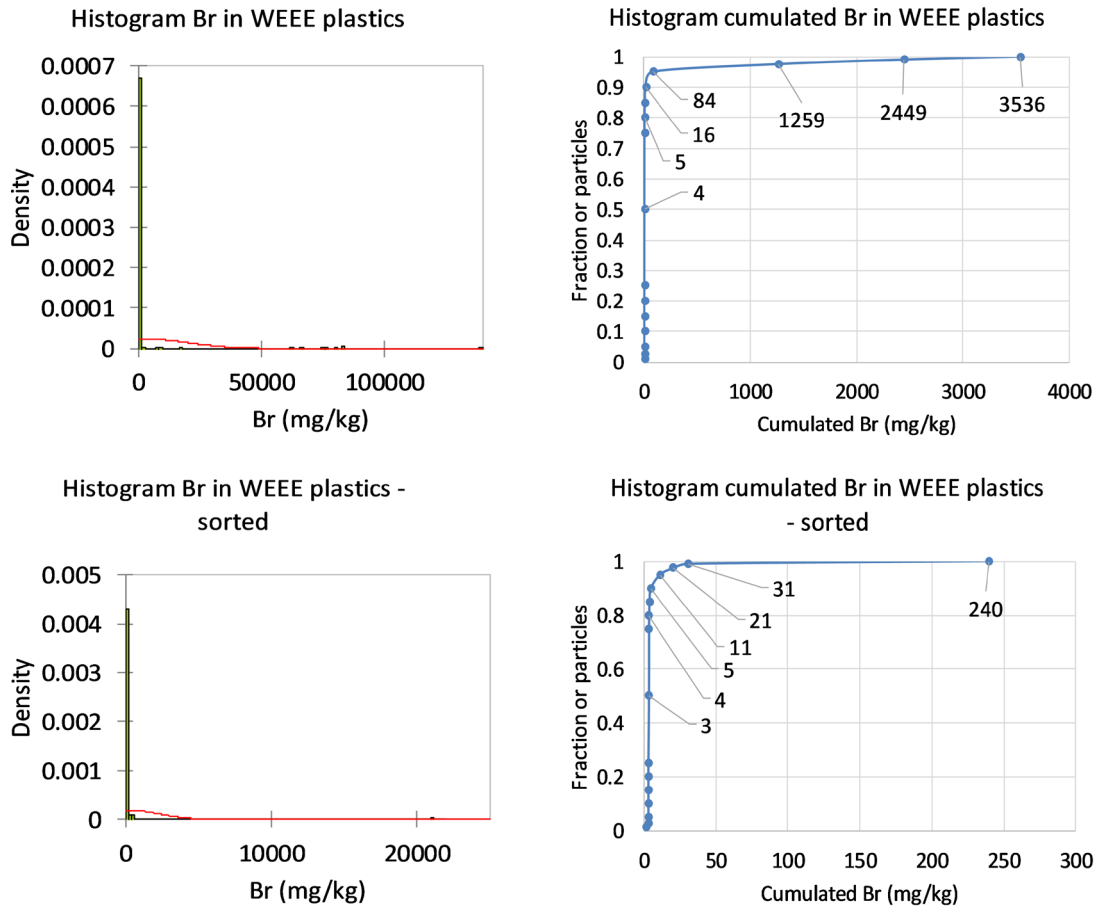

FIGURE 2: Particle concentration of bromine in waste of electrical and electronic equipment (WEEE) plastic scraps (left), mean concentration of bromine in the cumulated fraction of particles (right) with the mean cumulated concentrations of the 50th, 75th, 90th, 95th, 97.5th, 99th and 100th percentiles of the particles. The normal distribution with same mean and s is indicated (red line), clearly not fitting. Upper figures: plastics after shredder. Lower figures: plastic after density (1.08 kg/liter) sorting (Hennebert and Beggio, 2021).

of recycled waste (from 455 kg to 682.5 kg/tonne of waste) and a 40.9% reduction in SoC persistence (from (0.5+5) to (0.75+2.5) kg SoC/ton of waste). The non-linear effects of reducing the concentration limit and increasing the collection rate are attributed to the asymmetric distribution of additives or contaminants in the waste streams, distorted by some high values, with a majority of low or zero-value parts. The conclusion is that increasing the collection rate significantly reduces the persistence of SoC in material loops compared to reducing the concentration limit, emphasizing the need to prioritize efforts on increasing the collection rate. Producers and importers, who have profited from these goods, should assume greater responsibility for handling substances of concern, and the initial step is to enhance the collection rate.

Meanwhile, the everyday solution employed by the recycling industry to address the presence of hazardous substances in materials involves removing the fraction containing the hazard, especially when the contaminant is not uniformly distributed among the particles of the shredded waste. Examples of this approach include the selective dismantling of Waste Electrical and Electronic Equipment (WEEE) and End-of-Life Vehicles (ELV), as well as the sorting of plastics from WEEE by density to eliminate banned flame retardants. Other solutions for some cases are to remove some hazard properties - HPs (Hennebert, 2022):

- HP 4 'Irritant' and HP 8 'Corrosive' by acidity or alkalinity: acid/base neutralisation including passive or active carbonatation
- Reducing or oxidizing waste: redox neutralisation
- HP 9 'Infectious': sterilisation
- HP 14: if the waste does not have a near-neutral pH (pH 5.5-8.5), the share of ecotoxicity due to acidity or alkalinity and the associated soluble metals can be reduced up to non-active concentration by neutralisation and precipitation of metals of the waste. This must be done on the waste stream or batch and not (only) on the laboratory sample.
- HP 15 'Waste capable of exhibiting a hazardous property not directly displayed by the original waste': recommendations for safer backfilling of some waste can be found in Hennebert (2022).

These methods, however, have limitations, and it's not always possible to eliminate all hazardous substances. In the case of sorting, with current technologies, achieving a zero concentration cannot always be guaranteed.

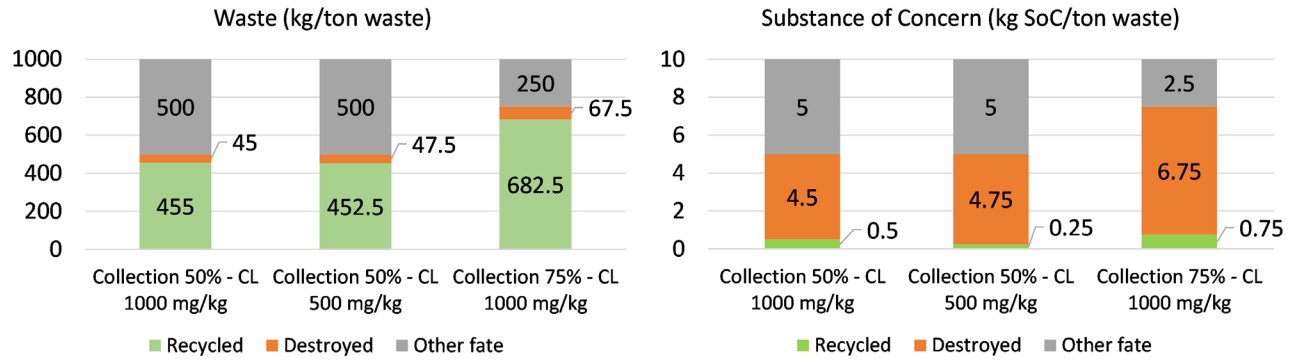

FIGURE 3: Theoretical calculation illustrating the impact of decreasing the concentration limit of a substance or increasing the collection rate of waste on the quantity of recycled material (left) and the amount of sorted-out and destroyed (CL) substance (right).

3.2 Proposition #2

Effective elimination of prohibited or regulated substances is achieved more efficiently by increasing the waste collection rate. In heterogeneous mixed waste, where the concentration distribution of certain parts is skewed, enhancing the collection rate proves to be more efficient than reducing the concentration limit in recycled material.

4. PROPOSITION 3: EXTENDED PRODUCER RESPONSIBILITY FOR THE HAZARDOUS, RESTRICTED, BANNED, REASSESSED SUBSTANCES AND EXEMPTIONS

To ensure effective control of regulated substances in material loops, it is imperative for the producers or importers of products containing controlled substances to take responsibility for those substances. Producers and marketers must be aware of the composition of their products. When a substance is restricted or banned, the establishment of an Extended Producer Responsibility (EPR) organization should be mandated. This organization would be responsible for funding the efficient tagging, identification, separate collection, sorting, and management of the portions of any waste stream containing these substances. Products and waste containing these substances can then be identified, and their management can be financially supported. The recycling industry can play a crucial role in assisting the EPR body. An additional and related aspect pertains to the property of recycled material. The scope of the Extended Producer Responsibility (EPR) system can be financial or both financial and organizational, as explicitly outlined in the Waste Framework Directive (WFD). However, the WFD does not explicitly include the case of an EPR system with financial, organizational, and operational actions. Furthermore, the ownership of recycled material is not defined in the WFD. EuRIC's experience indicates that EPR systems that tend to be operational often appropriate the recycled material. This situation eliminates real competition when an EPR has received a public mandate, sometimes acquiring a financial and organizational monopoly. This may lead to the selective and unequal appropriation of only valuable materials, which can be resold exclusively to members of the EPR system, affecting all producers and products without discrimination to prevent "cherry-picking" within a product family:

- either a company or companies organize their own take-back system, without a public mandate,
- either an EPR system receives financial and/or organisational power from the public authorities, according to contractual specifications with the authorities. This private law entity acts on the basis of an approval, that is to say a public mandate.

"No entity mandated by a public authority to manage a waste stream and being a total or partial monopoly by law can have an operational role on the market it manages and oversees. This a blatant breach of equality resulting from the abuse of a dominant position with private recycling companies, which must compete through tender procedures to obtain a share of the market falling under the scope of the EPR Schemes." (EuRIC, 2022).

No EPR organisation acting under a public mandate should carry out recycling operations and capture (valuable) recycled material itself.

EPR systems, when granted a public mandate, are often licensed as a hybrid entity, operating as both a non-profit organization and a for-profit company in EU Member States. This dual role raises questions about their potential involvement in operational activities, such as owning or co-owning recycling plants or participating in material capture.

Some manufacturers or marketers wish to regain via EPR ownership of the recycled material, even though they relinquished this ownership (against payment) when selling the articles, and this payment in fact includes now the net cost of recycling that the recyclers have negotiated for long, with or without an Extended Producer Responsibility eco-organization. Note that this claim has variable geometry: for instance, it does not address plastics that are not recyclable today, including plastics containing brominated flame retardants that were formerly authorized but are now POP and not recyclable. As everyone knows, certain parts have market value once processed by recyclers, and others have no recovery or are hazardous waste that must be destroyed or stored by specialized companies, and are therefore costs. Picking the best cherries is pleasant at first glance but economically disastrous for the recycler. The

seller has sold: he cannot claim new ownership. Eco-organizations receive a public mandate. Collecting the cost of recycling from the consumer on a public mandate and paying it back to the recycler does not make the eco-organization(s) the owner(s) of the recyclate(s). This principle of reality must be installed as a principle of collaboration and law for all circular economy loops.

EuRIC asserts the need for representation of the recycling industry within the governing body of EPR Schemes. Any EPR organization must adhere to Articles 8 and 8a of the WFD, which mandate the organization of collaboration among all stakeholders, including waste players at each stage. Numerous passages in the WFD emphasize the involvement and collaboration of all actors, including the recycling industry.

Building a robust circular economy necessitates a fair sharing of value between EPR organizations and collectors/recyclers. EPR organizations should not relegate the recycling industry to mere subcontractors but engage in a partnership characterized by an industrial project with long-term objectives. This relationship should not reflect the unbalanced dynamics observed between supermarket purchasing centers and the agri-food industry/farmers.

4.1 Proposition #3

Extended Producer Responsibility (EPR) should be established for all substances subject to restrictions, bans, or reassessments, with exemptions carefully evaluated based on evidence-based science. EPR organizations operating under a public mandate should not engage in recycling operations or directly capture valuable recycled materials.

5. PROPOSITION 4: HARMONISATION OF WASTE HAZARD CLASSIFICATION WITH PRODUCT CLASSIFICATION

Substances may have hazard statement code attributed by the notifier to ECHA, or by ECHA. Mixtures and preparations (called here "products") have hazard classification and labelling if the individual or summed concentrations of substances with hazard statement codes exceed concentration limits. Classification of waste as hazardous or not for 15 hazard properties HP 1 to HP 15 is first defined in the European list of waste (hazardous, non-hazardous, or "mirror entry", meaning hazardous or not depending on the concentration of hazardous substances in the waste or on tests results, that must be assessed on a representative sample). A guidance document is available (EC, 2018b) and practical solutions for classification are presented in Hennebert (2019). Note that the summation rules of concentrations and the concentration limits are not always the same between products and waste. Two problems of classification should be improved.

5.1 Waste classification by « worst case » substances

Laboratory analyses provide total element concentrations and not concentrations of element-containing substances, except for some limited cases with specific analytical methods (such as lime CaO or chromium VI). Since hazard statement codes are assigned to substances and not to elements, it is necessary to speciate the elements into mineral or organo-mineral substances, often relying on hypotheses.

Some classifiers, by precautionary principle and lack of knowledge of the waste science (processes, mineralogy, composition, physico-chemical domain of stability of substances) use the most hazardous mineral or organo-mineral substances to speciate an element. That method does not correspond to the reality of the waste (excepted some industrial waste that are intermediate in the chemical industry and do not join the common waste flows) and incorrectly classifies the waste as hazardous. More scientific methods are available, using physicochemical information, process information and avoiding hazardous intermediate substances from chemical industries that are not found in waste, to have a more realistic assessment (Hennebert, 2019).

5.2 Classification of HP 14 'Ecotoxic'

5.2.1 The use of multiplying factors for the concentration of the ecotoxic substances

To avoid discrepancy between waste and products, the multiplying factors of the concentration of the most ecotoxic substances (so-called M-factors, acute and chronic) should be used for the calculation of the sum of weighted concentrations of ecotoxic substances for HP 14. Many M-factors are available in the harmonised classification of substances (published by ECHA as an Excel file) and other M-factors have been published (Hennebert et al., 2014, 2016).

5.2.2 Assessment of HP 14 'Ecotoxic' by tests

The establishment of a validated European battery of ecotoxicological tests has been a longstanding topic. Currently, there are approximately 25 proposed tests and concentration limits (not an exhaustive list, as detailed in Hennebert, 2018). Building on a European interlaboratory trial conducted in 2006 and published in 2009 (Moser and Römbke, 2009), along with the associated test battery (Moser et al., 2010), a standardized battery applicable across all European countries is proposed. This battery includes six normalized tests, excludes variants and options, and features validated concentration limits determined by a group of 23 waste samples, both non-hazardous and hazardous, serving as a reference method based on both list and chemical composition. It is recommended to utilize only this battery, without modifying the sample (such as neutralizing the leachate), without incorporating options that may introduce high inter-laboratory variability rendering the results unusable (Hennebert et al., 2022).

5.2.3 Human and environmental bioavailability of substances

The assessment of waste should consider the bioavailability of the substances (EU 2017, 2018). According to ECHA guideline: "*In general, there are no specific environmental test methods developed to measure biological availability of substances or mixtures.*" (ECHA, 2017). Bi-

oavailability of elements and substances of waste is not measurable "in general". The bioavailable fraction is not limited to the (de-ionised water) leachable fraction: ingestion, inhalation, dermal contact are significant routes of exposure. It seems today that the best method to assess bioavailability for classification for ecotoxicity (HP 14) is to use a battery of biotests with validated concentration limits by matching with a reference method, as explained above (Hennebert 2019). The assessment of ecotoxicity of waste by a 1000 times diluted leachate of the waste (10 000 l/kg rather than 10 l/kg) is not relevant: the dissolution of 100 mg of element/l (corresponding to 10 000 l/kg) is a method to attribute hazard statement code to substances with element as ecotoxic acute or chronic level 1 to 4 (ECHA, 2017), and not to classify a mixture. Published data indicates that method classifies only one waste from 81, while the classical method classifies 50 wastes as hazardous, from the same set of 81 data (recalculated from, Hennebert 2018).

5.3 Proposition #4

Hazard classification of mixtures of substances in products and wastes: Progressively align the waste classification with the product classification, especially for HP 14 "Ecotoxic" hazard property, considering varying degrees of ecotoxicity (by M-factors), and advocate for the adoption of an EU laboratory test battery with validated concentration limits.

EuRIC suggests that DG ENV initiate a working group on harmonized classification through ecotoxicological tests applicable in EU countries, incorporating validated concentration limits.

6. PROPOSITION 5: TACIT END-OF-WASTE STATUS AT THE OUTPUT OF A CONTROLLED CERTIFIED INDUSTRIAL LOOP

6.1 The implementation of the end-of-waste has slowed down

According to many authors (as in EC, 2020b): "*However, now 10 years after its legal formulation [2008], it is clear that the implementation of end-of-waste has failed in most countries, for many reasons. First of all, at the EU level, end-of-waste criteria have only been defined for three different waste types: iron scrap, copper scrap and glass cullet. This despite the fact that the EU Joint Research Centre has developed criteria for several other waste types, such as paper, plastic, compost and aggregates. Many end-of-waste proposals have been halted since it has proven difficult for member states to reach an agreement.*" (Johansson and Forsgren, 2020). Member States have further implemented the process, but it has halted or at least slow down since 2016 (France, UK). The reasons are: excessive slowness, excessive precautionary principle, a part of arbitrary commission "expert" judgment who's some can be opposed to, delegation to local authorities that have not always the expertise, single waste by single waste approach with individual (small business) demanders that have not always the resources for best quality dossiers… Some propositions to improve this situation are presented in EC, 2020a.

6.2 Proposition to circumvent/solve the halting of EoW: "non-waste", "waste use potential", "certified material", "non-waste product", "secondary raw material"

The revised Waste Framework Directive (EU, 2018) states in recital 17 and article 6(1) that secondary raw material should have the end-of-waste status: "*In order to provide operators in markets for secondary raw materials with more certainty as to the waste or non-waste status of substances or objects and to promote a level playing field, it is important that Member States take appropriate measures to ensure that waste that has undergone a recovery operation is considered to have ceased to be waste if it complies with all the conditions laid down in Article 6(1) of Directive 2008/98/EC as amended by this Directive.*". The criteria for achieving end-of-waste status include a defined purpose, a corresponding demand, adherence to technical requirements, and the absence of adverse effects in the intended use. Given that secondary raw materials (or preferably called, raw materials from recycling) are inherently produced for a specific purpose, meet demand, and satisfy technical specifications while ensuring compliance with regulations safeguarding human health and the environment, these materials should, in principle, be eligible for end-of-waste status at the national and, ideally, EU levels. Member States or the EU should confer this status when waste has undergone a recovery operation.

Twenty-six years ago, the need for inclusion of resource in the definition of waste was already stressed (Bontoux and Leone, 1997; Pongrácz and Pohjola, 1997). The experts of EU Joint Research Centre JRC proposed in 1997 a report to the European Parliament "The Legal Definition of Waste and its Impact on Waste Management in Europe" with a section "*5. Towards a distinction between waste and non-waste… All the issues presented above show how crucial the distinction between waste and non-waste can be for all the actors. On the one hand, a legitimate concern from the legislator exists to ensure the proper handling of wastes, avoiding negative impacts on the environment and on public health (i.e. reducing risk). On the other hand, the legislation must promote the recovery of resources, preserve the Single Market and obey international obligations (World Trade Organization and Basel Convention)*". National approaches are detailed and a list of criteria for non-waste was proposed (Bontoux and Leone, 1997). One of the recommendations of the authors is "*To apply a risk assessment approach to the broad issue of shipment and handling of waste. However, this is closely linked to the processes used, and as such related to the technical state-of-the-art. Certification of facilities, processes and operators could be a way to promote and ensure the development of "best waste management practices.*". The authors, in fact, proposed the establishment of an end-of-waste status for the recovery of resources in certified industrial recycling industries 26 years ago, as outlined in this section of the paper.

Pongrácz (2002) states that "*"waste" means any substance or object which has been used in a step, which cannot, in its current state and under current technical and economic conditions, be reused for the same functions or as*

material (except backfill) in another step of a circular flow, and which the holder discards or intends or is required to discard … The main aim of waste management besides waste evasion is turning wastes to non-wastes".

Since then, other options were investigated. Waste use potential, a dossier that explains all the possibilities and the qualities of a waste, should promote waste as resources, not changing the actual waste definition (van Ewijk and Stegemann, 2020). Another option to escape to the dichotomy waste/product is to produce material with (quality) technical certificate co-defined by the producers and the users (Johansson and Forsgren, 2020; Johannson, 2022). The approach of compliance with quality standards has been largely used in UK with the name "Quality Protocol" using the new category of "non-waste product" (UK 2023a).

The terms "non-waste," "certified material," "non-waste product," "secondary raw material," or "pre-material" should be considered as having a product status. The potential hazardous nature of a waste alters safety requirements and the level or intensity of preparation operations but does not change the nature of these operations. The straightforward approach is that, once it exits the modern collection and recycling facilities, the material should be treated like any other raw material and enjoy the end-of-waste status (Hennebert, 2023).

In a report for the European Commission (EC, 2020b), it is proposed that the economic operators take the responsibility of the end-of-waste status, without prior approval by the authorities, and with ex-post control if necessary: "*Simplifying certain aspects of the decision-making process by referring to the 'ex-post' assessment of the EoW decisions taken by the economic operators.*" (p 131).

In France, the tacit (implicit) end-of-waste status by production installations exists since 2016 (MEDDE 2016). There is in 2023 a project of law "for the green industry" to allow waste managers to self-declare the end-of-waste of their material (with the same conditions as in the Waste Framework Directive) without prior approval by the administration, that can ex-post control their actions, including on requirement of NGOs or industries. That proposition is in line with the Article 6(1) of the WFD (EU 2018) which states: "*Member States shall take appropriate measures to ensure that waste which has undergone a recycling or other recovery operation is considered to have ceased to be waste if it complies with the following conditions…*" and with line with the Article 6(4) which states: "*Where criteria have not been set at either Union or national level under paragraph 2 or 3, respectively, a Member State may decide on a case-by-case basis, or take appropriate measures to verify, that certain waste has ceased to be waste on the basis of the conditions laid down in paragraph 1…*": "verify that certain waste has ceased to be waste" means that the regional producers or a single producer can claim the end-of-waste status and the authority checks whether the conditions are met. Ex-post decision making would fall under the category of appropriate measures of articles 6(1) and 6(4).

6.3 Proposition #5

EU-wide tacit end-of-waste status for the material supplied by certified industrial recycling facilities.

7. FURTHER ADVANTAGES OF THESE 5 PROPOSITIONS

7.1 Simplified EU waste shipment

Trans-boundary waste shipments are essential because not all countries possess the necessary waste treatment technologies. If a waste shipment is not prohibited, it must comply with either:

- 'green list' waste controls (also known as Article 18 controls), which are simplified controls for most non-hazardous materials, or
- notification controls (sometimes known as 'amber list' controls, typically hazardous waste), which require consent from all the competent authorities involved before it can be shipped.

In this latter case there are 12 administrative steps to receive a decision of notification (UK 2023b). Additionally, the classification of waste (as hazardous or not) differs from one EU country to another, and even between regions of a country like Germany. With the 5 propositions of this paper, the waste shipment between certified industrial recycling facilities will be eased. The implicit/tacit end-of-waste status for materials potentially upon entering but certainly at the output of an industrial recycling facility will reduce administrative burden and divergent national/regional interpretation for transport of the material to be recycled. As a first step, waste transport should be improved by the so-called "fast-track" system.

7.2 EU Level playing field of waste management

The implementation of waste regulations varies across Europe, leading to unequal business conditions. The annual assessment of environmental regulation implementation in the 27 countries highlights the need for progress in waste management in many Member States. The five propositions in this paper aim to establish a level playing field in collection, sorting, and preparation, promoting fair competition and enhancing waste collection and management in less advanced countries.

8. THE DEFINITION OF WASTE SHOULD ALIGNE WITH THE HIERARCHY OF WASTE PREVENTION, MANAGEMENT AND POLICY

'Waste' means any substance or object which the holder discards or intends or is required to discard (EU Waste Framework Directive 2008-2018).

The EU waste regulation is designed to avoid human and environmental exposure to contaminants when discarded. That exposure occurs typically in linear economy by littering and secondarily by incorrect landfilling. Waste has a legal status which aims to avoid the risks for the environment and public health if it is abandoned. The definition is based on the act of discarding, rather than the value of the material. Already in 2002, "*The main aim of waste management besides waste leaks should be today turning wastes to non-wastes*" (Pongrácz, 2002). In the circular economy, waste is collected in modern systems and treated in controlled industrial loops, so that there is virtually

no human and environmental exposure (the probability of exposure to the hazard, i.e., the risk, is very low).

In the linear and low-tech circular economy, waste can be abandoned or stored and this is probably the reason why its regulation is dominated by the hazard approach and the precautionary principle. In the high-tech industrial circular economy (Figure 4), waste is a resource that must be managed by risk, and not be defined solely by the abandonment by its holder.

There are different propositions to define materials in the circular economy: "non-waste" (proposed in 1997 by Bontoux and Leone of the Joint Research Centre of the EU, and deepened by Pongrácz and Pohjola, 1997 and Pongrácz, 2002), "certified material" (Johansson and Forsgren 2020), "non-waste product" (UK 2023a), "secondary raw material" (EURIC 2019, 2020) and the related product status.

8.1 Propositions of "pre-material" and new definition of waste

In compliance with occupational safety and health regulations and industrial standards during processing, and adhering to product regulations during its second life, the material transitioning into a secondary raw material, or pre-material, should be handled similarly to other hazardous or non-hazardous raw materials (virgin). It should obtain the end-of-waste status upon entering the loop (as detailed in Section 6).

It is proposed to create separate definitions of pre-materials (that are resources) and wastes (to be incinerated or eliminated) (Figure 5):

- Pre-materials are materials that can be prepared for reuse or recycled as material with end-of-waste status.
- Wastes are matter that can only be used as a resource by other recovery, e.g. energy recovery, or that can only be disposed of. Waste is not defined by the action or intention of its owner to dispose of it.

9. CALL FOR A DEBATE ON WASTE MANAGEMENT BY RISK

9.1 EU underlying principles of the discussion on hazard and risk: precaution versus responsibility

The underlying challenge is how to effectively manage contaminants while enhancing material circularity. An administrative approach, often tied to the precautionary principle and hazard-based methods, tends to favor incineration and landfilling. On the other hand, a more liberal approach, rooted in responsibility, self-regulation, and a risk-based strategy, encourages reuse and recycling. Striking the right balance between a centralized precautionary stance ("The administration rejects due to potential hazards to people and the environment...") and a decentralized approach that promotes industry-led, risk-conscious solutions for reuse or specific applications in secondary materials is a pressing question, as discussed in a report for the European Commission (EC 2020b): "*The balance between the precautionary principle and the liberal market is kept differently in the different MS.*" (p 20). "*Risk control versus hazard control: The industry states that the check on hazardous properties of the substances contained by End of Waste and/or By-Products should be assessed in term of bioavailability and bio accessibility. In other words, does the substance represents a real risk for human health and environment during all the life cycle stages? A major focus could be laid on risk control/reduction rather than hazard reduction/control. Waste classification, however, is solely hazard-based. As a result, the EoW [end-of-waste] or BP [by-product] assessment by authorities tends to be a hazard-based approach. Often these authorities use the hazard control approach out of respect for the precautionary principle, which is justifiable although it could hinder circular economy.*" (p 130). "*Simplifying certain aspects of the decision-making process by referring to the 'ex-post' assessment of the EoW decisions taken by the economic operators.*" (p 131).

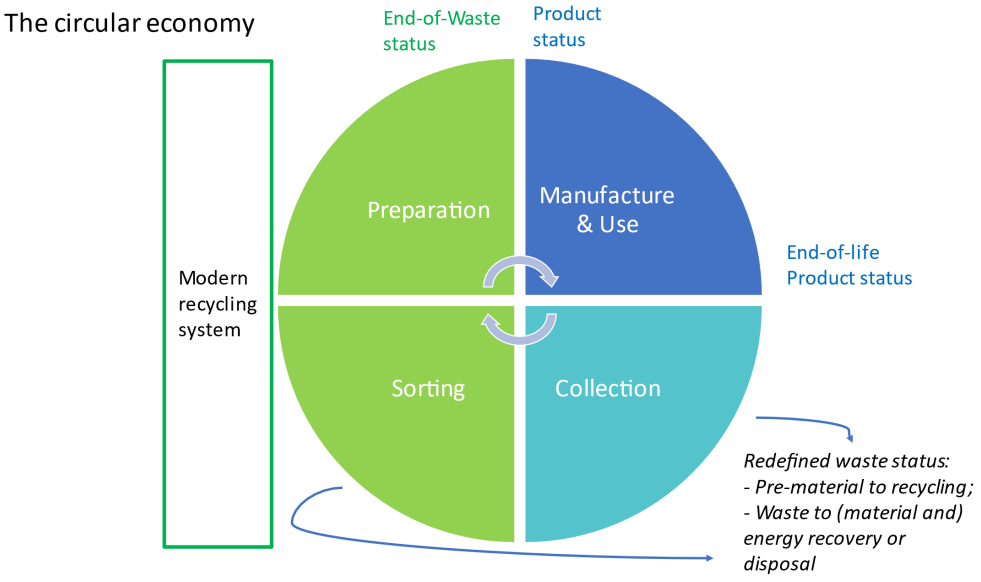

FIGURE 4: The circular economy and the corresponding status that materials/waste should have throughout the loop.

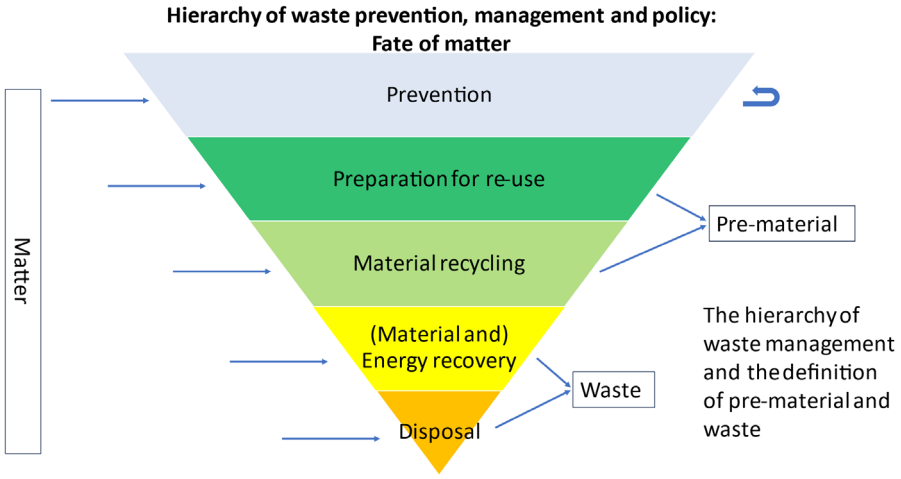

FIGURE 5: The definition of "pre-material" and "waste" based on the fate of materials within the waste hierarchy.

The ongoing discussion surrounding various products, materials, and waste could potentially find comprehensive solutions, particularly through the eco-design and "toxic-free" approach advocated by the European Commission. However, given the persistence of legacy substances and the prolonged lifespan of certain products, the recycling industry (namely EuRIC, the European Recycling Industries' Confederation), suggests that solutions emphasizing controlled risk in the intended use should be endorsed.

9.2 Call for a European Cooperation in Science and Technology (COST) action to debate

A large debate among the industry, the policy makers, the representatives, the NGOs, the consumers, the academic people involved in waste, products, substances, social aspects and law is necessary to promote the principle of responsible risk and to control the unlimited principle of precaution. A COST (European Cooperation in Science and Technology) Action is an interdisciplinary research network that brings researchers and innovators together to investigate a topic of their choice for 4 years. COST Actions are typically made up of researchers from academia, SMEs, public institutions and other relevant organisations or interested parties. Are funded: meetings, workshops, conferences, technical visits, research visits, communications, web sites. The objective is to share the ideas of this paper, and hopefully bring them to live. EuRIC participates in an initiative of the International Waste Working Group (IWWG), a scientific society, in the ongoing project "PREMAT FORUM", a forum to discuss waste management by risk and pre-material within the meaning of this paper.

10. CONCLUSIONS

In the circular economy, the management of recycled materials based on risk in the intended use plays a crucial role. The recycling industry suggests five proposals to endorse this approach, thereby fostering increased material recycling and facilitating waste shipment between certified industrial companies. These propositions could potentially warrant an EU-wide end-of-waste status for the material, potentially at the collection stage but certainly at the output of the certified recycling facility. To align with its status as a valuable resource, the legal classification of discarded materials should be determined by its place in the waste management hierarchy:

- Pre-materials: materials prepared for reuse or recycling.
- Wastes: materials only suitable for resource recovery (e.g., energy recovery) or disposal.

A COST (European Cooperation in Science and Technology) action is underway, led by the International Waste Working Group (IWWG, a scientific society) team, aimed at emphasizing the risk-based approach for waste management in the circular economy. The objective is to build consensus among stakeholders and enhance recycling practices.

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