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LETTER

Five methodological updates of the Danish Pesticide Load Indicator to support EU-wide pesticide risk reduction policies

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Abstract

The effectiveness of pesticide reduction policies in the European Union (EU) depends critically on robust, scientifically grounded indicators that can reliably monitor pesticide-related risks across Member States. The Pesticide Load Indicator (PLI), developed in Denmark in the 2000s, offers a transparent and policy-relevant framework for assessing pesticide risk. Although it has successfully supported Denmark's national strategies for over a decade and is drawing attention in other EU countries, several methodological limitations hinder its broader applicability. This letter identifies five such limitations and proposes corresponding updates to enhance the indicator's scientific robustness and scalability across the EU: (1) consistent hazard assessment across compartments, (2) precautionary treatment of missing data, (3) updated hazard metric selection, (4) harmonised normalisation procedures and (5) a statistically grounded weighting protocol. These methodological updates aim to establish a harmonised PLI suitable for EU-wide policy applications, such as fiscal instruments (e.g. differentiated taxation based on hazard levels) and pesticide risk assessments.

1. Introduction

The abandonment of the European Union's (EU's) proposed sustainable use of pesticides regulation urgently requires consolidation of the implementation of the existing sustainable use of pesticides directive (SUD; Directive 2009/128/EC) [1]. This is particularly important for the robust, scientific and transparent selection of indicators for assessing pesticide risk at the EU and Member State (MS) levels.

The Harmonised Risk Indicator (HRI-1), introduced by commission directive 2019/782/EU [2, 3] and incorporated into Article 15 and Annex IV of the SUD, shows a decreasing trend over time, in line with the objectives of the Green Deal and the Farm to Fork strategy [4–6]. However, the indicator lacks robustness, scientific validity and transparency. Recent literature has demonstrated that HRI-1 fails to provide a sound scientific basis, uses biased weighting factors, inadequately reflects actual risk and is inappropriate for effectively assessing the SUD's objectives, ultimately resulting in misleading signals [7–12]. This results in a need for improved pesticide policy instruments at EU level that has been widely acknowledged [7–14].

A vast number of other pesticide risk indicators have been proposed in the scientific literature over the years (e.g. [14, 15]). In particular, the Pesticide Load Indicator (PLI) [16–18], first developed and implemented in Denmark, has been shown to offer a scientifically grounded and policy-relevant alternative for pesticide risk assessment, and emerges as a strong candidate for integration into EU-wide pesticide policy frameworks [9, 19–21]. For more than a decade, it has successfully supported Danish national efforts to reduce pesticide risks, serving as the basis for a hazard-differentiated pesticide taxation that replaced the former value-added tax, and is now scheduled for revision under the current Danish National Action Plan (NAP) on pesticide reduction

[22–26]. Beyond Denmark, the PLI is being integrated into other national frameworks, such as the United-Kingdom's (UK's) post-Brexit pesticide policy [27–31], and is subject to review by the EU joint research centre [32]. It has also been implemented in an open-source *R* package [33] and applied in various contexts in the scientific literature as a reliable and informative risk indicator (e.g. [10, 14, 19, 27, 34] and the associated body of evidence published in Danish, e.g. [22–24][4]). Given this broad interest in the PLI from both the scientific community and policymakers, this is a timely opportunity to revisit and address the indicator's methodological limitations.

While the PLI has proven effective for national pesticide reduction strategy in Denmark, applying it across EU MS level requires addressing several methodological issues for both pesticide taxation and risk assessment. Specifically, the indicator: (1) applies heterogeneous definitions of hazard across its compartments, (2) adopts an optimistic approach to missing data, contradicting the precautionary principle of the placing of plant protection products on the market, (3) relies on outdated hazard metric selection, (4) uses normalisation procedures that are skewed and tailored to the temporal landscape of active substance authorisations in Denmark and (5) employs arbitrary weighting factors for aggregation that are tailored to the Danish ecological and political context.

These shortcomings, however, can easily be lifted to improve the indicator's scientific robustness and scalability. To address them, we propose five methodological updates partly informed by the Danish (DK-PLI) and British (UK-PLI) versions of the indicator. These include: (1) consistent active substance-level hazard assessment across compartments, (2) precautionary substitution of missing data, (3) updated hazard metric selection reflecting the latest scientific knowledge, (4) harmonised normalisation procedures to address skewness and contextualisation and (5) a statistically grounded weighing protocol to support coherent aggregation.

These revisions aim to support the development of a scientifically robust and Harmonised PLI (HPLI) that can be applied consistently across EU MS. This HPLI is intended to facilitate the implementation of the polluter-pays principle by enabling differentiated pesticide taxation based on hazard levels [36]. Combined with local pesticide use data, the HPLI could also serve as a foundation for more detailed pesticide risk assessments at finer spatial scales.

2. PLI

The PLI is a risk score indicator designed to assess the *potential* risk of negative environmental and human health impacts associated with pesticide use. It integrates hazard metrics across three compartments: (1) environmental fate (including persistence, transfer from agricultural soils to water bodies and bioaccumulation in biota), (2) ecotoxicity to various non-target organisms and (3) human toxicity. These metrics are aggregated into a single composite hazard score[5], which can serve as the basis for differentiated pesticide taxation. For risk assessment purposes, the hazard score is subsequently multiplied by pesticide use (or sales) data (at spatial scales ranging from individual fields to the national level) to form a risk score.

This risk score represents the *load*, i.e. the potential impact of pesticide use. The PLI does not account for specific application parameters (spray and protective equipment, weather conditions at application, soil composition and slope, presence of buffer zones or water bodies, etc), but instead reflects the potential impact based on the intrinsic hazard of pesticide active ingredients.

The PLI derives its hazard data from the Pesticide Properties Database (PPDB) [37, 38], curated since 1996 by the Agriculture and Environment Research Unit at the University of Hertfordshire, UK [39]. The PPDB consolidates regulatory data from the European Food Safety Authority (EFSA) and peer-reviewed scientific literature, ensuring access to the most comprehensive and consistently maintained pesticide database currently available[6].

3. Methodological updates

3.1. Consistent active substance-level hazard assessment across compartments

When the DK-PLI was first developed in Denmark in the late 2000s, human toxicity metrics where virtually unavailable[7] and the human health compartment of the indicator was based on hazard phrases from the labels of formulated pesticide products (in accordance with Regulation 1272/2008/EC [42]), which take into account both active substances and co-formulants. However, as the other two compartments are assessed based on active substance properties alone and as co-formulant composition is protected by industrial confidentiality, this approach lacks both comparability between compartments and transparency.

[4] A review of the literature published in Danish on the DK-PLI implementation, adoption by the stakeholders, adaptations and resulting pesticide load reduction in Denmark can be found in [35].

[5] The aggregation into a single score, essential for a pesticide tax definition, is not mandatory for other uses of the indicator: it can be used unaggregated to assess specific risk assessment, specific metric trends or compare the loads between non-target organisms, as is done in both the Danish (e.g. figures 7.3 and 7.4 in [23]) and British versions of the indicator.

[6] Including data from the Biopesticides Database (BPDB) [40] would even broaden the scope of the indicator.

[7] Human toxicology data beyond the basic oral median lethal dose (LD_{50}) for acute oral mammalian toxicity were only added in the PPDB around 2012 [41].

Since the initial DK-PLI development, data availability has improved significantly, with a growing body of human toxicological research produced in recent years. We therefore propose that the HPLI be defined consistently across all compartments using active substances properties from the PPDB, including those related to human toxicity (see section 3.3 for the selection of toxicity metrics).

3.2. Precautionary substitution of missing data

The DK-PLI currently replaces missing data with null hazard values [17], a practice that diverges from the precautionary principle of Article 1.4 of Regulation 1107/2009/EC[8] [43]. For HPLI pesticide taxation applications, we recommend adopting a conservative risk estimate by substituting missing values with high hazard thresholds[9] (table 1). For comparative risk assessments, however, imputing average values by pesticide functional group (e.g. herbicides, fungicides, etc; as in the UK-PLI approach [28]) may provide a more balanced alternative.

To further limit potential distortion of HPLI scores due to data imputation, we propose introducing a data coverage threshold in line with the UK-PLI approach [30]. Active substances would be excluded from the HPLI calculations where fewer than a defined threshold of the selected hazard metrics have available data in the PPDB. Rainford *et al* [28, 30] evaluated several possible thresholds and identified 60% as an optimal compromise that balances minimising distortion of the final score with maximising the number of active substances included in the indicator. Accordingly, we adopt the 60% data coverage threshold for the HPLI.

3.3. Updated hazard metric selection reflecting the latest scientific knowledge

The development of a holistic HPLI aims to integrate a comprehensive set of environmental fate and (eco)toxicity properties to assess the hazards posed by pesticide use more accurately. However, a key challenge in achieving this goal is still the limited availability of relevant hazard data in the PPDB.

To address this, we propose a streamlined protocol in which all hazard metrics available in the PPDB that fall within the three PLI compartments are considered (excluding tropical and marine organisms; see table S1 in the supplementary material), provided they have defined values for at least 60% of active substances authorised for use in the EU. The 60% threshold for metric selection (chosen to be equal to the active substance data coverage threshold, cf section 3.2) is introduced to avoid selecting metrics that would be dominated by imputed missing data.

This results in the selection of 20 hazard metrics (table 1) from the 42 available in the PPDB (table S1 in the supplementary material), including five metrics relating to environmental fate (soil and water persistence, transfer to surface and ground water and aquatic bioaccumulation), four relating to terrestrial ecotoxicity (acute toxicity to birds, earthworms, honeybees and mammals), five relating to aquatic ecotoxicity (acute and/or chronic toxicity to algae, aquatic invertebrates and fish) and six relating to human toxicity (acute dermal and inhalation toxicities, carcinogenicity, cholinesterase inhibition, neurotoxicity and reprotoxicity). For comparison, the DK-PLI includes 15 metrics [16, 17].

Local versions of the HPLI could be derived to support comparative risk assessments of pesticide products or active substances and for decision-support tools for pesticide users, by applying the 60% threshold to the pesticides used in a specific region and reference year rather than to all active substances authorised at EU level (see section 4).

3.4. Harmonised normalisation procedures to address skewness and contextualisation dependency

In order to aggregate the various hazard metrics into a single indicator, the metrics are first normalised into unitless values on a common scale. In the DK-PLI and UK-PLI versions of the indicator, normalisation is performed by dividing each value by the worst hazard value for each metric among all authorised active substances in a given country and reference year. This results in values ranging from 1 (the highest hazard) to 0 (the lowest hazard). However, these normalised values are context-dependent and lack intrinsic meaning, as they are tied to the relative temporal landscape of hazard thresholds rather than to absolute hazard thresholds. Additionally, extreme outliers in certain hazard metrics lead to highly skewed distributions, causing some metrics to disproportionately influence the aggregated PLI score[10]. Furthermore, this normalisation supposes direct linearity between metric values and hazard, whereas most dose-response curves are known to be non-linear (often sigmoidal, sometimes even non-monotonic) [44, 45]. To address these three issues, we propose a dual methodological improvement.

[8] '*In particular, Member States shall not be prevented from applying the precautionary principle where there is scientific uncertainty as to the risks with regard to human or animal health or the environment posed by the plant protection products to be authorised in their territory.*'

[9] This, in turn, will incentivise pesticide producers to submit more complete, scientifically robust toxicological data to address gaps in the PPDB and reduce the pesticide tax on their products.

[10] This ultimately led to the abandonment of the aggregation in the UK-PLI as they could not resolve this issue [28, 30].

Table 1. The 20 hazard metrics considered for the HPLI calculation (from the 42 available in the PPDB; see table S1 in the supplementary material), their respective proposed normalisation thresholds and resulting aggregation weights (calculated based on PPDB data last updated on 3 May 2024).

			Thresholds[a]									
	Metric	Property	0.00	0.10	0.25	0.33	0.50	0.67	1.00	1.50	References	Weights[b]
Environmental fate	Soil persistence	DT_{50} soil (d)	0		20		60		180	1 800	[47]	10.5%
	Water persistence	DT_{50} water (d)	0	1			14		30	300	[48]	6.6%
	Transfer to surface water	K_{FOC} (mg g^{-1})	10 000		1 000	500		75	15	0	[49]	5.2%
	Transfer to ground water	GUS	–18	0	1.8				2.8	28	[50]	5.1%
	Aquatic bioaccumulation	BCF	0				100		5 000	50 000	[51]	5.9%
Ecotoxicity (terrestrial)	Birds (acute)	LD_{50} (mg kg_{bw}^{-1})	20 000		2 000				100	0	[48]	2.9%
	Earthworms (acute)	LC_{50} (mg kg_{soil}^{-1})	10 000		1 000				10	0	[48]	3.2%
	Honeybees (acute)	LD_{50} (µg bee^{-1})	1 000		100				1	0	[48]	7.5%
	Mammals (acute oral)	LD_{50} (mg kg_{bw}^{-1})	20 000		2 000				100	0	[48]	3.1%
Ecotoxicity (aquatic)	Algae (acute)	EC_{50} (mg l^{-1})	100		10				0.01	0	[52]	4.6%
	Aquatic invertebrates (acute)	EC_{50} (mg l^{-1})	1 000		100				0.1	0	[48]	2.9%
	Aquatic invertebrates (chronic)	NOEC (mg l^{-1})	100		10				0.01	0	[48]	3.1%
	Fish (acute)	LC_{50} (mg l^{-1})	1 000		100				0.1	0	[48]	2.9%
	Fish (chronic)	NOEC (mg l^{-1})	100		10				0.01	0	[48]	3.1%
Human toxicity	Mammals (acute dermal)	LD_{50} (mg kg_{bw}^{-1})	50 000		5 000		2 000		200	0	[c]	5.1%
	Mammals (acute inhalation)	LC_{50} (mg l^{-1})	100		10		4		0.1	0	[c]	5.2%
	Human	Carcinogenicity	no				possible		yes			9.1%
	Human	Cholinesterase inhibition	no				possible		yes			2.9%
	Human	Neurotoxicity	no				possible		yes			3.5%
	Human	Reprotoxicity	no				possible		yes			7.4 %

[a] Threshold values are interpreted as follows: 0.00 = ‘very low’ load; 0.25 = ‘low’ load; 0.50 = ‘moderate’ load; 1.00 = ‘high’ load; 1.50 = ‘very high’ load.
[b] The weights sum to 33.3% for environmental fate, 33.3% for ecotoxicity (terrestrial + aquatic) and 33.3% for human toxicity.
[c] Data in the literature are limited and vary in format, making it difficult to extract accepted interpretation thresholds.

Firstly, to mitigate skewness and remove context dependency, we argue for defining absolute bounding hazard thresholds (i.e. fixed reference values derived from toxicological or regulatory limits; table 1) that represent a high-hazard level (corresponding to a normalised value of 1). Note that this allows normalised values of certain metrics to exceed 1 for substances with extremely high hazard (see section 4).

Secondly, to improve interpretability and reduce skewness further, we suggest introducing intermediate hazard thresholds (defining piecewise linear normalisation curves) to provide a clear meaning to normalised hazard values (table 1)[11].

3.5. Statistically grounded weighing protocol to support coherent aggregation

The comprehensive inclusion of metrics from the PPDB (cf section 3.3) can lead to redundancy, especially when closely related taxa are overrepresented compared to other functional groups (e.g. multiple metrics for beneficial insects). To address this issue, we propose a hybrid aggregation method combining (1) fixed, compartment-level weights that ensure balance across compartments and (2) statistically derived weights within each compartment to account for metric redundancy.

The fixed component of the weighting structure is proposed as follows: (1) one-third is assigned to environmental fate, (2) one-third is assigned to ecotoxicity (equally divided between terrestrial and aquatic ecotoxicity) and (3) one-third is assigned to human toxicity.

The statistically derived component proceeds as follows (figure 1; table 1)[12]:

1. A Spearman correlation matrix ρ_{ij} is computed for all metrics within a (sub-)compartment, using the full PPDB dataset.
2. For each metric i, the sum of its absolute correlations with all other metrics is calculated:

$$S_i = \sum_{i \neq j} \left|\rho_{ij}\right|.$$

3. Weights are then assigned inversely proportional to these sums:

$$w_i = \frac{1/S_i}{\sum_i (1/S_i)}.$$

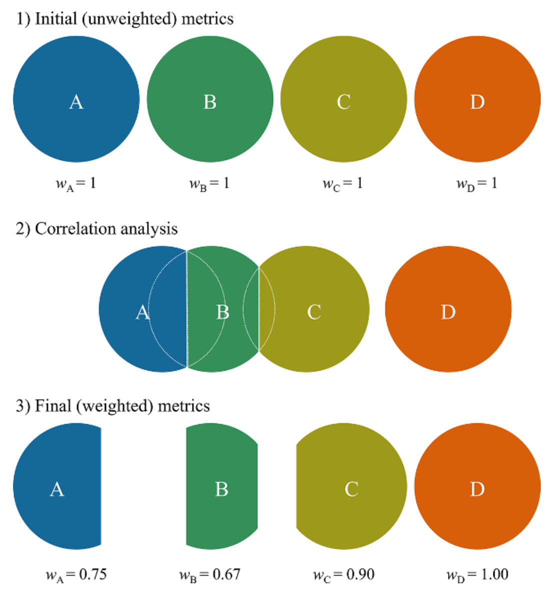

Figure 1. Inverse correlation weighting approach: (1) starting with unweighted metrics, (2) correlation analysis reveals redundancy in correlated metrics, (3) leading to weights that reflect the unique informational contribution of each metric within a (sub)compartment.

4. Finally, the weights are normalised so that they sum to 100 across all metrics used in the global HPLI score.

Using the complete PPDB dataset for the correlation analysis, including substances regardless of their contextualised regulatory status (e.g. authorised or banned active substances, metabolites or formulants), ensures that the derived weights reflect intrinsic relationships between metrics (physico-chemical and (eco)toxicological properties) rather than regulatory artefacts.

This approach down-weights metrics that are correlated with others, ensuring that each metric contributes distinct information (figure 1). Consequently, the dominance of redundant metrics on the overall HPLI score is reduced, as is the dependence on expert or stakeholder judgement for weight allocation. In addition to addressing redundancy, this method overcomes the context-specific nature of the original Danish weighting scheme, which was shaped by national negotiations and policy priorities in the late 2000s. The resulting protocol offers a more science-based and transferable aggregation framework, making it suitable for broader application across the EU.

Table S2 of the supplementary material provides an illustrative list of aggregated loads for substances authorised in EU passing the 60% data availability threshold. To facilitate exploration, visualisation and interpretation of the HPLI results, we developed a Shiny application that allows interactive visualisation of hazard scores (i.e. intrinsic load of active

[11] Figure S1 of the supplementary material provides an overview of normalised hazard values for six contrasting active substances for the local HPLI-Wal based on used substances in Wallonia.

[12] Figure S2 of the supplementary material provides an overview of *weighted* normalised hazard values for six contrasting active substances for the local HPLI-Wal base on used substances in Wallonia.

substances): the application is publicly available at https://sytra.shinyapps.io/HPLI.

4. Discussion

The proposed methodological updates for a HPLI aim to inform ongoing scientific and political discussions by providing a harmonised risk indicator for EU-wide pesticide policies and taxation purposes that is more scientifically grounded and transparent. These updates address the known limitations of the original DK-PLI and UK-PLI adaptations, particularly regarding metric normalisation and the definition of aggregation weights.

To ensure harmonisation at the EU level, particularly in the context of a differentiated pesticide taxation, we prioritised harmonisation over universality by restricting the selection of metrics to those for which data on active substances authorised at the EU level reaches the 60% coverage in the PPDB. A key strength of the five proposed methodological updates is that they can be regularly realigned with the latest scientific knowledge consolidated in the PPDB. As scientific research progresses, future updates of the HPLI may incorporate additional metrics. However, it is essential to maintain a temporal stability to the indicator to ensure its reliability over time and allow sufficient time for farmers and stakeholders to adapt to evolving policies or taxation mechanisms. To strike a balance between scientific rigour and stability, we recommend aligning HPLI revision cycles with existing EU policy frameworks. For instance, synchronising updates with the seven-year Common Agricultural Policy (CAP) cycle or with a ten-year cycle spanning two five-year NAP periods could provide a coherent, legally grounded revision process balancing stability and up-to-dateness.

Although the proposed HPLI framework is designed to transcend the Danish context and be applicable across EU MS, it allows for contextualisation where detailed pesticide use data are available. In Wallonia (southern Belgium), for example, applying the 60% threshold for metric selection to active substance use in 2022 [52] leads to the selection 27 metrics for a regional HPLI-Wal. The additional metrics include acute toxicity to predatory mites and parasitic wasps, chronic toxicity to birds, earthworms, mammals and aquatic plants, as well as human genotoxicity. Such contextualisation in metric selection enables more informative applications at local scales, beyond taxation. Additionally, metric weights could be redefined in such local versions of the indicator to reflect national priorities or ecological context. Future implementation of harmonised dataset, such as those from the Farm Sustainability Data Network (FSDN) [53], the Statistics on Agricultural Inputs and Outputs (SAIO) [54] and electronic records of plant protection products [55], will further support better informed, (de-)centralised HPLI version(s).

The applicability of the indicator goes beyond taxation and territorial assessment. For example, multiplying the load score of a pesticide (active substance or formulated product) by a standard dose would yield a 'standard load'[13]. This can be translated into a 'Pesti-Score' classification from A (low standard load) to E (high standard load) analogous to the Nutri-Score for food products[14], providing a user-friendly guide for pesticide users and advisers when selecting pesticide targeting the same pest.

Further discussion and refinement of the HPLI framework may be necessary. While our objective was to strengthen the scientific basis of the indicator, it remains (as any such tool) a utilitarian construct shaped by its intended purpose, whether that be taxation, monitoring or risk communication. Therefore, its design aims to balance scientific rigour, transparency and practical usability [57, 58]. For example, the revised weighting protocol (see section 3.5) introduces statistical coherence and addresses metric redundancy; however, it also depends on (arbitrary) structural choices, such as the definition of the indicator compartments and the fixed (compartment) weights, that may require further discussion or adjustment.

One limitation of our approach is the automatic imputation of missing values, in particular for inorganic active substances for which data gaps often stem from their 'naturally occurring' status. In such cases, neither assigning conservative hazard levels (as proposed here), null hazard levels (as in the DK-PLI) nor excluding partially these substances from specific compartments (as in the UK-PLI) does offer a fully satisfactory solution, as each option distorts the indicator structure and/or final hazard score to some extent. The same applies to active substances for which data on certain metrics are absent because their low hazard classification on other metrics indicates a low level of concern and makes their assessment non-mandatory.

In addition, the exclusion of substances with missing toxicity data above 60% may introduce bias, particularly if these substances are widely used or highly toxic to certain non-target organisms for which data exist. Exclusion should therefore be clearly documented and its implications carefully considered [35]. In practice, the precautionary substitution approach aligns with regulatory and taxation purposes, while

[13] In the DK-PL, this is referred to as the 'load index' [16].

[14] The Nutri-Score is a front-of-pack nutrition label that ranks food from A (healthiest) to E (least healthy) using a green-to-red colour scale. Based on a 100 g portion, it considers both positive (e.g. fibre, fruit, protein, healthy oils) and negative (e.g. sugar, saturated fat, sodium) nutritional components. It is endorsed by several EU MS, the European Commission and the WHO as a tool to guide healthier food choices [56].

allowing for updates when new toxicity data become available. Nonetheless, although a detailed sensitivity analysis is beyond the scope of this letter, it would be valuable for assessing the robustness of the HPLI with regard to the choice of threshold and imputation method. Future work could empirically evaluate the impact of different imputation strategies or coverage thresholds to support the ongoing refinement of the indicator.

Another limitation lies in the proposed normalisation method[15]. Allowing normalised hazard values to exceed 1 for extremely hazardous substances[16] could perpetuate the issue of metric dominance within the aggregated score, as observed in the UK-PLI (where environmental fate metrics dominated the aggregated indicator value[17]). While this may be acceptable for taxation purposes, where higher scores act as a stronger financial disincentive to use the most hazardous substances, it could be viewed as a bias in risk assessment applications as it increases the relative weight of the corresponding metrics. However, except *Bordeaux mixture* (with 38% of its hazard score due to missing data imputation), no substance authorised in the EU passing the data availability threshold has a total aggregated hazard score above 1. On average, no single metric contributes more than 8% of the total hazard score (with water persistence, mammalian acute inhalation toxicity, honeybee acute toxicity and algae toxicity being the highest contributors). This shows that our normalisation approach prevents the metric dominance seen in UK-PLI aggregation attempts.

The aim of this work is ultimately to provide a solid basis for discussion among scientists and policymakers on an EU-wide reference indicator that is both scientifically robust and politically relevant. It is crucial that the definition of the HPLI remains transparent and reproductive in order to enable both centralised and decentralised applications, while preserving legibility and usability for end users.

5. Conclusion

To enhance the scientific robustness of the PLI and harmonise its application across MS, we propose five key methodological updates for a HPLI. These refinements are intended to support the development of a coherent, precautionary and policy-relevant HPLI that enables both effective risk assessment and the implementation of the polluter-pays principle in the EU. The HPLI offers a promising and timely alternative to the HRI-1 for EU-wide assessment and taxation of pesticide risk.

[15] One alternative strategy to reduce the skewness caused by extreme values would be to apply a bounding box approach, such as using the 95th or 99th percentile as the upper threshold to define the 'high hazard' (i.e. the normalised score of 1). While this could mitigate skewness, it would not resolve issues relating to the contextualisation of the normalisation or the meaninglessness of the resulting values.

[16] This applies particularly to the environmental fate compartment, where most hazards increase as metric values increase, resulting in no 'absolute' cap. In contrast, (eco)toxicity metrics exhibit increasing hazard as metric values decrease, resulting in null toxicities representing an 'absolute' hazard threshold (see table 1).

[17] '*Using the Fixed approach calculated over the sum of all arable applications between 2010 and 2020, metrics of fate make up over 98% of the combined indicator value* […]' [28].

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Supplementary material available at https://doi.org/10.1088/1748-9326/ae269b/data1.

Supplementary data available at https://doi.org/10.1088/1748-9326/ae269b/data2.

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Conflict of interest

The authors declare that they have no conflict of interest.

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