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REVIEW **Open Access**

Critical review of the default values used in the environmental impact assessment of biocidal products applied in livestock production systems

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Abstract

Background The default values in the models used for environmental risk assessment are mostly more than a decade old. Market developments, structural and legal changes lead to adaptions of animal husbandry and manure management during this time. The scope of this research project was the critical review with regard to the topicality and plausibility of the default values for the assessment of insecticides/larvicides and disinfectants in stables, which are mentioned in the relevant emission scenario documents (Joint Research Centre, Institute for Health and Consumer Protection, Raffael B, Van de Plassche E (2012) Emission scenario document for product type 3: veterinary hygiene biocidal products. Publications Office. 10.2788/29747; OECD (2006) Emission Scenario Document for Product Type 18 No.14 Emission Scenario Document for Insecticides for Stables and Manure Storage Systems", ENV/JM/MONO(2006)4), supplemented by the draft of Addendum 1 (European Chemicals Acd 1999 agency (ECHA) (draft recommendation of 2021). Addendum to OECD SERIES ON EMISSION SCENARIO DOCUMENTS, Number 14: Emission Scenario Document for Insecticides for Stables and Manure Storage Systems, ENV/JM/MONO(2006)4 Version 1.2).

Results Several default values used in the current emission scenario documents (ESDs) were identified as outdated such as the housing scenarios for laying hens. It should be evaluated if outside climate housing was already covered by the existing scenarios or requires the addition of a new one. Additionally, the lack of valid data regarding for instance biocide application and biodegradation data, may also have an impact on the predicted environmental concentration (PEC).

Conclusions Based on the results of the present study an update of the ESDs is suggested.

Keywords Emission scenario documents (ESDs), Environmental risk assessment, Disinfectants, Product type 3, Product type 18

Introduction

Products containing biocidal active substances are commonly used in livestock farming for disease prevention [4]. These active substances function through means other than mere physical or mechanical action against harmful organisms and are used, for example, for disinfection or as insecticide treatments against pests in animal housings. Of course, the effects of active substances are not limited to pathogens or

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vectors; biocides also have adverse effects on the environment, human, and animal health [5–8]. To assess these adverse effects, an environmental risk assessment is conducted as part of the approval of the active substance as well as during the product authorization process. For evaluation of the environmental impacts of insecticides and disinfectants used in livestock operations, a comparison of the predicted exposure of all affected environmental compartments (predicted environmental concentration, PEC) with a concentration of the biocide that does not cause adverse effects on organisms (predicted no-effect concentration, PNEC) is performed [9]. The prediction models used for this purpose are harmonized throughout the EU. The use of biocidal products in livestock production is mirrored in different scenarios to calculate the PEC values, which are described in EU-wide agreed emission scenario documents (ESDs) [1, 2]. The ESDs are divided in different product types (PT) of biocides, which are shown in Additional file 1: Table S1. In livestock farming, products from PT3 and PT18 are predominantly used, therefore, this study focussed on these two PTs.

All emission scenarios used contain specific estimating equations, including input parameters and default values. The currently used emission models are based on data that have been checked for their topicality and plausibility only in specific cases since they were agreed upon at the EU level in 2006 and 2011 [1, 2]. To perform a more realistic assessment of the environmental impacts, the structural changes of the last decade in agriculture must be considered. This includes the adjustments in livestock farming, especially in animal husbandry, as well as changes in the management and usage of manure, e.g., the increase of biogas production. The type of animal or husbandry system also determines the number of animals in a stable as an important example for a default value. Since it is assumed that biocide residues enter the manure when used in animal husbandry [10], a relevant entry pathway into the environment is the application of manure as organic fertilizer to agricultural soils [11], resulting via circular bioeconomy back to food chains with, e.g., reused water. Here, both ESDs specify that manure application occurs on both grass and cropland. The associated model assumptions differ for grass and cropland based on the agricultural practice of manure application [1, 2].

The models in the ESDs, including the input parameters and default values, have not yet been reviewed. Therefore, the standard assumptions no longer necessarily reflect the current framework of biocide applications in animal hygiene and pest control in livestock farms in the EU. The aim of this study was to critically review the current assumptions to build a basis for discussion between the member states to initiate any necessary revisions to the ESDs or coordinated research activities to fill possible research gaps before revising the ESDs.

Methodical procedure

The following four documents were critically reviewed:

- OECD ESD PT 18 No.14 "Emission Scenario Document for Insecticides for Stables and Manure Storage Systems" [2],
- ESD PT 3 "Veterinary hygiene biocidal products" [1],
- Supplementary Addendum 1 (draft 2021) [3]) and
- corresponding sections of the Technical Agreements for Biocides Environment [12].

The focus of the review was from the animal science perspective. The documents were evaluated according to the following criteria:

1. Topicality and plausibility of the mentioned animal categories and husbandry systems in a pan-European context.
2. Topicality and plausibility of the mentioned standard assumptions for the input pathways from livestock buildings, particularly farm manure, into the environment.
3. Completeness of procedures used in agricultural practice within the corresponding scenarios.

The information in the original sources was carefully read and screened for all assumptions and descriptions related to animal husbandry. This information was compared with established practice and legal situations in the European member states. Since for many member states only limited data about practices and management were available, in this case of missing dataparticular emphasis was put on the practice in Germany. Additionally, in case of missing international published data for EU member states and Germany, German national ordinances, guidelines, court decision and other grey literature were used. If this comparison revealed discrepancies, all selected references were checked with wording from the original sources used as search keywords. In many cases, the literature search was limited to current references using the function "dated between 2015 and 2022".

Outdated data were listed, and open research questions were identified and compiled in this critical review.

Results

Default values specific to animal species

Animal species, types of housing and age are summarized in the category-subcategory (cat-subcat) variable, as shown in Table 5.1 in ESD PT 18 No. 14 [2]. In particular, some poultry housing types (battery and unenriched cages) are currently no longer permitted EU-wide according to CD 1999/74/EC [13] and, therefore, are no longer relevant (see Table 1, battery cages). These types can therefore likely be subsumed in one category (enriched cages). In particular, p. 25 and 26 of the original document [2], dealing with these banned poultry housing type scenarios, needs to be revised and/or checked for deletion. Although wastewater disposal and manure management might also differ in enriched cages, it would be preferable to have more empirical data about this husbandry system in practice to suggest only the minimal necessary number of worst-case scenarios. Furthermore, due to an increase in organic production, housing in a

Table 1 Variables of cat-subcat Index i1 involved in the model

Original value	Description of the variable content	Recommendation
Cattle		
1	Dairy cow	Remain, but include calves for remounting until heifer
2	Beef cattle	Remain
3	Veal calves	Remain
ENV 220 [12]	Calves in igloos	Integrate
Pigs		
4	Sows, in individual pens	Since farrowing also takes place in groups, it is recommended to change the wording to "sows in farrowing units"
5	Sows in groups	Remain
6	Fattening pigs	Remain
	Weaner piglets	Currently missing, suggested to add if not covered by the fattening pigs as a worst-case scenario
Poultry		
7–10	Laying hens in battery cages	This housing system has been permitted throughout the EU since 2012; recommend to shorten to one variable "Laying hens in enriched cages"
11	Laying hens in free range with litter floor (partly litter floor, partly slatted)	Delete the supplement in brackets since the slatted floor in hen husbandry seems to be outdated
12	Broilers in free range with litter floor	Remain
13	Laying hens in free range with grating floor (aviary system)	Change order and list before broilers
14	Parent broilers in free range with granting floor	Remain
15	Parent broilers in rearing with granting floor	Remain
16	Turkeys in free range with litter floor	Remain
17	Ducks in free range with litter floor	Remain
18	Geese in free range with litter floor	Remain
	Quails and ostriches	Should be checked if relevant
19	Manure storage—wet	Remain
20	Manure storage—wet	Remain
Other species		
	Horses	Not considered, because of missing data. Relevance of insecticide applications is unclear because of an increase of vector-borne diseases, but there are limited data if prevention is performed via chemical or physical vector elimination [16–20]
	Goat	Should be checked if relevant
	Sheep	Should be checked if relevant
	Rabbit	Integrate the decision of the BPC WG ENV IV 2020 that for rabbits, the default values from animal category 10 should be used; however, the amount of nitrogen produced per animal per day should be replaced by the default value for ducks
ENV 207 [12]	Mink	Integrate
	Farmed game	No worst-case scenario expected, but should be checked for the sake of completeness
	Insects	No worst-case scenario expected, but should be checked for the sake of completeness

Variables from the ESD were checked based on the literature research regarding systemic categorization from Haupt et al. [15]

natural outdoor climate and animal husbandry on pasture with only shelters, data should be generated about how biocide applications are performed. It seems that the current ESD follows a definition of housing that differs between indoors and outdoors. Indoor housing in the ESD is likely used as a synonym for closed warm stalls. Since pigs, turkeys and all cattle are commonly housed with permanent access to fresh air in open indoor stables with open sidewalls, overshot roofs, open ridges, short upstands or ridge caps, the air exchange between indoor stables and their surroundings may facilitate the emission of biocides or their metabolites [14].

In the description of the cat-subcat variables, age was named as one crucial factor included in this category. Age does not seem to be systematically implemented since remounting of dairy cows and weaned piglets is missing (see Table 1).

Generally, the aim should be to simplify the exposure assessments and reduce the number of scenarios. Therefore, not only the decisions but also the detailed consideration of the relevance, including the assumptions, should be made transparent and public. Reports from possible future evaluations of relevance should also be published, especially information that certain scenarios are already covered by another worst-case scenario. The numbers of animals per farm fit the current statistics and can be kept.

The assumed defaults [2] regarding production cycles, house size, and nitrogen excretion rates per animal appear to be often valid as a worst-case scenario but outdated as representative average values. This can be explained by a few examples in more detail:

Production cycles were assumed to be 12 months for laying hens (original Table 5.6) and up to 42 d (original Appendix 5 p. 87, Index i1 #12, 14 and 15) or 52 d (original Table 5.6 and 5.7) [3] for broilers. These periods still represent the shortest possible duration in conventional farming and thus are realistic worst-case scenarios. However, considering the substantial proportion of organic production with lower growth rates for broilers and recent developments to increase lifetime performance of laying hens [21, 22], the average production cycle will be longer, affecting the Tbioc-int interval (original Table 5.7 of the ESD [2]). It is unclear why storage times in some poultry categories (12, 14 and 15, original Appendix 5 p. 87) [3] can be shorter than the production cycle (original Table 5.6 [2]). Inconsistencies should be addressed in an update.

Improvements in animal welfare and disease prevention predominantly lead to decreases in animal density [23–25]. Standard and branded meat programs announced 10 and 20% more space per animal in the last five years [26], which is partly mirrored in higher minimum space requirements for some animal species. As a result, the default values for floor area require revision. Additionally, the standard and branded meat programs require functional areas in the stable and provide some areas without a fully slatted floor to enable animals to physically separate activities such as lying, eating and dunging. In Germany, these stable structures are mainly implemented in practice [27–29]. This means that in some cases, the slatted area can likely be reduced based on scientific evidence. With the reduced proportion of fully slatted areas combined with the enhanced organic farming, the proportion of litter increases, and previously irrelevant dry storage or manure heaps (marked as n.r. in Appendix 5, table) [3] have potential to become relevant. However, representative EU-wide data or a synopsis of all legal minimum space and floor requirements are lacking. For duck fattening, slatted floors were nearly completely exchanged by plain floors with litter [30], which is correctly indicated in Table 5.3 [2] as not relevant.

A trend in dairy cow production is that some standards and dairy programs require cows to be kept on pasture for at least 120 days per year dependent on the region to promote the milk as pasture milk [31, 32]. For those cases, the current models presume either that cows kept on pasture are outside during the daytime and in the stable at night, resulting in an assumption that 40% of the manure goes to storage or that cows graze day and night and visit the milking parlor twice a day, with the assumption that 15% of the manure goes to storage. First, in practice, cows avoid heat and noontime sunlight. If pasture access can be chosen voluntarily, cows prefer to be in the stable around noon and enjoy pasture in the morning, late afternoon, evening, and at night [33]. Second, stressful situations are mirrored by increased dropping of feces as seen in sheep [34] and likely appear more often in the stable than on pasture [35]. Therefore, 15% manure entry to stable storage for 24 h pasture access and 40% for half-a-day pasture scenarios appears to be underestimated.

A new German fertilizer ordinance came into force in 2020, including, among other things, restrictions of the nitrogen content per area of organic fertilizer for application on crop- and grasslands [36]. Nutrient resources for livestock are limited as well as expensive. As a consequence, farmers increasingly aim to optimize the feed ratio regarding amino acid composition to reduce nitrogen intake [37]. Therefore, the nitrogen excretion rates per animal may now be lower than rates a few years ago, as also noted in a critical review of the models for environmental risk assessment of veterinary medicinal products [15]. However, recent data on N-excretion for comparison are limited.

Default values regarding manure management

Animal excretions usually become stored manure for later use as organic fertilizer on grass and croplands [38]. However, disregarding the production type, animal excretions are often diluted either by cleaning water or by precipitation. These liquid entries dilute the manure, which is not consequently considered in the ESDs. To reduce emissions, some manure storage tanks has been covered with lids in the last few years, which was supported by special funding programs [39]. This impedes rainwater entry. Furthermore, the entry of cleaning water is highly dependent on production cycles, which are less frequent for some animal types, also resulting in lower water entry per year. Dilution of slurry with water may be technically necessary, e.g., when dry matter is increased by feeding, manipulabe or bedding material [40–42] otherwise it is difficult to process without additional water because of its low fluidity. Nowadays, a major proportion of liquid and solid manure is collected for fermentation in biogas plants [43, 44], a process that is completely missing in the models for biocide risk assessment. Consideration that manure will be further diluted or processed with heat before being applied to crop and grasslands is also lacking. It will be necessary to examine what influence these processes have on the level of PEC for active substances.

The other assumed parameters for manure application (period and frequency) and the incorporation depth for grassland seem to represent a realistic worst-case scenario for Germany [45]. Considering the regional drought and heavy rainfalls during the most recent summer periods due to climate change [46], it is likely that in northern and southern Europe, the total duration of 212 d and the number of manure applications of four times per year on grassland are unlikely to be realized. The assumptions for croplands appear to be realistic. For both land types, trafficability, weather and nutrient uptake by the plants are the main drivers for scheduling the application. Currently, plough incorporation at a depth of 20 cm is used less than in prior decades [45]; however, this process is still used for cellulose-rich previous crops to ensure humus formation. It is also sound to assume that sewage sludge and fermentation substrates are incorporated deeper due to their higher dry matter content. On grassland, turf is typically preserved, so any depth lower than 5 cm is unlikely [45].

Entry of stable wastewater into public sewage treatment plants

In poultry stables with a plain floor with litter only, it is common to only remove the solid manure, while the liquids, mainly cleaning water, flow into the public sewer system. Therefore, the possibility of connecting animal stables to public sewage treatment plants is correctly implemented in the models. Currently, ESD PT 18 No. 14 describes this option for certain poultry houses, which appears reasonable. However, some inconsistencies have to be addressed in an update here as well; for example, on p. 27 of ESD PT 18 No. 14, additional Index i1 #9 is described as being connected to a sewage treatment plant (see also Fig. 4.2, STP), whereas in Table 5.4 release fractions to STP are only mentioned for cat-subcat Index i1 #8, 11, 12, 16, 17 and 18 [2].

In addition, all indoor stables with a fresh air climate (as described above) harbor the possibility that some biocide steam, dust, fumigation or spray applications (except smearing and bait) will escape through the openings. Therefore, they may enter the rainwater disposal system via the roof or run into the public drainage system through open sidewalls over paved courtyard areas. This scenario applies not only to poultry but also to cattle, horses and pigs and will mainly affect the fraction released to air due to the unlimited air circulation (e.g., for spray application, currently a release into air of zero is assumed). Moreover, it may be necessary to include an additional fraction indicating the portion released to adjacent areas (e.g., paved courtyard with subsequent release to STP). In this context, the models for deposition processes should be reviewed.

Additional aspects of default values of further PT 3 scenarios

Another example of an assumption for a default value that needs to be revised is the dairy cow herd size in ENV 63 [12]. A dry-off period of 50 to 65 days is quite realistic per lactation, but the assumption per year also accounted for non-lactating heifers in dairy herds. In the case of only accounting for times of dry off, 84% of the herd is lactating. Additionally, dairy farms have a remounting proportion of 25% and higher, which leads to values of approximately 70%. Unfortunately, no current data are available to specify a lower default value. However, a proportion of 82% lactating cows per herd seems very high. Another relevant entry of disinfectants appears after the transport of livestock. The original document differs between two scenarios: 1. Transport of slaughtered animals: animals are transported from farms to slaughter houses and 2. Transport of production animals from one farm to another. This does not include transport activities within a farm, which likewise very often occur. This transfer of farm animals is not defined as transport from a judicial perspective, because animals can also be drifted or lead, but were performed frequently using a vehicle. After this kind of on-farm transport of animals, cleaning and probably a subsequent disinfection of the vehicle are conducted somewhere on a paved area on the farm. Wastewater runs either to a manure collection system or to a public sewage system.

Further considerations regarding assumptions and regulations

The environmental risk assessment used the statutory user´s instructions as a basis for calculating how to mix the final concentration and how often to apply the preparation. Particularly in the field of biocides, where there is less documentation on farms compared with veterinary medicinal product application, dosages and frequencies of application were often adapted, and applications beyond the authorization scenarios may occur more frequently [47]. Experience from several hygiene projects on farm [48] indicates that in severe cases of contaminations advisory salesmen suggest higher application dosages and/or higher frequencies of application, representing a more relevant worst-case scenario than the scenario approved and documented in the statutory user´s instructions. On the other hand, strict hygiene measures, such as combining stable cleaning with the emptying of manure cellars, lead to a reduced need to apply insecticides. Based on the experience with hygiene projects, farmers prefer to use the service period (time between production cycles) for all types of biocide applications and avoid exposing housed animals. If it is impossible to schedule biocide applications during the service period (without animals being present), farmers try to schedule it as far as possible from the production of safe food, such as the slaughtering process. Service periods occur only in all-in-all-out concepts, which are not consequently implemented in, for example, pig production, as shown in Fig. 1 [49].

The previously described application behavior, combined with the production cycle frequency and seasonal effects (e.g., lack of flies during winter in the Northern Hemisphere), leads to fewer possible applications per year, as currently assumed in the ESDs [1, 2]. This assumption could be confirmed by an empirical research project. In general, it would be helpful to have some field data about the timing of biocide applications, dosages and frequencies to use in modelling and defining realistic worst-case scenarios.

Primarily, the legal framework with the minimum requirements represents the worst case. However, this does not apply to the disinfection of stables. Here, the German pig husbandry hygiene regulation stipulates an obligation to disinfect fattening pig stables during every service period [50], which is not implemented on some farms with very low levels of pathogens in their stable

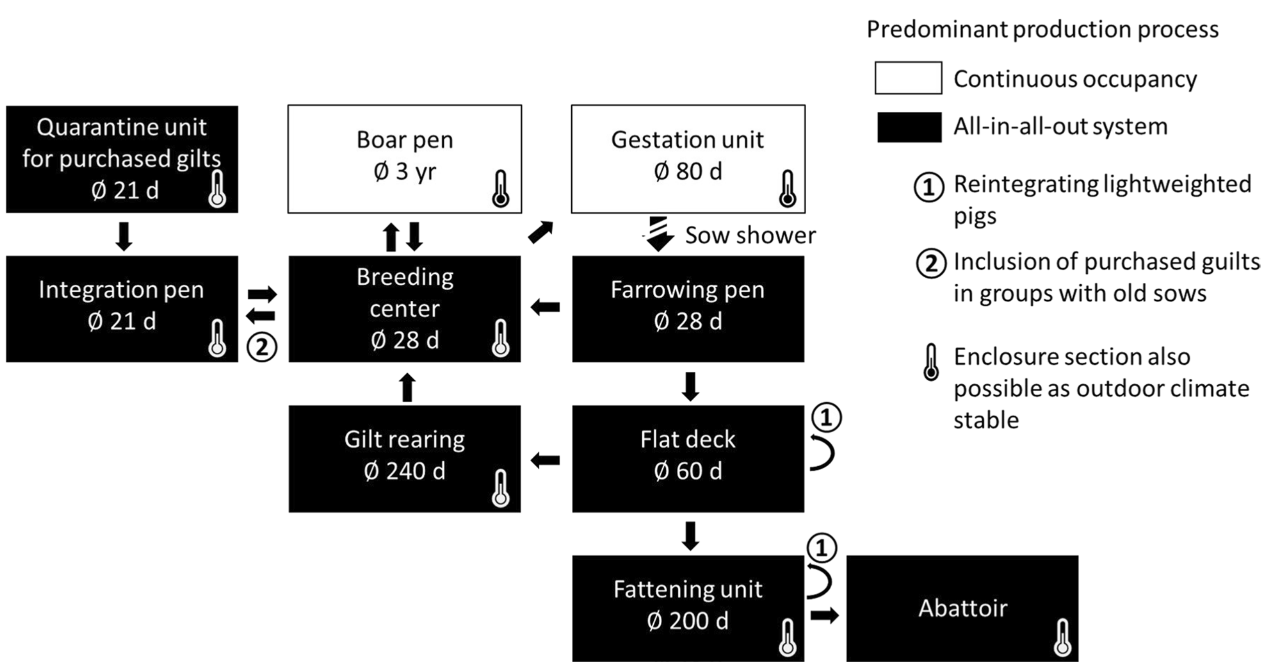

Fig. 1 Illustration of the production cycles and specialized husbandry sections in pigs. Modified image of the original by Heinemann [49]. It is also illustrated to what extent the stables exist as outdoor climate stables

microflora. This environmentally friendly abstention from using biocides should urgently be legalized. The choice of disinfectants does not primarily depend on temperature, as stated in the ESDs [1, 2], but more on the goals of eradication and economic parameters, such as the drying time and price. The choice of a suitable disinfection agent should be made addressing the target organisms. The drying time should determine the duration of the service period. A current critical challenge in the application of disinfectants in practice is that disinfections are frequently applied before all areas have dried, and possible effect losses by dilution are compensated for using higher dosages.

Ideally, environmental risk assessment should be carried out by a "one active principle, one assessment approach". This means, within the biocidal products used in livestock, some substances are registered also as veterinary medicinal product such as neonicotinoids, permethrins or fipronil. Therefore, a comprehensive environmental risk assessment should consider the combined contribution from biocidal and veterinary medicinal product uses. Furthermore, certain substances share the same adverse outcome pathway resulting for example in a relationship between biocide resistance and antibiotic resistance [51]. Following a preventive approach, a post marketing monitoring and pharmacovigilance system for biocidal products would be valuable.

Conclusion and research gaps

The precautionary principle is enshrined in Article 20a of the Basic Law in Germany [52] and the EU. This mandates the state to protect the natural foundations of life, also in responsibility for future generations, which serves as a basis for environmental risk assessments. Some passages in the current documents list lack of data or unclear relevance as reasons for not having an exposure assessment for the questionable scenario. If the precautionary principle is taken into account accordingly, it is essential to emphasize that a lack of data does not equate to missing relevance or negligible risk for environment. It is highly recommended to put the required effort in data collection, monitoring systems and funding of basic research to close the previously mentioned research gaps. The following data should be collected in the future:

- Animal production data such as the proportion of cows lactating, production cycles, nitrogen excretion rates, the proportion of animals on pasture, the proportion of slatted floor
- Biocide application data including times of application, dosages, frequencies, number of applications, conditions during application, the relevance of animal types and documentation of adverse effects
- Dropping behaviour of animals on pasture
- Pathways of manure from farm to crop- and grasslands including conditions and duration of storage, proportion passed through a biogas plant, dilution by wastewater or by precipitation
- Biodegradation data of biocides in solid manure or fermented substrate from biogas plants

Abbreviations

BMEL	Bundesministerium für Ernährung und Landwirtschaft
DLG	Deutsche Landwirtschafts-Gesellschaft
ESDs	Emmission scenario documents
OECD	Organization for Economic Co-operation and Development
PEC	Predicted environmental concentration
PNEC	Predicted no-effect concentration
PT	Product type
QS	Qualität und Sicherheit GmbH
SchHaltHygV	Pig Husbandry Hygiene Ordinance (Schweinehaltungshygieneverordnung)
STP	Sewage treatment plants
TAB ENV	Technical Agreements for Biocides Environment

Supplementary Information

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Additional file 1: Overview about product types (PTs) listed in the ESDs.

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Author contributions

JSW was involved in the funding acquisition, RH, CH, RMV and JSW conceptualized the data search, JSW drafted the manuscript, JSW and CH created the figure, RH, CH, RMV reviewed the manuscript with major contribution and JSW edited the draft. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets and records used in the present study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no conflict of interest. The content is solely the responsibility of the authors and does not necessarily represent the official views of the Federal Environment Agency.

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