European Commission

Scientific Committee on Health and Environmental Risks

SCHER

Final Opinion on

new conclusions regarding future trends of cadmium accumulation in EU arable soils

Scientific Committees
- on consumer safety
- on emerging and newly identified health risks
- on health and environmental risks

Adopted by the SCHER during its plenary meeting of 27 November 2015

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They are: the Scientific Committee on Consumer Safety (SCCS), the Scientific Committee on Health and Environmental Risks (SCHER) and the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) and are made up of external experts.

In addition, the Commission relies upon the work of the European Food Safety Authority (EFSA), the European Medicines Agency (EMA), the European Centre for Disease prevention and Control (ECDC) and the European Chemicals Agency (ECHA).

SCHER

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All Declarations of Working Group members and supporting experts are available at the following webpage:
http://ec.europa.eu/health/scientific_committees/environmental_risks/members_wg/index_en.htm

ABSTRACT

In 2002, the former Scientific Committee for Toxicity, Ecotoxicity and Environment prepared an Opinion on "The Member State Assessments of the Risk to Health and the Environment from Cadmium in Fertilizers" (CSTEE, 2002). Since then, new scientific information has become available. The Commission requested the SCHER to consider whether this new information was of sufficient scientific quality to warrant an update of the CSTEE Opinion of 2002. The new information provided contains data on the current levels of cadmium in the environment, which now are an order of magnitude lower compared to the data used in 2002. It also includes new estimations of some of the parameters used by CSTEE and a more advanced model that allows a refined calculation. The SCHER concludes that, in general the newly acquired information is of sufficient scientific quality and forms a sound basis for the current assessment. Therefore, the SCHER is of the opinion that the conclusions of the report can be supported and the indicated new, low environmental cadmium (Cd) levels warrant revision of the conclusions presented by CSTEE in 2002.

Although the newly acquired information is accepted by the SCHER in general, the SCHER does want to make several recommendations to improve the current modelling results. Indeed, some assumptions cannot be accepted by the SCHER as they are based on insufficiently sound scientific information. For some other parameters the SCHER would prefer another choice for the realistic worst-case assumption provided in the new information. Examples of these suggestions are the upper limit Cd deposition on soils from the atmosphere, the value assumed for the Cd-concentration in manure, the assumed pH of the soils and the assumed organic carbon in EU 27 + Norway soils. In addition, the SCHER suggests a higher worst-case fertiliser input. According to the SCHER, these suggestions may affect the outcome of the model although it is not expected that the results will change dramatically. Nevertheless, a recalculation of the final Cd soil concentrations using these SCHER proposals is recommended.

Keywords: cadmium, fertiliser, human toxicity, environmental effects, accumulation, arable soils

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EXECUTIVE SUMMARY

In 2002, the former Scientific Committee for Toxicity, Ecotoxicity and Environment prepared an Opinion on "The Member State Assessments of the Risk to Health and the Environment from Cadmium in Fertilizers" (CSTEE, 2002). Since then, new scientific information has become available. The Commission requested the SCHER to consider whether this new information was of sufficient scientific quality to comment on the modelling results and on the selection of several parameters that were used to recalculate the original estimates of the CSTEE Opinion (2002). In addition, the SCHER was requested to comment on whether an update of the CSTEE Opinion of 2002 was warranted. The Terms of Reference included three main mandates: (1) to assess the overall quality of the report and identify any significant deficiencies, (2) to provide an Opinion on the appropriateness of the scenarios studied, and (3) to provide an Opinion on the reliability and validity of the conclusions. The first question contained a series of specific questions on the background concentration of cadmium, the average content of cadmium in fertilisers, the atmospheric deposition of cadmium, the quantity of phosphorous fertilisers used in the EU-27 + Norway and the scenarios used, the statistical treatments and the conclusions drawn from the new modelling exercises. The new information provided also includes a more advanced model that allowed a refined calculation. The SCHER concludes that, in general, the new information and data presented is of appropriate scientific quality and based on sound data and is comparable with the quality of the CSTEE Opinion of 2002. Therefore, the SCHER is of the opinion that the conclusions of the report of Smolders and Six (2013) provided indicate sufficient low levels of cadmium to revise the currently used forecasts estimated by CSTEE in 2002.

The new information presented and contained in Smolders and Six (2013) describes a more advanced modelling approach by including an average background concentration of cadmium in soils of 0.28 mg Cd kg^{-1} soil, compared to 0.3 mg Cd kg^{-1} soil by CSTEE (2002) and also includes atmospheric deposition with a load of 0.35 g Cd ha^{-1} y^{-1}. These values are accepted by the SCHER. The SCHER concludes that, although a weighted mean would be a better proxy than the average value used by Smolders and Six (2013), the weighted mean cannot be used because the data required to use this approach are not available. In addition the SCHER is of the opinion that the FOREGS database cannot be used as a reference database for agricultural soils as this type of soils are explicitly excluded from that database. The SCHER also concludes that the average content of cadmium in fertilisers of 36 mg Cd (kg P_2O_5)$^{-1}$ can be accepted. The SCHER considers several parameter assumptions made in the study of Smolders and Six (2013) debatable, and have looked at the possible implications of using different values for these parameters. According to SCHER, the use of these alternative values will not lead to any significant changes in the outcome of the model and the SCHER considers that the general conclusions will remain unchanged. Nevertheless, the SCHER recommends that the values be recalculated to ensure all these considerations are taken into account. The assumptions that SCHER questioned are the following: The SCHER could not support the assumption used in Smolders and Six (2013) on the cadmium load on agricultural soils due to the application of manure. The assumed value (0.01 g Cd ha^{-1} y^{-1}) is not sufficiently supported by data. The SCHER provided several suggestions to improve the current modelling results. Some assumptions are not accepted by the SCHER as they are based on insufficiently sound scientific information. For some other parameters, the

SCHER would prefer another choice for the realistic worst case assumptions provided in the new information. Examples of these suggestions are the upper limit Cd deposition on soils from the atmosphere. Smolders and Six (2013) assumed a maximum of 0.7 g Cd ha^{-1} y^{-1}, whilst the SCHER is of the opinion that a value of 1.3 g Cd ha^{-1} y^{-1} would be a better estimate. The assumption of an average pH for European soils of 5.8 should, in the opinion of the SCHER, be treated with caution especially as it does not take into account the variability of pHs in European soils. Finally, the SCHER is of the opinion that the assumed organic carbon (OC) content in European soils is too high as many soils in the southern European countries have OC contents of less than 2%. In addition, the SCHER suggests a higher worst case fertiliser input.

1. BACKGROUND

On 28 April 2014, the EU inorganic fertiliser industry notified the Commission of a report updating assessment of the effects of using inorganic phosphate fertilisers on cadmium accumulation in EU arable soils.

Current EU legislation concerning fertilisers (in particular Regulation (EC) No 2003/2003) does not contain limits on the content of cadmium, although some risks (See Appendix I below) relating to the presence of cadmium in the food chain have been well identified.

DG GROW is currently engaged in a profound revision of Regulation (EC) No 2003/2003 that would include limit value for cadmium for the whole EU. As cadmium concentration in crops increases with increasing soil cadmium concentrations, all other factors being constant, predicting long-term change in soil cadmium content is considered important to determine trends in cadmium exposure of the general population through the food chain.

In 2002, the Scientific Committee on Toxicity, Ecotoxicity and the Environment (CSTEE) used a mass-balance approach to calculate the concentration of cadmium in inorganic phosphate fertilisers that would not lead to a net accumulation of cadmium in arable soils in EU-15+Norway over 100 years. The report concluded that at a concentration of 20 mg cadmium/kg P_2O_5 in inorganic phosphate fertilisers, accumulation of cadmium is not expected in most EU soils.

The objective of the study conducted for Fertilisers Europe was:

1. To update that mass-balance assessment with recent data on input and output parameters applicable to EU-27+Norway taking into account that since the assessment of 2002, atmospheric emissions of cadmium have decreased, the use of inorganic phosphate fertilisers has decreased and there are now better tools to estimate cadmium leaching from soil.

2. To calculate scenarios of long-term change in soil cadmium on the basis of the new estimates.

2. TERMS OF REFERENCE

In view of the relevance of the above-mentioned report to our review of Regulation (EC) No 2003/2003 on fertilisers, we request that it be submitted to SCHER for an Opinion on the following aspects:

1) **Assess the overall quality of the report and identify any significant deficiencies**. Has the methodology for assessing soil accumulation used by the CSTEE in 2002 been followed? If not, is the model used by the author pertinent? Is the quality of the report comparable to the evaluation prepared by the CSTEE in September 2002? In particular, please evaluate the soundness of some basic assumptions, including:

    a. The **average background concentration of cadmium in soils**: wouldn't a weighted mean on the basis of the surface area of arable land in the countries considered in Table 3 on p. 12 (*See* main report in Annex 3) be a better proxy for a European mean?

       Is the FOREGS data representative as reference values for agricultural soils? According to the sampling strategy for the FOREGS project[1]; '*residual soil from areas with agricultural activities was avoided, since the top soil is usually affected by human activities'*.

    b. The **average content of cadmium in fertilisers** on the basis of Nziguheba and Smolders (2008): is this single source a sufficient basis for this fundamental parameter in the calculation (see p. 20 – Annex 3)? Are the 196 samples considered in that paper broadly representative of the phosphate rock fertiliser sources used in the EU? If so, is an arithmetic mean representative of the distribution presented in Fig. 10?

    c. **Atmospheric deposition** (*See* Table 6 and Fig. 9 on pages 18 and 19 of Annex 3): please evaluate the appropriateness of 0.35 g Cd ha^{-1} y^{-1} as the best estimate of the mean cadmium deposition, as well as the standard deviation and the realistic worst case (p. 20 –Annex 3), also taking into account the 2011 EEA report on Hazardous Substances in Europe's Fresh and Marine Waters[2], and the content of the report on the study on diffuse water emissions in E-PRTR by Deltares[3] (although cadmium from diffuse agricultural sources specifically was not considered). Is the assumption on pages 16-17 of the Fertilisers Europe report appropriate, i.e. that dry deposition can be ignored?

    d. **The quantity of P fertiliser used in EU-27 + Norway** (22 kg P_2O_5 ha^{-1}): please elaborate on the soundness of the calculation in Table 7 page 22 of Annex 3, in particular on the (implicit) weighing factors used to calculate the value in the column "Total arable land". What would be the impact on future trends in soil cadmium accumulation of other scenarios of P

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[1] http://weppi.gtk.fi/publ/foregsatlas/article.php?id=10
[2] http://www.eea.europa.eu/publications/hazardous-substances-in-europes-fresh
[3] https://circabc.europa.eu/w/browse/43b37b86-5706-4e2d-80cd-88007dd31319

consumption of 40 kg P_2O_5 ha^{-1}, 60 kg P_2O_5 ha^{-1}, 80 kg P_2O_5 ha^{-1} and 100 kg P_2O_5 ha^{-1} (*See* Annex 7).

e. **Scenarios used, statistical treatments and conclusions drawn from this.** Future accumulation rates have been modelled using 2160 different scenarios (table 23, p 40 – Annex 3). These scenarios are the results of making all possible combinations of a set of levels for all included parameters (e.g. 0, 0.35 and 0.7g Cd ha^{-1} y^{-1} for deposition and 2, 2.5, 3, and 4 % for organic matter content, etc.). This means that all values for each parameter are represented by the same amount of values among the 2160 scenarios i.e. for 33% of the scenarios the deposition is set to 0, 0.35 and 0.7g Cd ha^{-1} y^{-1} respectively etc. (It appears unrealistic that 33% of the soils have close to zero in deposition.) This set of scenarios has then been used to calculate statistics for the accumulation of cadmium in European soils, figures that are also reported in the conclusions and abstracts. Is it scientifically sound to establish these kind of statistics based on a set of hypothetical scenarios and to present conclusions for European soils based on these statistics?

2) **Opinion on the appropriateness of the scenarios studied** in particular as regards the algorithm representing soil/water distribution coefficient (K_D). Could the new model lead to an overestimation of soil cadmium leaching at EU and national level? What are the implications of the new model for estimates of the effects of leaching on surface and groundwater concentrations of cadmium? How have new pH estimates affected the outcome of the model and the conclusions?

pH has a large influence on the outcome of the accumulation modelling. In the new reports, an average pH for European soils has been set to 5.8 (based on new data from the GEMAS database). In former studies, e.g. the EU RAR (ECB 2007)[4], the European average soil pH was set to 6.5. The reason for this difference of almost one pH unit is not explained.

How has this change in average pH been addressed in the K_D/leaching estimates, which are strongly dependent of pH? If the reported soil pH is dependent on the analysis method it must be crucial that the same analysis method for pH is used for the soils to be modelled, as in the underlying data used for developing algorithms for K_D. It is not clear which methods have been used to measure pH in the 4 underlying studies (table 20, p 37 – Annex 3) for the K_D/leaching algorithm used in the new reports. It is mentioned in Six and Smolders (2014)[5] that when pH_{H2O} was available, a conversion was made to reflect pH_{CaCl2}, but nothing explains how this conversion was done.

Can SCHER analyse whether the change in average pH is a consequence of the use of different analytical methods or has soil pH really changed in Europe? How has this change affected the conclusions on accumulation compared to former studies?

[4]ECB, European Chemicals Bureau, 2007. European Union Risk Assessment Report- Cadmium oxide and Cadmium metal Part I – Environment. 3rd Priority List, Vol.72. European Chemicals Bureau, European Commission. (EUR 22919 EN).

[5]Six, L. and Smolders, E, 2014. Future trends in soil cadmium concentration under current cadmium fluxes to European agricultural soils. Science of the Total Environment 485–486 (2014) 319–328.

Is the choice of the cropping systems (cereal mono-cropping, potato mono-cropping and cereal-potato rotations) representative of EU agricultural practice?

3) **Opinion on the reliability and validity of the conclusions (**pages 39 to 51 – Annex 3) concerning the accumulation of cadmium in EU arable soils and its likely leaching to waters. In the light of the answers to the questions above, what would be the possible implications for human exposure of accepting the conclusions of the Fertilisers Europe report?

3. SCIENTIFIC RATIONALE

3.1. Introduction and scope

On 28 April 2014, the EU inorganic fertiliser industry notified the Commission of a report (Revisiting and updating the effect of phosphate fertilizers to cadmium accumulation in European agricultural soils by Smolders and Six (2013)) that provided an update of the assessment of the effects of using inorganic phosphate fertilisers on cadmium accumulation in EU arable soils.

Current EU legislation concerning fertilisers (in particular Regulation (EC) No 2003/2003) does not contain limits on the content of cadmium, although some risks (See Appendix I below) relating to the presence of cadmium in the food chain have been well identified.

DG GROW is currently engaged in a profound revision of Regulation (EC) No 2003/2003 that would include a limit value for cadmium for the whole EU. As cadmium concentration in crops increases with increasing soil cadmium concentrations, all other factors being constant, predicting long-term change in soil cadmium content is considered important to determine trends in cadmium exposure of the general population through the food chain.

The SCHER is of the opinion that the methodology outlined in the CSTEE opinion of 2002 has correctly been followed by Smolders and Six (2013). The SCHER is also of the opinion that the quality of this report is comparable to the quality of the CSTEE Opinion of 2002.

3.2. Evaluation of new information

3.2.1. Background concentrations in soil

In their report, the authors (Smolders and Six, 2013) used additional information that was not available at the time of the preparation of the CSTEE Opinion of 2002. The authors used an average background concentration of cadmium in soils of 2.8 mg Cd kg^{-1} soil and an average Cd content of cadmium in fertilisers derived on the basis of Nziguheba and Smolders (2008). In addition, they took into account the effects of an atmospheric deposition of 0.35 g Cd ha^{-1} y^{-1} as the best estimate of the mean cadmium deposition and the quantity of P fertiliser used in EU-27 + Norway being 22 kg P_2O_5 ha^{-1}. The authors calculated possible accumulation rates by modelling 2160 different scenarios representing combinations of (soil) parameters relevant for the EU (including Norway) (e.g. 0, 0.35 and 0.7 g Cd ha^{-1} y^{-1} for deposition and 2, 2.5, 3, and 4 % for organic matter content, etc.). This means that all values for each parameter are represented by the same number of values among the 2160 scenarios i.e. for 33% of the scenarios the deposition is set to 0, 0.35 and 0.7 g Cd ha^{-1} y^{-1}, respectively, etc. This set of scenarios was then used to calculate statistics for the accumulation of cadmium in European soils, figures that are also reported in the conclusions and abstracts.

A weighted mean on the basis of the surface area of arable land in the countries may certainly be a better proxy than the method currently used in the report (Smolders and Six, 2013). However, data to establish this weighted mean over the EU-15 or EU-27 (including Norway) are not available. Therefore, the SCHER is of the opinion that the method used in Smolders and Six (2013), given the data availability, is probably the best scientific approach to determine the average of the data as proxy for the Cd-concentration in arable soils.

The FOREGS database is not intended to provide reference values for agricultural soils. In the FOREGS database, it is clearly mentioned that soils with visible or known contamination should be avoided. Agricultural soils are implicitly contaminated by potentially long-term application of pesticides (plant protection products). Therefore, the SCHER is of the opinion that the FOREGS database should not be considered as representative for the derivation of reference values for agricultural soils.

3.2.2. Average content of cadmium in fertilisers

The average content of cadmium in fertilisers (36 mg Cd (kg P2O5)-1) has been determined on the basis of data published by Nziguheba and Smolders (2008), which is based on an analytical study aimed at establishing current and reviewing and specific value(s) for the mean content of Cd in P fertilisers. The SCHER is of the opinion that this study (Nziguheba and Smolders, 2008) provides values that are representative for the Cd content of phosphate rock fertiliser sources used in the EU.

3.2.3. Atmospheric deposition

For deposition, an average value of 0.35 g Cd ha^{-1} y^{-1} is assumed (standard deviation 0.21) to be representative of atmospheric deposition in the EU (Smolders and Six, 2013). This value is one order of magnitude lower than the 3 g Cd ha^{-1} y^{-1} assumed as worst case in the CSTEE (2002) Opinion. According to that CSTEE Opinion, the contribution of other (than fertilisers) diffuse sources to the Cd soil content was 0.3 g Cd ha^{-1} y^{-1}, while 3 g Cd ha^{-1} y^{-1} was proposed as the worst case for atmospheric deposition. The latter value should currently be considered as unrealistic for future calculations in the light of the dramatic decrease of cadmium emissions in recent years. The deposition values in 2002 ranged between 0.15 and 4 g ha^{-1} y^{-1}, depending on country and sampling method. In 2010, measured depositions ranged between 0.1 and 0.6 g Cd ha^{-1} y^{-1} (Smolders and Six, 2013).

Pacyna, *et al.* (2009) present a large amount of data and is therefore considered a good basis for deriving the average value for deposition. The worst case value of 0.7 g Cd ha^{-1} y^{-1}, however, seems too low as several experimental data reported in Pacyna *et al.* (2009) are higher. Excluding some unrealistically high outliers in Smolders and Six (2013), the SCHER is of the opinion that the upper limit of the range of experimental data (1.3 g Cd ha^{-1} y^{-1}) should be used as a realistic worst case.

Cadmium is emitted to the atmosphere from anthropogenic and natural sources. The anthropogenic sources of Cd include industrial and domestic combustion, flue gas of industrial processes, waste incineration and others (EMEP, 2012).

Cadmium emissions in both the EU and the EEA-32 decreased by 27% between 2002 and 2011 and by about 58% between 1990 and 2008 (EEA, 2011). In general for Europe, 60% reduction of Cd emissions has resulted in about 45% reductions of Cd-concentrations in precipitation at the stations studied during the last 2 decades (Pacyna, *et al.*, 2009).

In Europe, air pollution and fertilisers (both mineral and organic) contribute almost equally to annual exposure of soils to cadmium (RIVM, 2008). The main Dutch sources of cadmium load to surface water in 2005 was attributed to several sectors: agriculture

(25%), sewer systems and sewage treatment (33%), chemical industry (12%) and atmospheric deposition (22%) (RIVM, 2008). The European air quality target value for Cd is set at 5 ng/m^3 air and entered into force on 31 December 2012 (EU, 2015). The same value (5 ng/m^3) was set by WHO AQG to prevent any further increase of cadmium in agricultural soil and thus to limit the dietary Cd intake of future generations (WHO, 2000). The values specified are maximum annual averages that countries were required to meet by 2013.

The current measurements of Cd in precipitation using ICP-MS (inductively coupled plasma mass spectrometry) allow determination of lower Cd-concentrations compared to previous methods (graphite furnace atomic absorption). Hence, the actual Cd-deposition rates can now be estimated with greater accuracy compared to the 1990s–2000s (Six and Smolders, 2014).

Combined wet and dry deposition of cadmium across Europe is variable, generally ranging between 10 and 50 g km^{-2} y^{-1} (meaning 0.1-0.5 g ha^{-1} y^{-1}) but reaching in excess of 100 g km^{-2} y^{-1} in some parts of central and south-eastern Europe (EEA, 2013).

Dry deposition can be ignored if bulk values (bulk value equals dry + wet deposition) are available. SCHER recognises that Smolders and Six (2013) used bulk values, therefore these authors did not ignore dry deposition in their calculations. If no information on bulk concentrations is available, the deposition may be underestimated by about 25% (based on Table 6, p. 18) if only based on wet deposition as a rough estimate.

In summary, taking into account all available information, the SCHER concludes that the value of 0.35 g Cd ha^{-1} y^{-1} is probably the best estimate of the mean cadmium deposition while 1.3 g Cd ha^{-1} y^{-1} is probably a more realistic worst case value than the value of 0.70 g Cd ha^{-1} y^{-1} proposed and used in Smolders and Six (2013).

3.2.4. The quantity of P fertiliser used in EU-27 + Norway

The input from phosphate fertiliser, as a European average, is calculated on the basis of two assumptions:

- the average consumption of fertilisers in Europe is 22 kg P_2O_5 ha^{-1} y^{-1};
- the average ratio between Cd and P in fertilisers is 36 mg Cd (kg P_2O_5)$^{-1}$.

This led to a Cd input of 0.8 g Cd ha^{-1} y^{-1}.

The development of the scenarios for the mass balance calculation is based on the cereals/potato cropping system and on the following assumptions:

- the use of fertilisers is: 21 kg P_2O_5 ha^{-1} y^{-1} (cereals), 45 kg P_2O_5 ha^{-1} y^{-1} (potato), 29 kg P_2O_5 ha^{-1} y^{-1} (cereals/potato rotation);
- different values are selected for the ratio between Cd and P in fertilisers: 20, 40, 60, 80 mg Cd (kg P_2O_5)$^{-1}$.

The calculation presented in Smolders and Six (2013) is correct and the assumptions are sufficiently supported by literature data. However, in some conditions (e.g. potato crops in some countries) the consumption of fertilisers may be higher. The possibility of this type of realistic worst case should therefore be considered. For example, fertiliser applications estimated in the UK for cereals and potatoes should be considered more representative of a worse case, where a fertiliser use of 30 kg P_2O_5 ha^{-1} y^{-1} (cereals), 130 kg P_2O_5 ha^{-1} y^{-1} (potato) and 63.3 kg P_2O_5 ha^{-1} y^{-1} (cereals/potato rotation) has been reported.

Concerning manure, it is stated that: "a *typical Cd-concentration in manure is at least a tenfold lower than the Cd-concentration in P fertilizers*". This statement is not supported because Cd-concentrations in manure (0.2 mg Cd (kg dry matter)$^{-1}$) are not comparable with those in fertilisers (36 mg Cd (kg P_2O_5)$^{-1}$) without information on the amount of P in manure or on the amount of manure applied in agriculture. These data are not provided in the report. Moreover, the input from manure is assumed as a recycling of Cd taken up by crops and reapplied on soil. So, only the Cd derived from imported feed is considered. This amount of Cd spread on the whole European arable land led to a European average of 0.01 g Cd ha^{-1} y^{-1}. This amount is not sufficiently supported.

With respect to the contribution made from lime, data on Cd-concentrations in commercial lime and application rates of lime are not available. So the proposed values (European average of 250 kg CaO ha^{-1} y^{-1} with lime which contains 0.35 mg Cd (kg CaO)$^{-1}$) seem realistic but are not sufficiently supported by sound information. This results in an annual Cd input of 0.09 g Cd ha^{-1} y^{-1}.

More information is available for the estimation of the Cd contribution from sewage sludge. The European average of 0.05 g Cd ha^{-1} y^{-1} is well supported. However, in this case too, a realistic worst case (e.g. the value of 0.25 g Cd ha^{-1} y^{-1}, typical for the UK) should be considered.

The input from manure, lime and sludge is combined under the item "others" with a value of 0.15 g Cd ha^{-1} y^{-1}. These inputs were not calculated in the CSTEE (2002) Opinion. So, their inclusion may be considered as an improvement. However, due to the uncertainties mentioned above, the value must be considered as "tentative".

3.2.5. Scenarios used, statistical treatments and conclusions drawn from this

The procedure used for the mass balance calculation is a combination of the different values selected for the various parameters used for describing environmental scenarios (e.g. three values for deposition, five for background, three for typical crop, etc.), calculating the output for all the possible combinations. This has led to a total of 2160 combinations that were then reduced to 14 more representative scenarios.

A sensitivity analysis was also performed to evaluate the effect of the different parameters on the final result.

Some comments on the parameters used for the description of the scenarios, also in comparison with the scenarios applied in the CSTEE Opinion, are listed below.

- Atmospheric deposition: 0 deposition was also used in the CSTEE Opinion and may be assumed as an extreme "best case". On the other hand, 0.7 is too low as a realistic worst case and SCHER recommends using 1.3 g Cd ha^{-1} y^{-1} (see comments in section 3.2.3).
- Precipitation excess (water surplus): the range proposed (0.1-0.3 m y^{-1}; average 0.2 m y^{-1}) seems reasonable and is only slightly different from the range proposed in the CSTEE 2002 Opinion (0.1 – 0.4). However, the proposed new values seem to be poorly supported by data as the cited paper (Degryse and Smolders, 2006)

only reports the average value without any further justification (by e.g., experimental data, historical data, etc.).

- K_D: the Smolders and Six (2013) report mentions a K_D range from 0.44 to 192000 L kg^{-1} (Sauvè, *et al.*, 2000). This range refers to a pH range from 2 to 10 and is therefore unrealistic for the purposes of this Opinion. The models proposed in table 20 of the same report are more environmentally realistic and are acceptable. The variability of K_D-values calculated with the 4 proposed models is not too high and the average (model 5) may be accepted as a reasonable estimate.
- Cropping system: on a surface coverage basis, the choice of the cropping system is not representative of EU 27. It is representative for cereal growing areas that cover about 45% of the EU fertilised area, but potato covers an area of about 1% (EFMA, 2012). Other crops (e.g. permanent crops, such as vine and fruit, particularly relevant in southern European countries) may be more relevant in terms of surface coverage. However, the cereal/potato system can be accepted as an example of an agricultural practice other than cereals, with different fertiliser rates and crop offtake. Thus it adds additional information to the crop scenario of the CSTEE 2002 Opinion which only considered cereals (wheat-maize). Therefore, it is the opinion of the SCHER that the cropping scenario may be considered as representative for the purpose of this assessment.
- Other inputs: a constant value of 0.15 g Cd ha^{-1} y^{-1} is assumed for manure, liming and sludge. This value is not sufficiently supported by data (see comments in section 3.2.4). These inputs were not considered in the CSTEE Opinion and their inclusion may be an improvement. Therefore, it is the opinion of the SCHER that the proposed value can be accepted as "tentative".
- Crop offtake: crop offtake is dependent on the cropping system. The SCHER can agree with the chosen cropping system as it refers to an existing situation keeping in mind that another crop can result in a different offtake. In this case the cropping system and the related crop offtake are considered adequate.
- pH: the different methods used for measuring pH in soil may justify the differences in values presented in Smolders and Six (2013) and the CSTEE Opinion (2002). As a general rough indication, pH measured in $CaCl_2$ and KCl may give values of about 0.5 and 1 pH units, respectively, lower than pHs measured in H_2O (Comolli, pers. com.). It is important to note that this is not a change in the "actual" pH value of the soil (i.e. a more precise measure) because measuring pH in $CaCl_2$-pH, KCl-pH and H_2O-pH solutions provides different pH values and are considered different parameters. Smolders and Six (2013) propose a wide range of pH values (4.5, 5.5, 6.5, 7.5) and a European average of 5.8 (standard deviation 1.1), quoted from the NGU (2011) report describing the data from the GEMAS (GEochemical Mapping of Agricultural Soils) survey of 2008. The same GEMAS data are described with more accuracy and detail by Fabian *et al.* (2014). Indeed, the value of 5.8 does not represent a median value (*i.e.*, not an average value) with no standard deviation. The range proposed by Smolders and Six is even wider than that proposed by CSTEE (2002) and covers values from the 10 to the 90 percentile of the pH distribution in Europe (Fabian et al., 2014). The European average of 5.8 should be treated with caution, especially as it does not take into account the high variability of pH levels in European agricultural soils (that range

from < 4 to 8). To conclude, the SCHER considers that the proposed range is representative of the pH variability of European agricultural soils, while the average value of 5.8 is considered not representative of a European average.

- Organic carbon (OC): 2% is quite high as a lower limit of the range; in most agricultural soils in southern countries (France, Spain, Italy, Portugal, Greece) the OC content is lower than 2%. In the CSTEE Opinion (2002) a range of 1 to 4% as organic matter (about 0.5-2% as OC) was selected. This is also supported by the map of OC in Europe produced by the JRC-IES (JRC, 2005), where levels lower than 1% are characteristic for many important agricultural areas, mainly in southern Europe. It is the opinion of the SCHER that the range of OC values should be enlarged to include a minimum value of 0.5%, as was proposed in the CSTEE (2002) Opinion.

3.2.6. Comments on the outcome of the model calculation

In general, the rationale and methods supporting the leaching model, for the mass balance and the statistical approach used by Smolders and Six (2013) is sufficiently sound and acceptable. However, next to the comments made for some specific parameters (see above), some issues need to be highlighted with respect to the procedure used for the selection of the 14 representative scenarios. Some of the parameters selected for these scenarios are not representative, particularly for some realistic worst case scenarios and for scenario 14 (EU average). In particular:

- a value of 1.3 for atmospheric deposition would be more suitable as a realistic worst case for scenarios 9 to 13;
- a higher realistic worst case for fertiliser input should be considered;
- the average pH value of 5.8 (scenario 14) is not sufficiently justified;
- a lower value of organic carbon (0.5 – 1) should be used as a realistic worst case (scenarios 3, 4, 7, 8, 11, 12); probably, the average (scenario 14) should be revised as well.

Some of the parameters considered in the model calculations (Cd input, pH and OC) should be modified, at least for some scenarios. For pH, it is suggested that the average value is deleted as the proposed range is representative of the majority of European agricultural soils.

In Smolders and Six (2013), the same approach was used as in the CSTEE Opinion (2002). Input, output and model parameters, like K_D, pH, etc. were adapted. The fundamental structure of the model was not changed. According to the SCHER, this approach makes it easier to compare the outcome of the models.

On the basis of the comments on the selection of some specific parameters, an additional scenario may be proposed. The parameters selected for the scenario are shown in Table 1.

Table 1. Parameters selected as representative for a European realistic worst case scenario

Scenario	Cd input				Cd output					Cd soil
	Atmospheric deposition g Cd ha^{-1}	Cropping system	P fertilisers kg P_2O_5 ha^{-1}	Others g Cd ha^{-1}	Crop offtake		Leaching			t_0 mg Cd kg^{-1}
					TF	yield tonnes ha^{-1}	pH	OC %	f	
EU realistic worst case	1.3	potato	130	0.15	0.06	26	7.5	4	0.1	0.6

The parameters shown in Table 1 may be assumed as representative of a scenario of "Very high input" and "Very low output", using the terminology adopted by Smolders and Six (2013).

This scenario represents a European realistic worst case but is considered not unrealistic because all parameters have been documented in literature for some parts of Europe. Although the probability of the occurrence of this scenario is low, it is not impossible that this type of combination may occur in the EU 27.

The long-term change in soil Cd for these scenarios was calculated with the mass balance model and are presented in Table 2, in relation to the different amounts of Cd in fertilisers.

Table 2. Predicted long-term change in soil Cd (%) after 100 years of exposure to Cd input in agricultural soils, according to the European realistic worst case scenario described in Table 1.

Scenario	Cd concentration in P fertiliser mg Cd (kg P_2O_5)$^{-1}$			
	20	40	60	80
EU realistic worst case	+15	+29	+43	+57

The SCHER would like to emphasise that, although not impossible, these scenarios are - in the opinion of the SCHER - quite unlikely and rare as it would require a situation combining worst cases of different EU27 + Norway extremes. These worst case scenarios are not recognised in the CSTEE Opinion (2002). Therefore, the SCHER concludes that the general and realistic tendency of the development of the Cd accumulation in soil is reflected by the results presented in Smolders and Six (2013).

3.2.7. Uncertainties

The SCHER recognises that there are many uncertainties in the assumptions used in the calculations and discussion given above. Not only the assumptions but also the input values used for the calculations introduce uncertainty in the results. Nevertheless, the SCHER is of the opinion that the best available data were used to estimate the effects on accumulation of Cd in soil and supports the results of Smolders and Six (2013) as they are based on newly available scientific data of good quality and correct calculation methods.

4. OPINION

4.1. Question 1 of ToR

***Assess the overall quality of the report and identify any significant deficiencies**. Has the methodology for assessing soil accumulation used by the CSTEE in 2002 been followed? If not, is the model used by the author pertinent? Is the quality of the report comparable to the evaluation prepared by the CSTEE in September 2002? In particular, please evaluate the soundness of some basic assumptions.*

The SCHER agrees with the fact that the mass balance approach, calculations and conclusions presented by the CSTEE in 2002 should be revised and updated to take into account new knowledge gained in the past 12 years. Most of the new information used for the mass balance approach reported by Smolders and Six (2013) is well supported by literature data and many of the assumptions are sound and acceptable: the procedure is detailed and methodologically sound. Most of the evaluations are based on realistic European scenarios. Nevertheless, SCHER notes that some other realistic worst cases (e.g., atmospheric deposition, pH and organic carbon content) are not considered by Smolders and Six (2013) and thus should be assessed. In general, the SCHER agrees with the approach and conclusions of Smolders and Six (2013).

4.1.1. Background concentrations in soil

Question 1a

> ***The average background concentration of cadmium in soils**: wouldn't a weighted mean on the basis of the surface area of arable land in the countries considered in Table 3 on p. 12 (See main report in Annex 3) be a better proxy for a European mean?*
>
> *Is the FOREGS data representative as reference values for agricultural soils? According to the sampling strategy for the FOREGS project; 'residual soil from areas with agricultural activities was avoided, since the top soil is usually affected by human activities'.*

A background value in soil of 0.28 mg Cd kg^{-1} is proposed by Smolders and Six (2013). This value is slightly lower than that proposed in the CSTEE 2002 Opinion (0.3 mg Cd kg^{-1}) but the difference is not significant. The new value is well supported by data. The SCHER is of the opinion that these two figures are sufficiently similar and do not influence further calculations and comparisons.

According to the SCHER, the method used to determine the mean Cd-concentration in soil may not be the best proxy compared to a weighted mean, but the data needed to apply the weighted mean are not available in the EU. Therefore, the SCHER is of the opinion that the best method – in view of the data available - was applied.

The FOREGS database is not intended to provide reference values for agricultural soils. The FOREGS database describes that soils with visible or known contamination should be avoided. Agricultural soils are implicitly contaminated by the potential long-term application of pesticides (plant protection products). Therefore, the SCHER is of the opinion that the FOREGS database should not be considered as representative for reference values of agricultural soils.

4.1.2. Average content of cadmium in fertilisers

Question 1b.

***The average content of cadmium in fertilisers** on the basis of Nziguheba and Smolders (2008): is this single source a sufficient basis for this fundamental parameter in the calculation (see p. 20 – Annex 3)? Are the 196 samples considered in that paper broadly representative of the phosphate rock fertiliser sources used in the EU? If so, is an arithmetic mean representative of the distribution presented in Fig. 10?*

The average content of cadmium in fertilisers was based on a thorough review of the available data and therefore the SCHER supports the proposed value of 36 mg Cd (kg $P_2O_5)^{-1}$ as the best possible estimate. The SCHER is of the opinion that the study used (Nziguheba and Smolders, 2008) is representative for the phosphate rock fertiliser sources used in the EU.

4.1.3. Atmospheric deposition

Question 1c.

***Atmospheric deposition** (See Table 6 and Fig. 9 on pages 18 and 19 of Annex 3): please evaluate the appropriateness of 0.35 g Cd ha^{-1} y^{-1} as the best estimate of the mean cadmium deposition, as well as the standard deviation and the realistic worst case (p. 20 –Annex 3), taking into account also the 2011 EEA report on Hazardous Substances in Europe's Fresh and Marine Waters, and the content of the report on the study on diffuse water emissions in E-PRTR by Deltares (although cadmium from diffuse agricultural sources specifically was not considered). Is the assumption on pages 16-17 of the Fertilisers Europe report appropriate, i.e. that dry deposition can be ignored?*

Concerning the atmospheric deposition the SCHER is of the opinion that an average value of 0.35 g Cd ha^{-1} y^{-1} is adequately supported by measured data and therefore is the best possible estimate. The SCHER, however, considers the maximum value proposed by Smolders and Six (2013) to be too low and recommends that a maximum value of 1.3 g Cd ha^{-1} y^{-1} is used as a realistic worst case estimate.

The SCHER recognises that Smolders and Six (2013) used bulk values: the authors therefore considered dry deposition in their calculations.

4.1.4. The quantity of P fertiliser used in EU-27 + Norway

Question 1d.

***The quantity of P fertiliser used in EU-27 + Norway** (22 kg P_2O_5 ha^{-1}): please elaborate on the soundness of the calculation in Table 7 page 22 of Annex 3, in particular on the (implicit) weighing factors used to calculate the value in the column "Total arable land". What would be the impact on future trends in soil cadmium accumulation of other scenario of P consumption of 40 kg P_2O_5 ha^{-1}, 60 kg P_2O_5 ha^{-1}, 80 kg P_2O_5 ha^{-1} and 100 kg P_2O_5 ha^{-1} (See Annex 7).*

The SCHER supports the estimation of the quantity of P-fertilisers used in the EU 27 + Norway as it is based on sound data taken from the literature. It is the opinion of the SCHER that the estimates for the UK (30, 130 and 63.3 kg P_2O_5 ha^{-1} y^{-1} for cereals, potato and cereal/potato rotation, respectively) may be considered representative of a realistic worst case scenario. The SCHER, moreover, is of the opinion that the inputs indicated as “others” (manure, lime and sludge) are insufficiently substantiated by sound literature data and should be taken as “tentative”.

4.1.5. Scenarios used, statistical treatments and conclusions drawn from this

Question 1e.

Scenarios used, statistical treatments and conclusions drawn from this. *Future accumulation rates have been modelled using 2160 different scenarios (table 23, p 40 – Annex 3). These scenarios are the results of making all possible combinations of a set of levels for all included parameters (e.g. 0, 0.35 and 0.7g Cd ha-1 y-1 for deposition and 2, 2.5, 3, and 4 % for organic matter content, etc.). This means that all values for each parameter is represented by the same amount of values among the 2160 scenarios i.e. for 33% of the scenarios the deposition is set to 0, 0.35 and 0.7g Cd ha-1 y-1 respectively etc. (It appears unrealistic that 33% of the soils have close to zero in deposition.) This set of scenarios has then been used to calculate statistics for the accumulation of cadmium in European soils, figures that are also reported in the conclusions and abstracts. Is it scientifically sound to base this type of statistics on a set of hypothetical scenarios and to present conclusions for European soils based on these statistics?*

In section 3.2.5 the SCHER has provided some comments/criticism on the selection of the different parameter values used for modelling. The SCHER is of the opinion that in some cases a better choice could have been made. Additionally, the SCHER has specifically commented on the scenarios selected for the model calculations in section 3.2.6. Some of the choices made by Smolders and Six (2013) are considered insufficiently supported by literature data.

With respect to the model applied and the processes included, the SCHER supports the approach taken by the authors but recommends also taking the suggestions for improvement given here into account.

Although mathematically sound, the chosen scenarios may not be fully representative of all possible conditions in Europe. The consequences of possible alternative scenarios, indicated by a new calculation using a different selection of parameters, are discussed under Q2.

4.2. Question 2 of ToR

Opinion on the appropriateness of the scenarios studied *in particular as regards the algorithm representing soil/water distribution coefficient (K_D). Could the new model lead to an overestimation of soil cadmium leaching at EU and national level? What are the implications of the new model for estimates of the effects of leaching on surface and groundwater concentrations of cadmium?*

On the basis of the comments in sections 3.2.5 and 3.2.6, the model and the statistical approach used are appropriate and scientifically sound. However, for some specific cases the input data do not cover the full range of conditions that may - albeit rarely - occur in EU 27 + Norway. In particular, possible realistic worst cases are not sufficiently accounted for.

The new calculation, performed with a different selection of parameters, is reported in section 3.2.6. According to this new calculation, the SCHER is of the opinion that the scenarios used in Smolders and Six (2013) are adequate to describe most of the situations likely to occur in Europe. Nevertheless, the possibility for hot spots with higher Cd accumulation in the EU 27 + Norway cannot be excluded (section 3.2.6). Although these hot spots are probably limited to extreme site-specific conditions, attention should be given to particularly vulnerable situations.

Considering the leaching model, the SCHER is of the opinion that the new model will not lead to overestimation of soil cadmium leaching. The implications of the new model for soil leaching for cadmium for surface and ground water need to be examined (modelled, calculated) extensively as the newly developed model does demonstrate higher leaching fluxes to these compartments.

pH has a large influence on the outcome of the accumulation modelling. In the new reports, an average pH for European soils has been set to 5.8 (based on new data from the GEMAS database). In former studies e.g. the EU RAR (ECB 2007) the European average soil pH was set to 6.5. The reason for this difference of almost one pH unit is not explained.

In Smolders and Six (2013), there is no mention of a change of the average soil pH in Europe. In the EU RAR on Cd (ECB 2007) a European average of pH in soil is not mentioned. In the CSTEE (2002) Opinion a pH range was proposed (5.5, 6.5, 7.5), without any mention of a European average. The 6.5 value was just the intermediate value of the range. As already mentioned in section 3.2.5, it is the opinion of the SCHER that the adopted pH range is representative of the European situation, while using a European average (or median) is not appropriate considering the variability of pH in European agricultural soils.

How have new pH estimates affected the outcome of the model and the conclusions?

As mentioned above the pH-values mentioned in the CSTEE Opinion are not related to any specific pH-data collected in the EU27 + Norway. It is an example range of 5.5 to 7.5 and the intermediate value of 6.5 should not be regarded as a mean pH. Smolders and Six (2013) proposes a wider range (4.5 – 7.5). Generally, European soils are acidic and the proposed range is suitable to represent the variability reported in the GEMAS database. The SCHER has no reason to question this range and accepts it as such.

How has this change in average pH been addressed in the KD/leaching estimates, which are strongly dependent on pH? If the reported soil pH is dependent on the analysis method it must be crucial that the same analysis method for pH is used for the soils to be modelled, as in the underlying data used for developing algorithms for KD. It is not clear which methods have been used to measure pH in the 4 underlying studies (table 20, p 37 – Annex 3) for the K_D/leaching algorithm used in the new reports. It is mentioned in Six and Smolders (2014) that when pH-H_2O was available, a conversion was made to reflect pH-$CaCl_2$, but nothing explains how this conversion was done.

The papers of Degryse *et al.* (2003) and Nolan *et al.* (2005) refer to pH-$CaCl_2$, the same parameter as that used in the GEMAS survey and pH maps for European soils developed by JRC (2010). No information is available to the SCHER for the other two studies quoted by Smolders and Six (2013). A precise conversion factor between pH-$CaCl_2$ and pH-H_2O cannot be given because it may depend upon many soil characteristics. As mentioned above, it may be assumed as a general rough indication that pH-$CaCl_2$, is about 0.5-1 pH units lower than pH-H_2O (Comolli, pers. com.). An attempt for defining a relationship between pH-$CaCl_2$ and pH-H_2O is described by Libohova *et al.* (2014) who propose the following equation:

$$\textbf{1:5 water pH = 0.41 + 1.01 x 1:2 } \mathbf{CaCl_2} \textbf{ pH } (\mathbf{r^2 = 0.92})$$

However, considering the bulk of information available on pH in soil, it is reasonable to assume that most pH data on European soils are pH-$CaCl_2$.

Can SCHER analyse whether the change in average pH is a consequence of the use of different analytical methods or has soil pH really changed in Europe? How has this change affected the conclusions on accumulation compared to former studies?

There are no reasons for assuming that a pH change in European soils has occurred; this is not mentioned in Smolders and Six (2013). The value of 6.5 mentioned in CSTEE (2002) was not intended to describe an average, just a value in between the minimum and the maximum of the pHs used in the calculation.

Is the choice of the cropping systems (cereal mono-cropping, potato mono-cropping and cereal-potato rotations) representative of EU agricultural practice?

The SCHER is of the opinion that the choice of the cropping system, although not representative, of EU agricultural practices in quantitative terms, may be assumed as representative of a range of fertiliser rates and crop offtake for the purpose of this assessment.

4.3. Question 3 of ToR

Opinion on the reliability and validity of the conclusions *(pages 39 to 51 – Annex 3) concerning the accumulation of cadmium in EU arable soils and its likely leaching to waters. In the light of the answers to the questions above, what would be the possible implications for human exposure of accepting the conclusions of the Fertilisers Europe report.*

In the CSTEE Opinion (2002), the drainage process, leading to Cd concentrations in groundwater as a potential source of drinking water, is used as an independent variable indicating the flow of water through the upper soil layer. The values mentioned are 0.1 and 0.4 m y^{-1}. In view of the relatively high sorption coefficient of Cd as indicated in section 3.2.5, the SCHER is of the opinion that the risk for groundwater contamination is expected to be low.

The SCHER also concludes that, in accepting the conclusions of Smolders and Six (2013), the human exposure to Cd-concentrations in crops taken of the contaminated fields would be less than those expected on the basis of the results of the CSTEE Opinion from 2002.

5. Commenting period

After finalisation of the Opinion on the 31st of May 2015, a commenting period was established for interested parties. The commenting period lasted from 24 June to 29 July 2015. Comments were received from 7 institutions addressing about 4 to 7 items in the Opinion. Several comments supported the SCHER conclusions, while some comments stressed that the situation in their country deviated from the average conditions the Opinion assumed.

The SCHER considered carefully all comments and changes in the Opinion are based on the reflection of the SCHER on the comments provided. SCHER agreed to several comments that stressed the need for more specific information. SCHER disagreed that the sample of 196 measurements for the Cd content of fertilisers was insufficient. In general, the SCHER recognised the differences across the EU27 + Norway but it is of the opinion that accounting for these differences was not in the ToR of the SCHER. Country specific calculations with the model developed can, of course, be carried out but the SCHER focused on the average situation across Europe. The SCHER considers several parameter assumptions made in the study of Smolders and Six (2013) debatable, and have looked at the possible implications of using different values for these parameters. According to the SCHER, these alternative values will not lead to any significant changes in the outcome of the model and the SCHER considers that the general conclusions will remain unchanged. Nevertheless, the SCHER recommends that these values be recalculated to ensure all these factors are taken into account. The SCHER is confident that with these changes, all comments provided during the commenting period have been appropriately addressed.

6. MINORITY OPINION

None.

7. LIST OF TERMS AND ABBREVIATIONS

AQG	Air Quality guidelines
CCE	Coordination Centre for Effects
CEIP	Centre on Emission Inventories and Projections
CSTEE	Scientific Committee on Toxicity, Ecotoxicity and the Environment
E-PRTR	European Pollutant Release and Transfer Register
EEA	European Environment Agency
EEA	European Economic Area (32 countries)
EFMA	European Fertilizer Manufacturers Association
EC	European Commission
ECB	European Chemicals Bureau
EMEP	European Monitoring and Evaluation Programme
EU	European Union
FOREGS	Forum of European Geological Surveys
GEMAS	Geochemical Mapping of Agricultural and Grazing Land Soil
GF-AAS	graphite furnace atomic absorption spectrometry
GROW	DG Internal Market, Industry, Entrepreneurship and SMEs
ICP-MS	inductively coupled plasma mass spectrometry
IES	Institute for Environment and Sustainability
JRC	Joint Research Centre of the EU
NGU	Norges Geologiske Undersøkelske (Geological Survey of Norway)
OC	organic carbon
RAR	Risk Assessment Report
RIVM	Rijksinstituut voor Volksgezondheid en Milieu, The Netherlands
SCHER	Scientific Committee on Health and Environmental Risks
TF	Transfer function
UK	United Kingdom
USA	United States of America
WFD	Water Framework Directive
WHO	World Health Organization

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