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Impact-pathway approach and metals: monetisation of external costs of cadmium emissions to soil from agricultural fertilizer

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1. Introduction

The Impact-Pathway Approach (IPA) is widely recognized as methodology for the monetary evaluation of environmental impacts associated with the emission of contaminants from human activities. However, only few examples exist of IPA applied to study emissions of persistent trace contaminants such as metals [1, 2]. Calculating the external costs of metal emissions is challenging since metal-specific fate models are required to decrease the modelling uncertainty and to account for metals’ persistence over an appropriately lengthy timescale. Moreover, the impacts and costs to future generations must also be accounted for. The choice of the time horizon and discounting method thus becomes critical.

We address these issues by presenting a study on the monetization of the health-related impacts of cadmium (Cd) in soil. We considered agricultural application of phosphorous-rich fertilizers in Denmark as a source of Cd emission to soil, and dietary intake of cereals as exposure pathway. High Cd concentrations can be found both in mineral fertilizers (due to the Cd content of the phosphorous-ore) and in sludge obtained from wastewater treatment. Due to the high persistency of Cd in soil, and high soil-to-plant transfer rates, humans may be exposed to Cd through their diet. Chronic low-level exposure to Cd has adverse effects on renal function and the skeletal system (osteoporosis) [3].

2. Materials and methods

We used an updated version of the Simplified Fate and Speciation model (SFSM) [4] to calculate Cd increase in soil for different future scenarios of agricultural application of fertilizer (each fertilizer with appropriate P and Cd content) to Danish soil, over a time horizon of 100 years. The model accounts explicitly for metal speciation and is calibrated for Danish conditions. Based on soil-plant bioconcentration factors [5] and Danish dietary intake rates [6], we determined human exposure. We used updated dose-response functions (DRF) linking lifetime Cd intake with the probability of developing Cd-induced renal disease and osteoporosis [7]. These impacts are converted into monetary values by using the EU standard value of VONLY (40000[€]) adjusted for quality of life experience. Total costs over 100 years are then annualized and discounted at 3% to present value (year 2010) to obtain the external costs. External costs are presented in two different units: [€/kg Cd] to soil and [€/kg P] to soil, since the Cd:P ratio differs between sewage sludge and mineral fertilizer.

Figure 1: Cd accumulation in topsoil for different fertilizer application scenarios. BAU, business as usual; T3, sludge from aerobic treatment; T6, sludge from anaerobic treatment.
3. Results and discussion

Figure 1 shows the calculated trends in Cd accumulation in soil for different fertilizer application scenario. We determined the increment in soil Cd concentration ($\Delta$-Cd$_{soil}$) due to the application of fertilizer, by subtracting the BAU scenario results from the fertilizer scenario results. This marginal approach allows isolating the impacts of Cd applied with fertilizer from background levels of Cd in soil. We also determined the background level of average daily dietary Cd intake via food for the Danish population, which is 0.31 [$\mu$g/day*kgBW] (BW, body weight). This allows shifting from marginal to absolute units when applying the non-linear DRF. Preliminary results indicate that the present value of Cd external costs is of $\approx$3800 [€/kg Cd] for sludge application, and $\approx$4100 [€/kg Cd] for mineral fertilizer, due to the lower Cd content of sludge in [mg/kg dry matter]. However, when P content is considered, costs are of $\approx$0.092 [€/kg P] for sludge and $\approx$0.089 [€/kg P] for mineral fertilizer, due to the higher content of P in the latter. Since the method is currently at a pilot stage and is still under development and testing, these values must be considered as only preliminary. However, they show the feasibility of our approach for estimating external costs. Final results will be presented at the conference, together with assessment of uncertainty and sensitivity analysis for the entire IPA approach. Indication about how to transfer correctly the estimated external cost values to other studies, by taking into account spatial and temporal conditions, will be provided as well.

4. Conclusions

The pilot study is a unique example of monetization that considers a previously uninvestigated impact pathway: the emission of Cd to soil through fertilizers followed by human exposure through diet. This enables the IPA approach to be explored beyond its classic applications (e.g. airborne non-persistent contaminants: CO$_2$, NO$_x$, etc.) and to address in detail critical issues such as uncertainty assessment, long-term modelling perspective and discounting. Moreover, the study provides useful insights to related research fields, in particular to Life Cycle Impact Assessment (LCIA). Most LCIA methods apply a similar emission-to-impact causal chain approach, and the same models (fate and exposure models, DRF) can be used for both IPA and LCIA. Although IPA is applied to a limited (often only one) set of contaminants, the assessment method applied here is more detailed than LCIA concerning the definition of temporal and spatial conditions. For the case of Cd and fertilizers, the innovative modelling of Cd fate in soil and the identified DRF could also be applied, for example, to improve LCIA of metals.

5. References