Improvement of odor assessment in a life cycle assessment framework

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ABSTRACT

Odorous emissions are a key concern for intensive livestock industries, wastewater treatment and other industries due to growth and increasing overlap with urban areas. Relatively little effort has gone into the development of methods for odor within the field of life cycle assessment (LCA). Traditionally, the mass of gas emitted and its detection limit by humans are considered. So there is a simple effect model, but no transport model. Detailed approaches for odor transport modeling exist outside LCA but they are difficult to apply in strategic environmental assessments. To support debate around the development of a midpoint indicator with transport aspects for odor, we calculated characterization factors for an "odor footprint", using data on the rates of diffusion and reaction to model persistence and spreading. We suggest that a simplified approach to transport modeling is reasonable within the LCA context.

Keywords: odour, footprint, midpoint

1. Introduction

Many food production systems involve components that generate odor, particularly those where animal wastes are involved. Management systems for some textile factory wastewaters, sewage, sludge and other organic materials have similar challenges exacerbated by urban encroachment. Odor entering domestic and commercial buildings reduces the amenity of indoor working and home environments. Strategic environmental comparisons between production systems or between odor management systems should preferably take odor into account but approaches for doing this in a life cycle assessment (LCA) framework have received little developmental attention over the last 20 years. Perhaps the first attempt was described in the original "Guide and Backgrounds" to LCA (Heijungs, 1992) where odor threshold values (OTVs) were the key element in a life cycle impact assessment (LCIA) for "malodorous air", a characterization approach based on critical volumes. The OTV is the concentration (kg.m^{-3}) at which a chemical is detectable by 50% of the population. Thus, for the mass *m* of each odorant *i*:

$$\text{malodorous air} = \sum_i \frac{m_{i,air}}{OTV_{i,air}}$$

What this means is that an emission of a mass of an odorant is characterized as the volume of air it would occupy if instantly diluted to its OTV. Heijungs (1992) proposed that this could be the basis for future development of a "smell creation potential" indicator, including transport and fate considerations. But this has been a long time coming: Heijungs' original approach and the 60 characterization factors (CFs) he obtained from an older document (Roos, 1989) were duplicated in the subsequent Nordic LCA guidelines (Nord, 1995) and the updated Backgrounds document (Guinee, 2002). The method is suggested (without providing data) in the popular Hitch Hiker's Guide to LCA (Baumann and Tillman, 2004). The recent International Life Cycle Data System (ILCD) Handbook (JRC, 2010), does not provide any guidance on odor, so the most recent consensus guidance documents on odor use a life cycle impact assessment (LCIA) approach that has not changed in 22 years, using data which is 25 years old. One could call Heijungs' method the established approach since it has been reproduced as described, and has been used in several LCAs, but with the qualification that no odor method has been widely applied in the LCA literature.

Perhaps the most interesting thing to happen recently in this area is a proposal to modify the USEtox model as a basis for fate modeling of odorants (Marchand et al., 2013). USEtox is a consensus-based box-model for the calculation of LCIA factors for chemical contaminants, but it is feasible to extract steady-state concentrations for different atmospheric compartments from it and compare these with OTVs. Marchand's proposal involves a

number of adjustments to the environmental descriptors in the standard USEtox model to make it more relevant to the environmental assessment of a particular local area. It also suggests OTVs should be placed on a fuzzy scale, with potential effects below the nominal OTV. Another innovation on Heijung's approach was the suggestion that the ultimate odor burden be expressed in terms of 11 different midpoint indicators, one for each different type of smell (sweet, rancid, fecal etc.).

Balancing parsimony with accuracy is an important consideration in the development of LCIA (Hauschild et al., 2008). It is a consideration which is the more challenging when LCIA attempts to characterize emissions with local (as distinct from global) impacts. To encourage further discussion around this balance, the aim of this work was to develop a simple method for odor midpoint assessment in LCA.

2. Methods

We considered the cause-effect sequence between emission of an odorant and the reduction of the value of the protection objects typically included in LCA: human health, ecological systems and resources (e.g.: Kounina et al., 2013). That overview suggested the potential for a midpoint of "odor footprint" which does not represent the actual area disturbed by odor, but the relative potential of different emissions to cause odor problems. A more detailed description of the method will be provided in a journal article recently accepted after peer review (Peters et al., 201x) but salient details are summarized here.

The key decision to be made in developing an odor LCIA method may be what approach to take to wind dispersion. In normal odor dispersion modeling as applied to the assessment of single and mixed odorants, wind speed is a key input in the calculations and also determines dispersion parameters. The time step in the input meteorological data and subsequent modeling may be hours or even shorter intervals. Such dispersion models are commonly used in regulatory and detailed design processes, for example when decision-makers need to assess whether a particular emission will affect a particular urban area. We felt a simpler approach could be justified in an LCA context, as illustrated in the following example. Imagine that a landowner is considering construction of a facility on her land and commissions an LCA comparing production system 'A' which emits odorant 'X' and system 'B' that emits 'Y'. In either case, the same wind will blow, so the diluting effect of the wind on 1 kg of X or Y will be the same. On the other hand, degradation and diffusion rates, and odorant potency (OTV) may distinguish the impacts of X and Y, as these are based on inherent chemical properties. Since LCAs are often performed to compare alternatives, making a *relative* odor impact scale relevant, we chose to take these three factors into account and exclude wind. This will not replace the need for absolute assessments based on dispersion modeling for environmental regulation or detailed design, but may fill the need for strategic LCA assessments.

The approach to odor modeling in this article is illustrated by Figure 1. An initial mass of 1 kg of odorant is assumed to be uniformly distributed within a 1 m diameter hemisphere at ground level (the dashed volume outline in the figure). The gas is allowed to diffuse radially (path 'a' along axis 'r' in the figure), thus the land area at which the concentration exceeds the OTV increases. The increase is counteracted by simultaneous degradation reaction with hydroxyl radicals. Although certain gases may react with other anthropogenic and natural gaseous reagents, the most important route for the destruction of organic odorants is reaction with hydroxyl radicals (Kwok and Atkinson, 1995). The area exceeding the OTV reaches a maximum radius (the solid outline) and then collapses back to the origin (path 'b') due to the continuing degradation process.

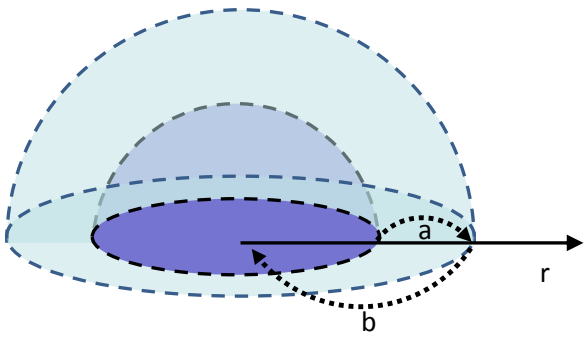

Figure 1. Odor modeling approach

For the calculations, OTV values were taken from Nagata (2003) who measured values for 223 gases using the triangle odor bag method. We obtained estimates of k_{OH} from the NIST database (Manion et al., 2008) and estimated D, the Brownian diffusion coefficient, using Fuller's method (Onken et al., 2008). Atmospheric pressure and 25°C were assumed, consistent with a typical daytime value of the atmospheric concentration of hydroxyl radicals [·OH] of 1.5 x 10^6 molecules.cm^{-3} (Allen, 2001). Computational modeling was implemented in Matlab® version 2012a.

3. Results

Figure 2 shows an example of the model output. Hydrogen sulfide diffuses approximately twice as fast as methyl ethyl ketone, and its OTV is a factor of 2000 lower. Both of these factors lead to the steeper, taller curve. The degradation rate of methyl ethyl ketone is a quarter of that of hydrogen sulfide, leading to the longer persistence of concentrations exceeding the OTV. The integral of the curve is the cumulative area x time the OTV is exceeded, i.e. the odor footprint.

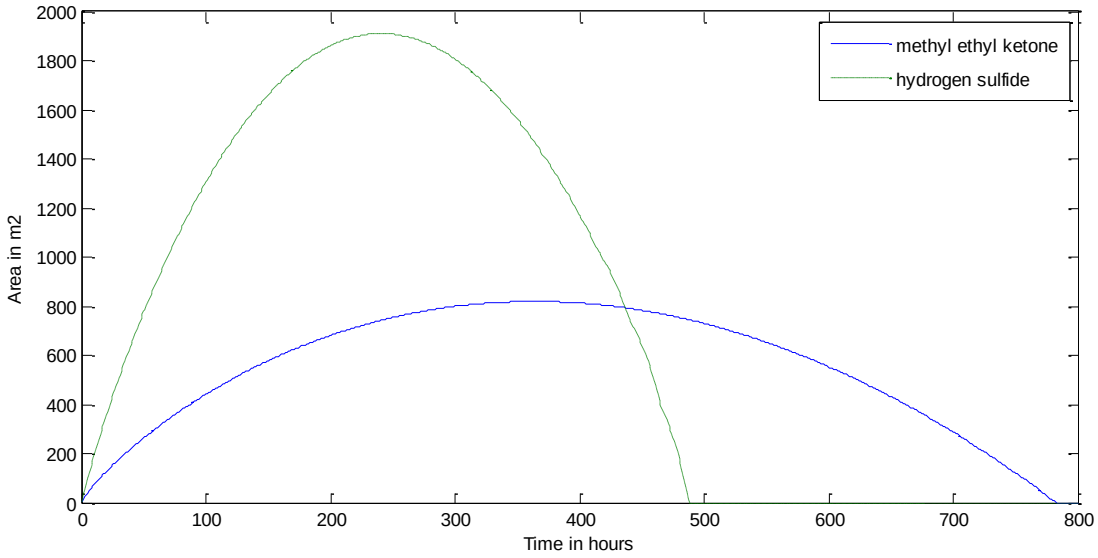

Figure 2. Illustration of footprint growth and decay over time

We have calculated characterization factors for 33 key odorants prioritized on the basis of their presence in LCA literature and the literature on emissions from agriculture and wastewater treatment (Peters et al., 201x). Two of these results are shown in Table 1. As can be seen from this table, the relative significance of a kilogram of the two contaminants is quite different if the analyst was to use Heijungs' method: a kilogram of hydrogen sulfide is equivalent to a volume of "malodorous air" 2267 times greater than a kilogram of butanone, while the odor footprint of the hydrogen sulfide is only 46% larger. The difference in these relationships is due to the more rapid decay of hydrogen sulfide which the new method considers.

Table 1. Sample results from characterization factor estimation

Parameter	**OTV**	**D**[1]	**k_{OH}**	**Odor footprint**	
Odorant	$g.m^{-3}$	$m^2.s$	s^{-1}	m^2s	kg H_2S-eq.kg^{-1}
Hydrogen sulfide	$5.72x10^{-7}$	$2.31x10^{-5}$	$7.05x10^{-6}$	$2.30x10^{9}$	1.00
Butanone (methyl ethyl ketone)	$1.30x10^{-3}$	$1.29x10^{-5}$	$1.80x10^{-6}$	$1.57x10^{9}$	$6.83x10^{-1}$

[1] Diffusion coefficient

4. Discussion

The expression "midpoint indicator" does not exactly describe the location of an indicator on the cause-effect chain between an emission and an impact on a protection object. Both the established metric for odor LCIA of Heijungs (1992) and the recent proposal of Marchand et al. (2013) could be called midpoint indicators, given that neither of them computes an output that is expressed in the terms of common endpoint indicators for human health (e.g.: DALYs), ecosystem quality (e.g.: $PDF.m^{-2}.year^{-1}$) or resources (e.g.: MJ). As suggested by Table 2, our proposal lies somewhere between these two in terms of the level of detail used in the modeling. An analogy can be made between our proposal and the characterization factors for the popular "carbon footprint" indicator, which do not predict potentially nonlinear consequences of climate change like species extinctions and human fatalities due to sea-level rises, but rather a change in radiative forcing – the gases' relative potential to cause these effects. This odor footprint model compares odorant's relative potential to affect air quality, rather than the likelihood of a particular, geographically defined receptor being disturbed.

Table 2. Comparison between established and more recent proposals for odor LCIA

	Heijungs, 1992	Marchand et al., 2013	This proposal
Output	Single indicator: "malodorous air" in m^3	11 indicators (kg-equivalents) based on a key odorant for different smell types	Single indicator: "odor footprint" in kg H_2S equivalents
Transport model	Gas dilutes instantly to OTV	Modified USEtox approach including degradation and removal by a constant wind.	Considers degradation and diffusion
Effect model	Comparison with OTV	Fuzzy interval (uniform factor of 1000) as a safety margin for effects below OTV	Comparison with OTV
Practical operation	Elemental flows easily divided by characterization (OTV) factors	11 factors adjusted in USEtox spreadsheet for each emission location. Model run for each odorant at each location. Steady-state concentrations extracted individually for comparison with effect model.	Elemental flows easily multiplied by characterization (odor footprint) factors.

The new approach we propose has the advantage over Heijungs' approach of considering the temporal aspect of odorant impact and the advantage over Marchand's approach of simpler implementation. The question we would like to answer in future research is whether modification of USEtox to describe odorant dilution at a facility and local scale is more meaningful and/or accurate than our simpler approach. Marchand provides an example based on ethylbenzene emissions from a composting facility, which includes initial dilution in a tall rectangular airspace 50 m square at the base and 240 m high, before subsequent dilution in a 6 km square and 1 km high, the latter "based on the average dispersion area of odorous compounds". In practice, the steady-state concentrations in the facility and local USEtox compartments are directly inversely proportional to volume. On the other hand, if one tests the sensitivity of USEtox by halving and doubling wind speed, rain rate or temperature (factors which Marchand suggests are the most sensitive) a much smaller effect on the steady-state concentration in the local air compartment is observed. This suggests that if adjustments are made to the scale of USEtox compartments in future studies which are not justified by first performing detailed odor dispersion modeling, then comparisons of odorous systems using the results generated by USEtox are unlikely to be more accurate than they would be using the proposed odor footprint method. Alternatively, if detailed odor dispersion modeling is performed for scaling purposes, there may be no need to assess odor in an LCA framework.

Another matter to consider when implementing any of the methods is the appropriate source of OTV data. The available OTV data has been augmented considerably since 1989. Furthermore, a transcription error occurred during production of the Nordic Guidelines (Nord, 1995) so the values in the bottom half of the list in the Guidelines are too large by a factor of 1000. So even if an analyst wishes to use Heijungs' method, it would be more appropriate to use it with the Nagata (2003) values. For example, in comparison to the data shown in Table 1, the original values of the OTV for hydrogen sulfide and butanone are quite different, $4.3x10^{-7}$ and $6.8x10^{-4}$

$g.m^{-3}$, respectively. The new compilation is superior compared to other available compilations of olfactometry results because the OTVs are corrected for recovery of single compounds and losses in the dynamic olfactometer are avoided (Hansen et al. 2013). Additionally, unlike other compilations of OTVs, the Nagata data all are obtained in the same lab using the same method. These factors are reasons why recent work on OTV prediction by Abraham et al. (2012) is also based on the data we obtained from Nagata (2003).

5. Conclusion

The established method for odor assessment in LCA effectively places emphasis on the detectability of an odor by the human nose. No consideration for the persistence of an odor impact is made. Our proposal is a way of including persistence in LCIA of odorants and gives more weight to slower reagents. We suggest that in practice, alternatives using USEtox to model odors for LCA purposes may lead either to unnecessary work or false precision, depending on whether or not the analyst has previously implemented site-specific dispersion modeling to assist in setting local parameters in USEtox.

The key difference between the LCA odor footprint proposed here and local odor impact prediction using dispersion models is that the disposition of sources and receptors is not known in LCA, so the influence of wind is excluded – the dispersion effect of wind dilutes all odorants equally. So while an odor footprint will not predict impacts which are particular to a site or climate (endpoint modeling), it is an improvement on the traditional LCA approach for ranking odors.

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7. References

Abraham MH, Sanchez-Moreno R, Cometto-Muniz JE, Cain WS (2012) An algorithm for 353 odor detection thresholds in humans. *Chem Senses*, 37(3):207-18.

Allen DT (2001) Evaluating Environmental Fate: Approaches Based on Chemical Structure. Chapter 5 in "Green Engineering: Environmentally Conscious Design of Chemical Processes," D. T. Allen and D. Shonnard, Prentice Hall, Englewood Cliffs, 539 pp. (2001).

Baumann H, Tillman A-M (2004). The Hitch Hiker's Guide to LCA, Studentlitteratur, Malmö, Sweden.

Guinee JB (2002) Handbook on life cycle assessment: operational guide to the ISO standards. Kluwer Academic. ISBN 1402002289

Goedkoop, M., Heijungs, R., Huijbregts, M., De Schryver, A., Struijs, J., & Van Zelm, R (2009) *ReCiPe 2008. A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level; First edition* Report I: Characterisation. Ministry for Housing, Spatial Planning and Environment. The Netherlands

Hansen M, Adamsen APS, Feilberg A (2013) Recovery of odorants from an olfactometer measured by proton-transfer-reaction mass spectrometry, *Sensors* 13(6)7860-7871.

Hauschild, M. Z., M. Huijbregts, et al. (2008). "Building a model based on scientific consensus for life cycle impact assessment of chemicals: the search for harmony and parsimony." *Environ Sci Technol* 42(19): 7032-7037.

Heijungs RJ, Guinee J, Huppes G, Lankreijer RM, Udo de Haes HA, Wegener Sleeswijk A, Ansems AMM, Eggels PG, van Duin R, de Goede HP (1992) Environmental Life Cycle Assessment of Products. Guide and Backgrounds. CML, Leiden University.

JRC (2010) International Reference Life Cycle Data System (ILCD), General Guide for Life Cycle Assessment – Detailed Guidance. Joint Research Centre, European Commission. ISBN 978-92-79-19092-6.

Kwok ESC, Atkinson R (1995) Estimation of hydroxyl radical reaction rate constants for gas-phase organic compounds using a structure-reactivity relationship: an update. *Atmos Res*, 29(14)1685-1895.

Kounina A, Margni M, Bayart J-B, Boulay A-M, Berger M, Bulle C, Frischknecht R, Koehler A, Milà i Canals L, Motoshita M, Núñez M, Peters G, Pfister S, Ridoutt B, van Zelm R, Verones F, Humbert S (2013) Review of methods addressing freshwater use in life cycle inventory and impact assessment. *Int J Life Cycle Assess*, 18:707–721

Manion JA, Huie RE, Levin RD, Burgess Jr. DR, Orkin VL, Tsang W, McGivern WS, Hudgens JW, Knyazev VD, Atkinson DB, Chai E, Tereza AM, Lin CY, Allison TC, Mallard WG, Westley F, Herron JT, Hampson RF, Frizzell DH (2008) NIST Chemical Kinetics Database, NIST Standard Reference Database 17, Version 7.0 (Web Version), Release 1.4.3, Data version 2008.12, National Institute of Standards and Technology, Gaithersburg, Maryland. http://kinetics.nist.gov/ accessed June 2013.

Marchand M, Aissani L, Mallard P, Béline F, Réveret J-P (2013) Odour and life cycle assessment (LCA) in waste management: a local assessment proposal. Waste Biomass Valor, 4:607-617.

Nagata Y (2003) Measurement of odor threshold by triange odor bag method. Pp118-127 in "Odor Measurement Review", Office of Odor, Noise and Vibration, Environmental Management Bureau, Ministry of Environment. http://www.orea.or.jp/en/PDF/Odor_Measurement_Review,.pdf accessed November 2013.

Onken U, Fisher K, Rarey J, Kleiber M (2008) Estimation of physical properties. In Ullmans Encyclopedia of Industrial Chemistry. Wiley.

Peters GM, Murphy KR, Adamsen AP, Bruun S, Svanström M, ten Hoeve M (2014) Improving odour assessment in LCA - the odour footprint. *Int J Life Cycle Assess*, 19:1891-1900.

Roos C (1989) Vooronderzoek financiële consequenties van een geurbelevingsnorm. MT-TNO report 88-230. Apeldoorn, The Netherlands.

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