The MIIM LCA Ph.D. Club: Presentation and Introduction

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Abstract

During 1998, the number of completed Ph.D.s on Life Cycle Assessment (LCA) seemed to be larger than any previous year. In order to mark this achievement, a special series is being published in the International Journal of LCA. In this introductory paper, the Class of MIIM outline the results of their research work over the last few years. A number of common points and tendencies have emerged through this work. First of all, the scope-dependency of LCA models: some of us have discerned in particular the need to distinguish between descriptive and change-oriented LCAs. Secondly, a number of the theses focus on the interaction between LCA and decision-making. Thirdly, the benefits of pluralism in impact assessment and allocation have been advocated in some of the theses. Finally, it may be noted that in these theses structuring the management of controversial issues seems to be preferred to eliminating such issues by a process of harmonisation. Future papers will map out the intellectual journeys undertaken in the development of these theses and discuss key findings in more detail.

Keywords: Agriculture; building; decision making context; food; LCA; LCI; Life Cycle Assessment; Life Cycle Inventory; participatory decision making; Ph.D.s of 1998; subjectivity; uncertainty

1 Introduction

As for so many things in life, the initiative reflected by this and a series of follow-up papers started as a kind of joke. Two of us met during the ConAccount meeting of November 21, 1998 in Amsterdam, and we inevitably started to talk about an experience we had recently shared: defending our Ph.D. theses related to the subject of Life Cycle Assessment (LCA). While talking, we realised that a considerable number of other people active in the circles of SETAC, LCANET and CHAINET had also completed their studies that year. Once we reached that point, the idea of founding a kind of MIIM LCA Ph.D. club was born. The first suggestion was to summarise our work in a series of papers that would jointly result in a special issue of this journal. But when it appeared that the number of 1998 Ph.D. graduates would simply be too large, it was decided instead to write this introduction with a series of follow-up papers to be published in subsequent issues of the journal.

Is it a special achievement that we all completed our Ph.D.s in 1998? It may be special that there are so many of us in one year, which was the primary reason for writing this article series. At the same time, it is clear to all of us that this series does not mean that the 1998 Ph.D. class is necessarily different qualitatively from the previous or subsequent ones.

Many outstanding Ph.D.s have been produced in previous years, and without doubt many will follow.

Yet, in a way we feel there is something special about 1998. The number of completed Ph.D.s on LCA seems to be larger than any previous year. A short review of the history of LCA may provide some explanation. The development of 'modern' LCA methodologies and applications started in the late eighties and early nineties in a number of European countries and the United States, quite soon leading to a dedicated and global discussion platform under the umbrella of SETAC. The group active in these circles consisted of a healthy mix of experienced scientists, who rather soon took up a natural 'parental' role, and a larger group of relatively young people in their late twenties or early thirties, eager to apply and work on the development of this new tool.

Now, after some five to eight years, the latter group has reached the position where their accumulated experience and research efforts allow them to produce extensive publications like Ph.D.s. Thus, the quantum jump of Ph.D.s in 1998 can be seen as a kind of landmark in the history of LCA: it is a(nother) sign that LCA is on its way to becoming a mature branch of science. Not that all the problems are solved: on the contrary, our work has shown that there are still quite a number of bullets to be bitten. Yet, LCA's diaper phase is clearly left behind.

2 Messages of the Theses and Future Activities of the Class

So what messages can be found in the work of the MIIM Class? And – with regard to the human interest aspect – what does life hold after completing a Ph.D. focusing on LCA? Following the intended sequence of the article series, we introduce the work of some of the MIIM class below who have been developing

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their research ideas in Europe over the last few years – divided into sections reflecting work on Life-cycle inventory, uncertainty and LCA, methodological elaborations for specific sectors, and the application context of LCA.

Life Cycle Inventory and allocation

Rolf Frischknecht (1998) structured Life Cycle Inventory Analysis (LCI) in relation to its use in decision-making. Similar to Baumann (1998), a distinction between descriptive and change-oriented LCAs is made. System models for change-oriented LCIs are classified according to the distinction of planning tasks in firms, i.e. short, long and very long-term decisions. For instance, short-term decisions comprise the optimisation of existing production facilities so that capital equipment is not included in the Short Run system model. In the case of long-term decisions, capital equipment is included in the Long Run system model depending on the status of the market situation of the product under analysis. In shrinking markets, where no replacement investments are made, capital equipment is left out, whereas it is included in expanding and saturated markets. Very long-term decisions require consistent scenarios about the future status of society, economy and the environment. For the support of very long-term decisions with the help of LCA, emphasis is put on the accuracy of the representation of the future status, and much less on the detailed modelling of the transition period towards that future status.
A disutility function is introduced, which adds up economic information (i.e. private costs) and environmental information to total "social" costs. For that purpose, an environmental exchange rate is used. The exchange rate mirrors the variable influence of environmental aspects on decisions in different political entities such as nations. It may also express differences in uncertainty perception of the actors directly and indirectly involved in the production of the good or service under analysis. The disutility function is applied for the default choice of (marginal) technologies or technology mixes within the product system of change-oriented LCAs, and in joint product allocation assuming that environmental aspects influence decisions of a firm and its clients.
Joint product allocation situations are discriminated according to the decision context, i.e. the number of decision-makers involved, and according to the market for which joint products are manufactured. In a single decision-maker situation within sufficiently working markets, allocation factors are chosen in view of the competitiveness of the joint products. The competitiveness of two or more joint products is determined using multi-objective optimisation. In a single decision-maker situation within monopolistic markets, the price-output relation is determined in view of maximising profits by means of constrained optimisation. In a multiple decision-maker situation, several parties negotiate for a voluntary coalition. The aim is to evaluate an allocation key satisfactory for all parties. A game theoretic approach is used to model such situations.
The cases "national electricity mix" and "small scale gas-fired combined heat and power generation" illustrate the new methodological approaches. It is concluded that the guiding principle formulated in this thesis, namely that LCA should complement economic information, leads to a consistent and feasible methodology capable of representing changes within the economic system.
Rolf did his work at the ETH Zurich, and now has his own consultancy firm in the field of LCA: ESU-services.

Uncertainty and subjectivity in LCA

Arnold Tukker (1999) concentrated in his work on the political-philosophical aspects of decision making processes in which LCA is applied, particularly with regard to toxicity aspects. He applies a combination of LCA, Substance Flow Analysis (SFA), and Risk Assessment (RA) in an in-depth analysis of the environmental bottlenecks related to the Dutch chlorine chain and the Swedish PVC chain. The aim of these project was to try to solve the debate with the help of natural science approaches. Yet, since this scientific approach did not end the debate, he also analysed the histories of the Dutch chlorine and Swedish PVC controversies, using insights from policy science and the philosophy of science (frame analysis, cultural theory, and discourse theory). His conclusion is that many aspects of the toxicity debate are trans-scientific (i.e. not fully answerable by science). Instead, it appears that actor coalitions in the controversy (often unconsciously) use specific, but different 'frames' (or 'paradigms' or 'views') by which they produce their own reading of the situation. The debate about toxicity problems appears to be rooted in these frame differences, and a productive discussion or deliberation on these frames is thus a key element in the solution of the debates. However, current methods of LCA (particularly Life Cycle Impact Assessment, LCIA) seem to be predominantly based on only one analytical paradigm. Hence, his work ends with a plea to incorporate lessons about decision making procedures from policy sciences into LCA. LCA methodologies should be adapted so that they can play a productive role in dealing with frame differences.

Göran Finnveden (1998) discussed different aspects and limitations of LCA methodology. New methods for describing landfilling and incineration of solid waste in LCAs are suggested. A new method for characterising resource depletion is developed based on exergy consumption. Life-cycle inventory data from different databases is compared in order to evaluate the uncertainties involved in typical LCAs and rules of thumb are suggested. Values involved in the valuation element of an LCA are discussed.
LCAs on recycling and incineration with energy recovery of paper packaging materials are used as an example to evaluate and determine the types of information produced (or not) by current LCAs. It is shown that some results are consistent in all studies. Other apparently conflicting results turn out to be consistent if consideration is given to some key assumptions. In a smaller study, some recent LCAs on flooring materials are also reviewed. However, none of the case studies can show the overall environmental preference for any of the alternatives compared, and it is suggested that this is typical. It is argued that even in situations where one product actually is environmentally preferable to another, this will normally not be possible to show by any method. This has some policy implications. For example, if policy changes require that it must be shown that one product is more (or less) environmentally preferable to another before any action can be taken, it is then likely that no action will ever take place. It must therefore be possible to take decisions on a less rigid basis.

Patrick Hofstetter (1998) has provided one of the possible answers on the problems identified by Göran Finnveden and Arnold Tukker. He noted that in the course of international standardisation of LCA, two main problems have been identified: (1) LCA is full of subjectivity and does not properly separate objective from subjective elements, and (2) the impact assessment records phantoms rather than actual damages. His thesis suggests a new framework for LCA designed to overcome these two problems. The new structure represents a radical departure from past attempts in LCA methodology development to distinguish clearly between so-called objective and subjective elements and to assign them to distinct process phases. It builds instead on acceptance of the view that LCA is the art of modelling and combining the valuesphere, ecosphere, and technosphere. This basic structure is then particularised with the use and combination of elements developed independently in many different research fields in the natural, social, and medical sciences. The careful

review and combination of these existing elements in the new structure results in a partly operationalised framework organised around a number of hypotheses. These have a high level of explanatory power for past developments and new trends and seem to offer a fruitful base for further validation. Besides a modelling of the valuesphere by making use of Cultural Theory, the main modelling focus lies on the triple-legged model for the ecosphere. The known damage is assessed by the modelling of causal chains and demonstrated using the examples of carcinogenic and respiratory effects. A proxy for unknown damage has been created using bioconcentration factors and present emissions. The manageability of damage considers the dynamic aspects of the damages and is quantified by indicators for the ease of damage reduction, the excess of target damage, and the success of regulation. A fourfold meaning of perspectives is worked out in Patrick's thesis: the LCA perspective of the world addressing the life-cycle view and its implications; the perspective of understanding LCA as a model of three spheres; the cultural perspectives leading to models that depend on world views; and finally the perspective of future developments supported by the openness of the framework.

Göran did a lot of his LCA work at IVL and combined this later with other appointments. After an intermediate landing at the Department for Chemical Engineering/Applied Electrochemistry at the Royal Institute of Technology in Stockholm, he came to fms (Environmental Strategies Research Group) where he is still working. Fms is a cooperation between different research institutions, among them the Department of Systems Ecology, at the Stockholm University where he finalised his Ph.D., and the National Defence Research Establishment (FOA) where he is currently employed and continuing his research.
Arnold worked on his Ph.D. since January 1997 next to his normal job as a senior consultant at TNO. He is still at TNO, extending his focus to 'Factor 4' transitions with a group of four colleagues.
Patrick did his Ph.D. and most of his other extensive LCA work at ETH Zurich. He is still attached to this university, but may well accept a new challenge in the near future.

Sector-specific elaborations:
The nutrition sector and the building sector
Sarah Cowell (1998) began her Ph.D. research by focusing on the development of LCA methodology for the assessment of agricultural systems. LCA was developed to assess industrial systems, and agricultural systems are sufficiently different that this area of application introduces new methodological issues for all phases of LCA. During her research, Sarah developed new methods for assessing the use of solar energy and water, soil quantity and quality, and biodiversity. The use of solar energy is assessed in relation to total incident radiation, and the use of water in relation to average annual rainfall reaching land in a system under analysis. Soil quantity and quality are assessed assuming that soil is an ancillary item in LCA; this requires careful modelling, use of Organic Matter and Soil Compaction Indicators, and inclusion of eroded soil in assessing abiotic resource depletion. A method for assessing physical habitat maintenance and change is presented which highlights some generic features of LCA mitigating against its acceptance among some stakeholders. A case study of breadmaking wheat production demonstrates a practical application of the methods. This suggests it may be equally, or even more, relevant to determine preferred locations of production rather than preferred farming practices in seeking to maximise the environmental performance of agricultural systems. She concluded by arguing the need for more flexibility in LCA methodology to adapt it to different decision-making contexts, balanced by a greater focus on the process of undertaking LCA.

Karin Andersson (1998) studied the application of LCA to food products and production systems. The overall objectives were to learn more about the feasibility and limitations of LCAs of food systems and to generate information on the environmental impact of such systems. Case studies of tomato ketchup and white bread were carried out. Ketchup was chosen because its life cycle represents a rather common food-product system and bread since it is an important staple food. The great scarcity of environmental data was one of the major problems encountered. Until high quality environmental data is accessible, there is a need for simplified methods which can be used as a compass to show the direction towards sustainability. Accordingly, the feasibility of combining the concept of sustainability principles and LCA for product development was examined and discussed. This combination was found to yield a simplified method well suited for screening analysis and product development. The semi-quantitative approach eases the inclusion of information and aspects not usually included because they are difficult to quantify; for foods, such information and aspects are often of major significance.

Åsa Jönsson (1998) wrote a dissertation with the main objective to demonstrate how LCA may be applied to building products, to describe what methodological LCA issues are specific to building products, to work out solutions to some of these issues and to relate LCA to other environmental assessment methods that may be applied to building products. The dissertation consists of six parts: a literature study, two LCA case studies (flooring materials and structural frames), two papers that examine the prerequisites for including indoor climate issues as an impact category in the LCA of building products, and a methodological, comparative study of six selected approaches for environmental assessment that may be applied to building products. It was concluded that the LCA method is applicable for the environmental analysis and assessment of building products. So far, the main use areas identified are communication and education, both towards external stakeholders and for internal use in a company or a trade association. When adapting LCA for applications in the building sector, a number of particular methodological issues arise: assessment of the impacts of the use phase, how to relate impacts to different system levels, description of future impacts, how to address indoor climate effects, and communication of the results.

Sarah is now employed as a Lecturer at the Centre for Environmental Strategy, University of Surrey, where she undertook her Ph.D. research.
Karin did her Ph.D. at SIK, the Swedish Institute for Food and Biotechnology. She is now employed at CIT Ekologik, the environmental business unit within Chalmers Industriteknik. Both SIK and CIT Ekologik are situated in Göteborg, Sweden.
Åsa did her Ph.D. at Chalmers Technical University in Göteborg, Sweden, and still has an assignment there – recently making a switch from the Department of Technical Environmental Planning to the School of Architecture.

The application context of LCA
Henrikke Baumann (1998) concentrated in her thesis on the practice of LCA. The fact that LCA methodology needs further development is frequently identified as a barrier to the further application of LCA. Consequently, the literature with suggestions for improving LCA methodology is extensive. However, her work concentrates on gaining understanding of the practice of LCA and, derived from that, discussion of application-dependent elements in LCA methodology in a practice-based manner. The study of LCA practice can also deliver a richer and more complex picture of the use of LCA for decision making in contrast to the

somewhat simplistic one in which alternatives A and B are compared in a rational way (and preferably in five minutes). A multidisciplinary approach, combining engineering and social sciences (especially, organisational theory), is used. Employed research methods included questionnaire surveys on the use of LCA in industry, case studies on LCA projects in two Swedish companies, and theoretical discussions on LCA methodology. The surveys investigate to what extent LCAs are used in industry in various applications. The case studies describe how LCA projects are organised, their role in the decision making process, and their part in the process of implementing LCA in the companies as well as the actual LCA methodology (the process of the goal definition, the process of the inventory, etc.). As LCAs are used in a broad range of applications, LCA has been identified as a tool for organisational learning rather than a tool for supporting single decisions. For example, the LCA studies in the case studies resulted in more outcomes than expected. This element of surprise is typical for learning processes. LCA methodology was not identified as a barrier in the case studies; the LCA practitioners, although beginners, could distinguish between various modelling strategies and their implications. Instead, identified barriers to LCA application mainly concerned the level of understanding of LCA methodology in the organisation and the process of gaining commitment for LCAs. For the implementation of LCA activities in a company, the presence of an "LCA entrepreneur" is judged to be important. By relating methodological approaches to applications, two principally different types of LCA were identified: Life Cycle Accounting and Life Cycle Assessment. The former is based on a modelling strategy characterised as "full and complete," and is used for comparing the accountable environmental burdens of existing single-type products. The latter is "relevance-guided", and used for investigating consequences of a change. Another conclusion was that descriptions of LCA methodology would benefit from a greater distinction between the procedure and the model. The LCA model is a "product" of the procedure, and can be described according to certain fixed characteristics. In contrast, LCA procedures and strategies for conducting LCA studies are more diverse than approaches to modelling. A few of these have been illustrated by the case studies.

Sven Lundie (1999) focussed his Ph.D. work on the participation of stakeholders in LCA and the practice-oriented evaluation of impact assessment results in order to deduce reliable environmental recommendations. The starting point of his thesis was an LCA on television sets, led by the Institute for Futures Studies and Technology Assessment (IZT), Berlin. This research project was carried out in close cooperation with industry, the Federal Environmental Agency, ecological consultancies as well as a consumer organisation. The collaboration, on the one hand, clarified the importance of an intensive information exchange with stakeholders and, on the other, it showed the problems of merging interests from different stakeholder groups. Hence, in his thesis, he combined LCA methodology with general decision-making theory and incorporated a stakeholder approach as well as decision making methods. He developed an 'ideal model of participation' in LCA that allows the choice of relevant stakeholder groups depending on the case considered. In his project he set up a method to evaluate the outcome of LCA studies without requiring explicit value statements. This procedure leads to results in most cases and avoids often fruitless discussions about the relative importance of different environmental problem areas.

Henrikke did her work at Chalmers Technical University in Göteburg, and works currently as a researcher with this university. *Sven* studied Industrial Engineering. From 1994 - 1998, he worked as a consultant and researcher in the field of LCA, Life Cycle Design, and Environmental Management Systems at Enerko Consult Berlin, IZT and CML. In 1999 he took over the position as a LCA project leader for the Centre for Water and Waste Technology and the Cooperative Research Centre for Waste Management and Pollution Control, Sydney.

And ... other members of the Class of MIIM

Those who know the LCA world may have missed a number of names in the list above who are also part of the Class of MIIM. Among them, *Matjaz Ros* (1998) completed a Ph.D. on uncertainty and fuzziness in LCA, also at ETH Zürich.
Ulf Sonesson (1998) wrote a dissertation on system analysis of waste management.
Bente Pretlove's (née Solberg-Johansen) Ph.D. is titled "Environmental Life Cycle Assessment of the Nuclear Fuel Cycle" (Solberg-Johansen, 1998). Unfortunately, they were not able to write an article within the agreed time schedule. For others not mentioned here, please write and let us know about your achievements as we hope to expand the listed membership (and possibly activities?) of the MIIM Club[2].

3 Conclusions

The summaries above show that our theses have been built on ideas from intellectual areas of enquiry as diverse as systems modelling, organisational theory, political analysis, toxicology, economy, medicine, anthropology, chemistry and engineering. They have also focused on a diverse array of subject matter including waste management, electricity mix and production, use of PVC in the economy, building materials, and agricultural products.
From this set of Ph.D. studies, a number of common points and tendencies can be recognised. First, a number of us have stressed the scope-dependency of LCA models, most notably Baumann and Frischknecht. They stress the importance of discerning between descriptive and change-oriented LCAs. Furthermore, quite a few of the theses focus on the interaction between LCA and decision-making. This indicates a tendency for LCA to become more connected to other fields of science – including both the natural and social sciences. Finally, some of the theses argue for pluralism in the methods used for impact assessment and allocation, a point that is currently under much debate in the LCA community. Generally, in the above abstracts, proposals are made for the structuring of controversial issues, rather than for eliminating them via harmonisation. The latter approach is either regarded as impossible, or is not seen as productive in resolving controversial debates.
Finally, if one conclusion can be made from the research described above, it is that our insights have been gained by drawing on a range of different academic disciplines. Yet we can all find aspects of each other's research that are relevant to our own research interests. This suggests that we are in the (not so) early stages of establishing a new discipline whose central core is characterised by a cross-disciplinary approach to environmental management along the entire life cycle of products, processes and activities. Not surprisingly, this new tendency is not yet reflected in the management of scientific research at some universities. Here, there is a potential for improvement through the establishment and support of cross-disciplinary research units. The need for such initiatives is particularly pertinent given the current developments in EU policy, the environmental management systems of companies, and legislation in different coun-

[2]We are almost certain that we missed some Ph.D.s of US LCA practitioners. In the first instance, please contact Arnold Tukker at Tukker@stb.tno.nl (see also note 1).

tries. As we, the Class of MIIM, move on to jobs in academia, industry and government, it will be interesting to see how the LCA agenda changes and develops. In the meantime, we hope you find this special series for the International Journal of LCA relevant and stimulating as we describe the intellectual journeys each of us has undertaken over the last few years.

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9th Annual Meeting of SETAC-Europe: Quality of Life and Environment in Cultured Landscapes

Leipzig, Germany, 25-29 May 1999

Programme Overview

Sessions

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1a Speciation, (Chramel, Sijm)
1b Stable isotopes, (Jung, Heltai)
1c Abiotic transformation, (Weber, Haderlein)
1d Long-range transport of contaminants, (Jones, Halsall, Steinnes)
1e Global distillation and distribution patterns of POPs, (Ockenden, van de Meent)
1f Temporal and spatial trends of ecosystems, (Fränzie, Rieche)
1g Pesticide residues and metabolites, (Kubiak, Arnold)
1h Xenobiotics in marine ecosystems, (Matthiessen, Hylland)
1i In situ methods for sediment contaminations, (Ahlf)
1j Solid-phase extraction, (Popp, Wennrich)
1k Biomarkers and biosensors, (Hansen, Narbonne)
1l Semipermeable membrane devices, (Vrana, Södergren)
1m Monitoring of biological effects in European coastal waters, (Oehlmann, Kunitzer)
1n Bioindicators, (Zechmeister, Markert, Breure)
1o Modelling and monitoring, (Matthies)
1p Monitoring of biological effects in limnic waters, (Triebskorn, Machala)
1q POP cycling in the Baltic, (Calamari)

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2a Scope and relevance of biotests, (Tarazona, Pärt)
2b Design of test strategies, (Kolossa, Länge)
2c Site-specific testing and TIE, (van Sprang)
2d Bioavailability, (Exley, Koelmans)
2e Testsystems for low solubility substances, (Mayer, Zok)
2f Modes of ecotoxic action, (Escher, Hermens)
2g Ecophysiological parameters, (Köhler, Stürenbaum)
2h Mixture toxicity, (Hermens, Alternburger)
2i Prolonged toxicity and long-term effects, (Pascoe, McCahon)
2j Endocrine disrupture, (Wenzel, Fent)
2k Behavioral toxicity, (Lillienthal)
2l Phototoxicity, (Ankley)
2m Site-specific vs. regional fate modelling, (Klein, Trapp)
2n Fate of pesticides, (Spiteller)
2o Bioaccumulation, (McLachian, Butte)
2p Exposure assessment strategies, (Feijtel)
2q Use pattern of industrial chemicals, (Wagner)
2r Modelling compound properties, (Altschuh, Kaiser)
2s QSAR, (Verhaar, Nendza)
2t Data interpretation and assessment strategies, (Brüggemann, Dohmen, Welzel, Mathes)
2u Earthworm ecotoxicology, (Heimbach, Römbke)

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3a Approaches for new and existing chemicals, (Bias, Ahlers)
3b Pesticides, (Köpp)
3c Water and sediment criteria, (Kussatz)
3d Soil quality criteria, (Eijsackers)
3e Risk communication and management, (Hulpke)
3f Pesticide risk assessment – cooperation in method development, (Hart, Lewis)

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4a LCA: Data, dynamic modelling and scenarios, (Bretz, Fleischer)
4b LCIA: characterisation, normalisation and weighting, (Jolliet)
4c LCIA: alternative approaches, (Krewitt)
4d LCA and decision-making, (Cowell, Neitel)
4e Substance flow analysis and regional development, (Baccini, Schertenleib)
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S2 Spatial aspects of exposure modelling, (Matthies)
S3 Field validation and ecological interpretation in soil ecotoxicity, (Kammenga, Weeks)
S4 Uncertainty and probabilistic approaches in human health and ecological risk, (Forbes, Calow)
S5 Role of science in environmental risk managemen, (McCarty, Power, Douben)
S6 New developments in the environmental risk of metals, (Janssen, Waeterschoot)

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