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HOW TO MAKE POLICY-RELEVANT LIFE CYCLE ASSESSMENTS OF FUTURE PRODUCTS?

LESSONS LEARNED FROM NANOMATERIALS

Rickard Arvidsson, Duncan Kushnir, Björn A. Sandén, Sverker Molander*

**Rännvägen 6, 412 61, Gothenburg, Sweden, rickard.arvidsson@chalmers.se*

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ABSTRACT

There is a demand from policy-makers for knowledge about environmental impacts of nanomaterials, and life cycle assessment (LCA) is one method that can be used to obtain such knowledge. Here, we have reviewed 16 LCA and LCA-like studies of nanomaterials, and investigated how these studies handled the fact that for many nanomaterials, complete life cycles do not yet exist to be assessed. We have discovered five different strategies, denoted *likely scenarios*, *extreme scenarios*, *exclusion*, *established system* and *sensitivity analysis*. Their relevance and areas of application are discussed, and it is among other things concluded that extreme scenarios and analogies to established systems can be relevant strategies to assess the environmental impact of very immature products.

INTRODUCTION

Policy-makers increasingly want to know the environmental impacts of products in a very early stage of development in order to avoid severe future negative impacts from the products. Along this line, a number of authors have highlighted the importance of assessing the environmental impacts of new nanomaterials, preferable along the whole product chains or life cycles. These calls generally reflect the idea that environmental assessments should be used to guide technology-relevant policy-making in an iterative fashion, as shown in Figure 1. This view on environmental assessment guiding technological development has been advocated by a number of authors, see e.g. Fogelberg and Sandén (2008). For this purpose, a number of methods that can be used to assess the environmental impacts of products exist, including life cycle assessment (LCA). However, assessing the life cycle environmental impacts, e.g. in terms of emissions and energy use, related to nanomaterials and products that contain them constitutes a great challenge, which makes it difficult to meet such needs from policy-makers.

The challenge is much due to the many uncertainties that surround new nanomaterials at an early point of technological development, which makes environmental assessment methods such as LCA difficult to apply. These uncertainties arise since parts of the product life cycle are not yet established, i.e. do not exist at all or in a premature state. When that is the case, we refer to the whole life cycle, whole product chain or single life cycle process as being *immature*. This term is inspired by the technical change literature, where technologies are often graded with regards to their maturity (Grübler 1998). This immature nature of many nanomaterial life cycles differentiates them from the life cycles of more mature products (such as cement and cucumbers). Assessing the environmental impacts of immature nanomaterial life cycles requires the assessor to make assumptions about the future, or rather some aspects of a number of possible futures. In this paper, we describe how the immature nature of nanomaterials has been handled so far in the LCA literature and similar environmental assessments. Strategies used to consider the future are outlined and their pros and cons are discussed in relation to policy-making. We also exemplify how environmental assessments such as LCA can be used in questionable ways when applied to immature life cycles with the purpose of obtaining policy-relevant results.

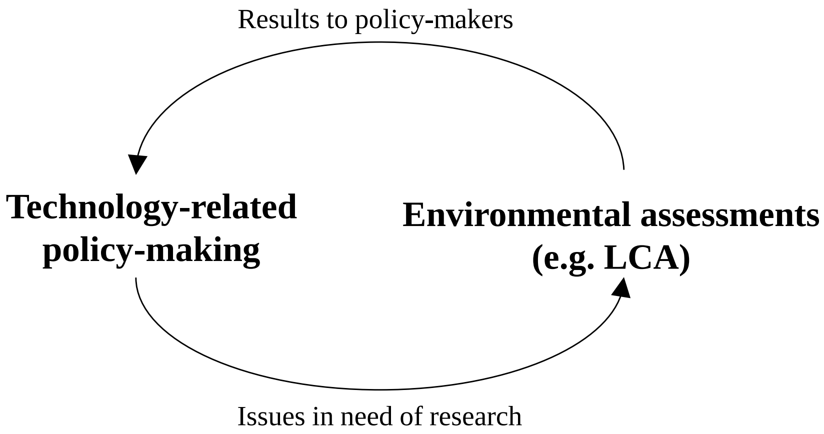

Figure 1. The relationship between technology-related policy-making and environmental assessments such as LCA.

MATERIALS AND METHODS

We have reviewed all existing LCA studies of immature nanomaterial products, which can be found in the reviews by Gavankar et al. (2012) and Hischier and Walser (2012), along with two LCA-like studies where life cycle emissions of immature nanomaterial products where assessed (Arvidsson et al. 2011, 2012). In total, this adds to 16 studies. The texts were coded based on categories representing different strategies used to describe and assess the immature processes in the product chains. The following strategy categories were developed iteratively during the coding:

- **Likely scenarios:** The immature processes are assigned parameter values that are considered likely based on technical arguments. It could be data from pilot projects or trend analysis results.
- **Extreme scenarios:** The immature processes are assigned very high or very low parameter values in order to illustrate extreme aspects or its potential. Worst case scenarios, e.g. assuming very high emissions or only electricity from coal power, belongs to this category.

- **Exclusion:** Immature processes are excluded due to lack of information, which effectively equals an extreme scenario where the environmental impact of the process is set to zero. An example is to exclude the waste handling since no immature product under study has ever been discarded.
- **Mature system:** As a specific variant of the likely scenario strategy, the immature system is here approximated to a mature, believed-to-be similar system. An example is to assume that production of silver nanomaterials will have the same environmental impact as that of ordinary silver.
- **Sensitivity analysis:** Certain parameters of the immature processes are varied within a reasonable range, for example ±X%.

RESULTS

As can be seen from Figure 2, likely scenarios is the most used strategy in the reviewed studies, followed by extreme scenarios, sensitivity analysis, exclusion and mature systems. Often, one study uses several different strategies, with an average of about 2.6 strategies per study. The choice of strategy is sometimes motivated, but most often not.

Another result from our review is that few studies differentiate between foreground and background systems. There are examples where immature nanomaterials are deemed to have high environmental impact, but where this environmental impact did not come from the production of the nanomaterial itself but from emissions from electricity production. Emissions from electricity production may vary considerably over time and says more about the energy system of the region that it does about the immature nanomaterial under study. We therefore consider such assessments to be of questionable use for policy-makers, and underline the importance of differentiating between foreground and background systems when assessing environmental impacts of immature products.

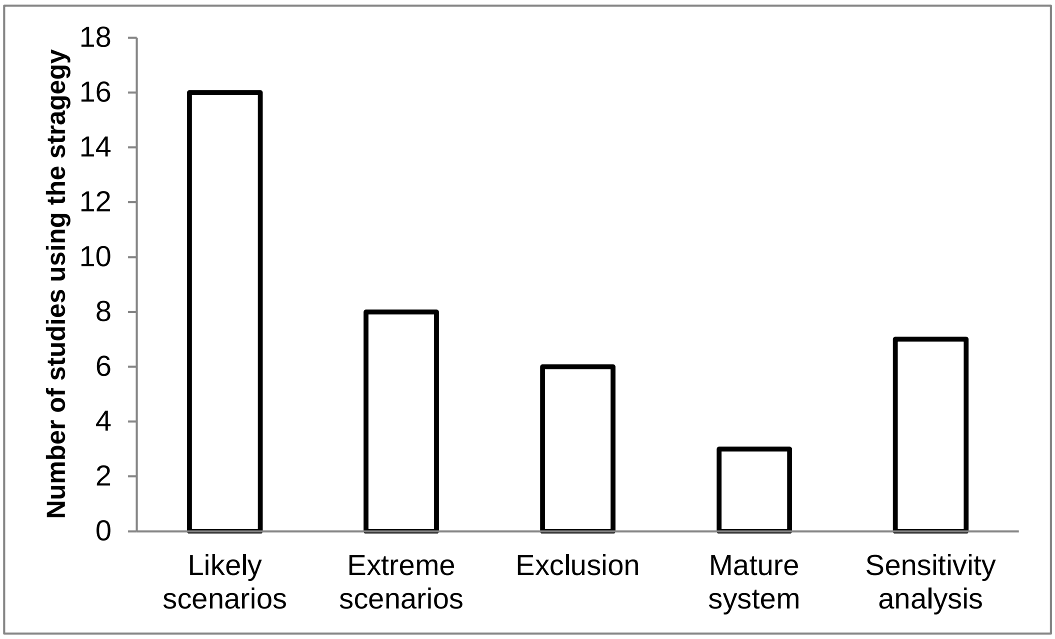

Figure 2. Results from the review of strategies used to consider immature product chains in LCA studies of nanomaterials. See the text for explainations of the strategies.

DISCUSSION

Which of the strategies in Figure 2 is then the most relevant for policy-making? As usual, this depends. Yet probably some strategies are more relevant for almost mature product chains, whereas others are more relevant when considering product chains that are very immature. Likely scenarios and sensitivity analyses are probably more relevant in a shorter time perspective, whereas extreme scenarios are more relevant in a longer time perspective to illustrate the long-term potential impacts of currently very immature products. Using likely scenarios and sensitivity analyses for very immature products, which are almost completely unknown, may create the false impression to policy-makers that the product is well-known. We therefore consider it important to clarify the aim of the study and relate the strategy used to the aim. If the aim is to inform long-term technology-related policy-making, likely scenarios may not be the most relevant strategy.

Although some of us have used the exclusion strategy (Arvidsson et al. 2011, 2012), we consider is unfortunate as it leaves the policy-maker with no information at all. In some cases, extreme scenarios combined with the mature system method may be used instead to provide at least some guidance (e.g. the immature process X is not likely to have a higher environmental impact than the mature process Y). For LCA studies with a very long-term ambition, studying immature product chains or processes, the use and/or combination of extreme scenarios and the mature system method is in general probably the most relevant method with regard to environmental technology-relevant policy-making.

CONCLUSIONS

We have outlined a typology of different strategies for describing and assessing the environmental impact of immature products: *likely scenarios*, *extreme scenarios*, *exclusion*, *established system* and *sensitivity analysis*. We have concluded that some of them are more useful for mature products, and others for very immature products. In particularly extreme scenarios are suggested as relevant for very immature products as it illustrates their potential and avoids assumptions that may appear likely now but may not be so in the future.

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