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# A model for screening and prioritizing consumer nanoproduct risks: A case study from South Africa

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ABSTRACT

The potential risks of the increasing variety and volume of engineered nanomaterials (ENMs) entering into the ecosystem remain poorly quantified. In recent years, information essential to evaluate the ecological risks of ENMs has increased. However, the data are highly fragmented, limited, or severely lacking. This limits the usefulness of the information to support holistic screening and prioritization of potentially harmful ENMs. To screen and prioritize ENMs risks, we adopted a two-phased approach. First, a holistic framework model was developed to integrate a diverse set of factors aimed to assess the potential hazard, exposure, and in turn, risk to the ecosystem of ENMs from a given consumer nanoproduct. Secondly, using published literature we created a database of consumer nanoproduct categories, and types based on embedded ENMs type. The database consisted of eight consumer product categories, eleven different types of ENMs, and twenty-three nanoproduct types. The model results indicates the largest quantities of ENMs were released from sunscreens, textiles, cosmetics and paints with dominant ENMs quantities in descending order (based on quantity) as $nTiO_2 > nZnO > nSiO_2 > nAg$, and $nFe_2O_3$. In addition, according to the results from this study, nAg from washing machine were found to likely the highest risk to the environment. Overall, our model-derived results based on the case study illustrated: (i) the holistic framework's ability to screen, prioritize, rank, and compare ENMs potential exposure and risks among different nanoproducts categories and types, (ii) the derived risk estimations could support nanowastes classification with likelihood of non-uniformity of nanowastes classes even from the same nanoproduct category (e.g. cosmetics), and (iii) the lack of a mass-based criteria specific for EMNs impedes realistic exposure and risk evaluation in the ecological systems.



## 1. Introduction

The last two decades have been marked by rapid commercialization and proliferation of consumer nanoproducts globally (Future Markets, 2011; The Danish Environmental Protection Agency, 2014; PEN, 2016; The Nanodatabase, 2016). In turn, this has triggered the development of databases and inventories with information on engineered nanomaterials (ENMs) incorporated in nanoproducts where many are either country or continental (regional) specific (Hansen et al., 2016a). In addition, the increasing use and number of nanoproducts, where even in the same nanoproduct category (e.g. cosmetics, paints, or textiles.) (PEN, 2016) different types of ENMs are used (Musee, 2011a; Vance et al., 2015), make it difficult to undertake hazard, exposure and risk assessments for every single variant of ENM and/or nanoproduct. As such assessments are labour, time, and cost intensive; and therefore, motivated calls for potential ENMs risks be undertaken on a case-by-case basis (Wiesner et al., 2008; Grieger et al., 2010; Musee, 2011a) as part of generating valuable data required, for example, for regulatory purposes (Becker et al., 2011).

To date the number of ENMs in commercial and industrial applications remain unquantified and are exponentially increasing as the breadth of their uses remain to be fully exploited. For example, databases for nanoproducts such as The Nanodatabase (2016) and PEN (2016) which are publically accessible have each have reported thousands of products currently available in commerce. This raises the question of how risk assessment of ENMs can be done rapidly, effectively, and at reasonable cost in order to protect the human health and the environment? To address these drawbacks, efforts by the research community and regulatory authorities over several decades have yielded the development of hazard- (Davis et al., 1994; Hertwich et al., 2001; Mitchell et al., 2002) and risk-assessment (Eriksson et al., 2005; Arnot and Mackay, 2008; USEPA 2009; Shin et al., 2015) models to screen and prioritize (Bu et al., 2013) large numbers of chemicals. The strength of these models is the ability to undertake screening and prioritization of chemicals hazard, exposure or risk estimation in data-scarce scenarios (Bu et al., 2013). For example, lack of data on chemical quantity and use information impedes – as no data imply no quantitative modelling is possible – the parameterization of exposure models (Breivik et al., 2012; Shin et al., 2015). As a result, has motivated the development and use of high throughput screening (HTS) techniques to screen, prioritize,

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classify, and rank potential risks of chemicals through incorporation of exposure and toxicity data (Committee on Toxicity Testing and Assessment of Environmental Agents, 2007).

ENMs are among an emerging class of contaminants (Yan et al., 2010; Boxall, 2012) that have triggered concerns partly due to limited understanding of their potential risks to humans and the environment (Oberdörster et al., 2005; Klaine et al., 2008; Kunhikrishnan et al., 2015; Krug, 2014; Pereira et al., 2015). It should be noted that although numerous studies have been conducted as part of addressing these risks, for example, under the Organisation for Economic Co-operation and Development (OECD) Sponsorship Programme (OECD, 2008), the published data does not provide a clear evidence of "nano effect" (Krug, 2014; OECD, 2016) as many studies have not provided a distinction between ENMs and conventional chemicals-induced toxicity mechanisms, for example, whether to the humans or the environment. Numerous reasons underpin these limitations, and mostly linked to inadequate ENMs testing and characterization (Krug, 2014; Part et al., 2015). According to a recent account on non-suitability of most published data on risk assessment of ENMs, Hansen et al. (2016b) highlighted lack of proper characterization, where data for environmental fate and toxicity, for example, were done in different laboratories under different conditions. As a result, data generated is found to be highly fragmented, and, hence can cannot support our collective ability to draw substantive conclusions on what aspects underpins the "nano effect". It is, therefore, no coincidence, that OECD and other authorities that have sponsored research in this field are defined by disclaimers, coupled with the strong warning against drawing any conclusion about the risk of nanomaterials (Hansen et al., 2016b) – which points to data and knowledge that are yet to be addressed.

In response to these concerns, calls have been made for the need to develop rapid screening and prioritization tools to assess potential risks of ENMs to humans and the environment, and for the effective management of these risks (Nel et al., 2013; Fadel et al., 2015); while acknowledging the limitations of related currently published data. Tools developed to this end have sought, for example, to promote sustainable use of nanotechnology (Subramanian et al., 2015). In addition, various reports have contributed towards our understanding of likely risks posed by ENMs, and how they can be assessed (Beaudrie et al., 2014; Hristozov et al., 2014), but also acknowledging the current limitations.

In this article we first present a framework tool developed to screen and prioritize potential risks of different ENMs incorporated in diverse nanoproducts. The tool takes into account limited and contradicting information on exposure and hazard in the environmental systems presently available. Second, we illustrate how even in the same nanoproduct category (e.g. cosmetics, paints) potential risk levels differ markedly from nanoproduct type linked to differences in types of ENMs used (e.g. nZnO, $nAl_2O_3$, $nC_{60}$), and ENMs concentration per nanoproduct type, among other factors as presented in section 2. Finally, we show how the risks of the same ENMs differ distinctively from one nanoproduct application category to another, and point out the associated implications for managing these risks using a case study. The primary purpose to use a case study was to illustrate the functionality of the framework proposed in this paper. This is because currently it is not feasible to cover the entire life cycle of nanoproducts or all waste pre-treatment, treatment, and post-treatment processes across many legislative regions and countries. The reason being due to lack of information about productions amounts, or release rates during reproduction, use, and disposal phases of nanoproducts.

## 2. Methods and materials

### *2.1. Identification of nanoproducts and ENMs of focus*

Numerous inventory databases, technical reports ( ) and scientific articles indicate that metal- and metal oxide-based ENMs are the mostly produced and widely used in consumer products and industrial applications (Hansen et al., 2008; Piccinno et al., 2012; Wijnhoven et al., 2009; Future Markets, 2011; The Nanodatabase, 2016; PEN, 2016; Musee, 2011b; Vance et al., 2015). To the author's knowledge, at present, there is no publicly accessible nanoproduct inventory in South Africa nor the ENMs types used despite increasing commercialization of such products in the retail market, for example. Hence, recent inventory for nanoproducts and applications in the UK (Tiede et al., 2015) was used to form the basis of this study. To this end, using a set of correction factors (discussed in Section 2.3.1) to the UK data was adopted to mirror the South African use pattern scenarios, and likely release of ENMs through different pathways into the environment.

The proposed framework is based on four assumptions concerning nanoproducts. First, the concentration of ENMs in a given nanoproduct is similar from country or region as the products are largely produced by the same manufacturers (multi-nationals) that trade globally (Musee, 2011c). Secondly, published data for a specific product category (e.g. sunscreens, coatings, etc.) usage per person daily (g/p/d) are global (European Chemicals Bureau (ECB), 2003). Thus, ECB usage values were considered applicable in countries with economics in transitions such as South Africa, and used in this model. Thirdly, market penetration of a given product category is dependent on socio-economic factors like income per capita, purchasing parity power (PPP), gross domestic product (GDP), and regional household income per capita (HI), for example, in a given country. And, a worst case scenario based on 100% release of ENMs from the products; which in effect would reflect likely highest possible concentrations in the environment. Such assumption has been used before for ENMs in modelling studies previously (Mueller and Nowack, 2008).

Here, the HI value was determined as a ratio of household income in Gauteng Province to the average overall South Africa income to account for regional income parities in the country (Table S1 in supporting information). Next, correction factors (cfs) (Table S2 in supporting information) were applied to estimate market penetration of nanoproducts in South Africa derived based on published UK data (Tiede et al., 2015). Use of cfs was to account for variations in nanoproducts consumption due to income differences among different population groups. Similar approach based on use of cfs is described elsewhere, and its suitability is well established (Musee, 2011c; Keller and Lazareva, 2013). Based on use categorization of nanoproducts and applications in the UK inventory the most dominant product categories were: cosmetics, sunscreens, clothing, cleaning, paints and coatings, among others (Tiede et al., 2015). According to nanoproducts data bases, each use category was found can be made using different types of ENMs (Table 1). Therefore, using databases, it was established that a given nanoproduct type can be manufactured using different types of ENMs. Next, using websites, to market various nanoproducts, we identified the most frequently marketed or claimed to contained as eight products (Table 1). Finally, using the published we identified ENMs used in a given product, and those included had the ENMs concentrations per product item had been published by Tiede et al. (2015). In light of this criteria eleven ENMs and eight nanoproducts as listed in Table 1 were identified, and therefore, considered in this study for illustrative purposes on the applicability of the proposed framework.

### *2.2. Hierarchical prioritization model*

The decision analytic hierarchical approach was adopted to develop a ranking tool that can rapidly, efficiently, and effectively screen and prioritize ENMs potential risks from different consumer nanoproduct categories to the environment. The prioritization framework data comprised of hazard (toxicity) and exposure since risk is a function of both. This was achieved through systematic structuring of complex and multiple factors that govern environmental risks of ENMs. Fig. 1 depicts the hierarchical framework developed in this study. Selected factors for inclusion in the hierarchical architecture (Fig. 1) were partly intended to ensure each factor was independent and relevant for evaluating