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Assessing the Social Impacts of Nano-Enabled Products through the Life Cycle: The Case of Nano-Enabled Anti-Microbial Paint

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	CuO) based paint with anti-microbial functionality, is assessed with respect to its social impacts. The method was applied to twelve indicators at the company level. Classification of social indicator scores and aggregated scores showed that the n-CuO paint has high net benefits. Conclusions The framework and method offer a flexible structure that can be revised and extended as more knowledge and data on social impacts of nano-enabled products becomes available. The proposed method is being implemented in the Social Impact Assessment sub-module of the SUN Decision Support System (SUNDS) software. Companies seeking to improve the social footprint of their products can also use the proposed method to consider relevant social impacts to achieve this goal.
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Assessing the Social Impacts of Nano-Enabled Products through the Life Cycle: The Case of Nano-Enabled Anti-Microbial Paint

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Abstract

Purpose

This paper proposes a method to assess the social impacts of nano-enabled products through the life cycle that is a) quantitative, b) integrates performance and attitudinal dimensions of social impacts, and c) considers the overall and stakeholder balance of benefits and costs. Social Life Cycle Assessment (s-LCA) and Multi-Criteria Decision Analysis (MCDA) are integrated to address this need, and the method is illustrated on a case study of a nano-enabled product.

Method

The s-LCA framework comprises of fifteen social indicators within the classification structure of Benefit/Cost and Worker/Community. The method includes four steps: a) Normalization of company level data on the social indicator to country level data for the year, b) Nested weighting at stakeholder and indicator level and its integration with normalized scores to create social indicator scores, c) Aggregation of social indicator scores into benefit score, cost score and net benefit scores as per the s-LCA framework, and d) Classification of social indicator scores and aggregated scores as Low/Medium/High based on benchmarks created using employment and value added proxies.

Results and Discussion

A prospective production scenario involving novel product, a nano-copper oxide (n-CuO) based paint with anti-microbial functionality, is assessed with respect to its social impacts. The method was applied to twelve indicators at the company level. Classification of social indicator scores and aggregated scores showed that the n-CuO paint has high net benefits.

Conclusions

The framework and method offer a flexible structure that can be revised and extended as more knowledge and data on social impacts of nano-enabled products becomes available. The proposed method is being implemented in the Social Impact Assessment sub-module of the SUN Decision Support System (SUNDS) software. Companies seeking to improve the social footprint of their products can also use the proposed method to consider relevant social impacts to achieve this goal.

Keywords: Social Life Cycle Assessment, Sustainability Assessment, Decision Analysis, Nanotechnology, Decision Support System, Case Study

1. Introduction

In the recent years, Life Cycle Assessment has been extended to social aspectsand the resulting social Life Cycle Assessment (s-LCA) is an approach to assess social impacts associated with the Life Cycle of an activity (Althaus et al., 2009). s-LCA is a relatively young method (Petti et al, 2016; Jorgensen et al, 2007; Hunkeler, 2006), but its value in assessing the social impacts of products has already been recognized by companies (Benoit et al, 2010). Roundtable of Product Social Impact Assessment (RPSM, 2014) and World Business Council of Sustainable Development chemical method (WBSCD, 2016) harmonize definitions of social impacts and suggest measurable indicators to be applied in a company context. s-LCA for products has been implemented within SEEBALANCE sustainability assessment tool (Schmidt et al., 2004), Social Hotspots Database scoping assessments (Benoit-Norris et al, 2012) and LICARA NanoSCAN tool [1](van Harmelen et al, 2016). s-LCA has been widely applied to product systems and organizations (Ramirez et al, 2016; Siebert et al, 2016; Smith and Barling, 2014; Hosseinijou et al, 2014; Manik et al, 2013; Foolmaun and Ramjeeawon, 2012; Hunkeler, 2006; Norris, 2006; O'Brien et al, 1996).

[1] LICARA NanoSCAN is the only assessment tool that specifically addresses nano-enabled products.

There are, however, important gaps to be addressed to link s-LCA to real world decision-making. Social impacts inherently have both performance and attitudinal dimensions that should be incorporated explicitly in decision-making. Furthermore, the decision-making framework and method should make explicit benefits and costs, and how these are distributed along the value chain. There are additional methodological issues that remain to be addressed for credible assessment of the social impacts of nano-enabled products. Subramanian et al (2016b) highlight some of these issues pertaining specifically to nanotechnology including lack of metrics on contribution of innovation to sustainable development goals and information sharing on environmental health and safety risks in the value chain, as well as the challenge in operationalizing impacts with substantial ethical and cultural dimensions.

Subramanian et al (2016b) propose an s-LCA framework for nano-enabled products and couple it to a Multi-Criteria Decision Analysis (MCDA) method to address the problem described above. This quantitative method is being implemented in the Social Impact Assessment (SIA) sub-module of the Socioeconomic Assessment (SEA) module in Tier 2 of SUNDS (Subramanian et al, 2016a). The SEA module in Tier 2 of SUNDS compares sustainability aspects of scenarios of manufacturing nano-enabled products of similar functionality (Subramanian et al, 2016a). Each product manufacturing scenario will be characterized through the Life Cycle using outputs of ecological and human health risk assessment, lifecycle impact assessment, economic assessment and social impact assessment. Instead of a mathematical integration of these outputs to derive a sustainability indicator, a classification profile indicating hotspots for further investigation based on technical criteria, benchmarks and user preference profiles is proposed for the SEA module.

This paper describes the method implemented in the SIA sub-module and its application to an actual industrial product at pre-production stage. First, we review the s-LCA framework for nano-enabled products (Section 2.1). Then, the method comprising of normalization, weighting, and aggregation and classification steps is described (Section 2.2). A case study of a nano-enabled product is introduced (Section 3.1) and results of application of the method to this case study are presented and discussed (Section 3.2). Finally, future improvements to the SIA method are discussed (Section 4).

2. Method

2.1 s-LCA Framework

The procedure followed to select social indicators for the assessment of nano-enabled products has been described comprehensively in a previous publication (Subramanian et al., 2016b). A list of social impacts was developed by reviewing the following sources and harmonizing categories: a) Corporate Social Responsibility Guidelines (ISO 26000, 2010) and Global Reporting Initiative Metrics (GRI, 2014), b) List of social impact in method guidance documents (ECHA, 2011, s-LCA Consumer Health and Safety Sheets, 2010, Althaus et al., 2009; EC IA, 2009), c) existing product sustainability assessment tools (van Harmelen et al, 2016; Benoit-Norris et al, 2012; Schmidt et al., 2004), and d) nanotechnology Ethical Legal and Social Implications literature. Indicators available in statistical databases were reviewed and fifteen distinct social indicators were chosen to operationalize to these social impacts (Table 1). These indicators selected covered two stakeholders, namely worker (8 indicators) and community (7 indicators). The coverage in terms of classification as benefits and costs is as follows: 10 benefit indicators (6 indicators for workers and 4 indicators for community) and 5 cost indicators (2 indicators for workers and 3 indicators for community). Expert assessment deemed five indicators to be particularly relevant for nano-enabled products (shown in bold in Table 1). Two indicators in the community cost category are relevant only to developing countries (indicated in text in Table 1).

[Table 1 here]

2.2 Social Impact Assessment Sub-module Method

The s-LCA framework was linked to an MCDA method which comprises of the following steps: a) Normalization, b) Weighting, c) Aggregation, and d) Classification. MCDA comprises a large class of methods for the evaluation of different alternatives based on relevant criteria (Giove et al., 2009). In the Multiple Attribute Value Theory (MAVT) method, a value function is specified for each criterion (Giove et al., 2009) and modified according to normalization and user weights and finally integrated into a common domain. The classification step proposes a method to derive benchmarks according to which outputs of the SIA sub-module can be compared to provide guidance to the user of Decision Support System (DSS).

In environmental LCA, impacts can be clearly linked to functional unit but the cause and effect relationship is more ambiguous in the case of s-LCA (Swarr, 2009; Klopffer, 2008; Dreyer et al, 2005). Ideally, the unit of analysis for the production scenario should be fairly specific but the appropriate level is not always easy to pinpoint, obtain data for, or interpret. For example, perhaps the most discrete unit of analysis for a production scenario is the manufacturing production line in which the product is manufactured. Having annual data for the production line allows the analysis of a decision context where a manufacturer can manufacture two types of products with similar functionality. However, the same production line is used to manufacture more than one product (particularly in medium and large industry) and hence the social indicator score in such contexts cannot be viewed as strictly associated with a single product. Due to the dynamic nature of the company context (e.g. mergers, data collection processes, etc.), data aggregated at higher units of analysis over the year is viewed as more reliable, meaningful and typically used in reporting. The explanatory value of the analysis results is a further test of the use of the appropriate unit of analysis.

2.2.1 Normalization

Social indicator scores represent the product development's annual share contribution to the country level social impact. Product development's social impact is defined in terms of the annual contribution of the chosen unit of analysis within the company. As available social indicator data for countries is not disaggregated in terms of Small and Medium Sized Enterprises (SME) and Large Industry (LI) contributions, country-level proxies for which data is classified as SME/LI are used to derive proxies. The "relative potential" of an SME or LI company to create a social impact in a country was derived using a) average number of employees for SME and LI, and b) average value added for SME and LI. Relative potential index was calculated for 22 EU countries and EU-28 group. Each social indicator is linked to one of these relative potentials based on if it was more closely linked to employment or value added. In the case of the 15 social indicators listed in Table 1, two are classified as linked to value added (i.e. Social Benefits & Pension and Research & Development investment), and the rest are classified as linked to employment. Both these relative potentials are used to derive the adjusted total number of companies, which in turn is used to derive the mid-level value for the social indicator for a SME and LI.

2.2.2 Weighting

Weighting involves the assignment of an importance value to social indicator scores based on personal, social or policy preference, mathematical properties, panel weighting approaches based on polls, etc. s-LCA categorizes social impacts as being relevant to stakeholders like worker, consumer, value chain, legal framework, community or society. The SUNDS user may attach different value to different social indicators, as well as stakeholders through the Life

Cycle. The SIA sub-module method accounts for this by using a nested weighing scheme. Users are asked to define weights on a scale of 1-5 first at stakeholder level and then at social indicator level. MAVT value functions for both sets of weights are normalized in order to have a sum of one. Stakeholder and indicator weights are integrated with each (normalized) social indicator value function.

2.2.3 Aggregation

Normalized and weighted social indicator value functions are aggregated as overall benefit and cost scores using weighted sum of the social indicator scores classified as benefit and cost respectively. Net benefit score is the difference between benefit and cost score. In addition, stakeholder percentage of impacts calculate the relative share of benefits and costs generated by each stakeholder.

2.2.4 Classification

Social indicator and aggregated scores are closely tied to the relevant social context and can vary significantly even in the same country in terms of social values, type of industrial structure, laws and regulations, preferences and other factors. To guide the user, a classification system was developed and implemented as default option in SUNDS. It is based on the assumption that one of the key factors that can cause social impacts or benefits are significantly different for companies of different sizes. The overall social impact in a country is composed of different activities within that country (including industry), and the size of the industrial enterprise influences its capacity to create social impacts at country level. We therefore explored the idea to develop thresholds of High, Medium and Low classes for SME or LI.

The mid-value of the social impact (obtained as described in Section 2.2.1) is divided by the social indicator data at country level to obtain benchmarks for SME and LI. Low/Medium and

Medium/High thresholds are defined using 80% and 120% of benchmark's value. Thresholds for aggregated scores are calculated for SME and LI by following the same process of weighting and aggregation.

3. Application to Case study

3.1 Case study description

A production scenario involving novel product being considered for industrial production, a nano-copper oxide (n-CuO) based paint with anti-microbial functionality, is assessed with respect to its social impacts. Wood preservation treatment is indispensable to increase the service life of timber by imparting it with bactericidal, fungicidal and insecticidal properties (Freeman and McIntyre, 2008, Lebow et al. 2004). Moreover, improving the efficacy of wood preservation treatments and ability to use a variety of timber species can limit deforestation and also save human labour to build essential infrastructure (http://www.wei-ieo.org/woodpreservation.html). Usually, chemical preservatives are used to treat softwood intended for commercial uses, and copper-based preservatives are commonly used for this purpose (Freeman and McIntyre, 2008, Lebow et al. 2004). The paint formulation provides an additional aesthetic functionality, in addition to preserving timber currently in use.

The functional unit for this application is the provision of one million square meter of exposed softwood exterior cladding for one year. While it is more precise to express scores in terms of functional unit, we do not do this in the current application as the scores are already quite small numbers due to normalization with country level data and converting data to functional unit has no impact on the method or decision context. The unit of analysis considered is company level for a LI based in Germany in which the paint will be manufactured. Cradle to grave lifecycle stages in so far as quantitative social indicators are available. The company level data was obtained from company reports, and company level data was available for 12 social indicators for the year 2014 (directly or could be inferred by combining data). Data on patents and employees in R&D were available at higher levels of aggregation (i.e. worldwide) and employment of handicapped persons was not measured. The source of country level data used to normalize these indicators is given in Supplementary Information (Table 1).

3.2 Case study results and discussion

Stakeholder weights are assigned as worker=4 and community=2, to consider a scenario where community is more important to the user than the workers and to counterbalance the higher number of worker benefit indicators in this illustrative application. All indicator weights are assigned equally as 1. Underlying data and employment and value added benchmarks for SME and LI for Germany are provided in Supplementary Information (Table 2). In a case study including more than one product, at this stage, social indicator scores could also be scaled down to the company sub-division level using current proportion of employment and sales at sub-division level for indicators classified as associated with employment and sales respectively.

The social indicator score benchmarks for LI are used to further calculate low, medium and high thresholds for each social indicator incorporating also the weights assigned. These thresholds, n-CuO paint scores and resulting classification of social indicators for the case study are presented in Table2. Overall, seven indicators were classified as high, and five indicators were classified as low. While the order of magnitude of the thresholds is 10^{-5} or 10^{-6}, n-CuO scores range from zero to 10^{-9}. The highest scores for the n-CuO case study are for professional training (classified as worker benefit) and R&D expenditure (classified as community cost); both of which are relevant to nano-enabled products. n-CuO paint performs as desired on most social indicators. The only exception is contribution to social security and pension, where the resulting classification is LOW. High scores can be good or bad, that depends strongly on the type of indicator and must be defined for each indicator.

[Table 2 here]

Aggregated scores for the benchmark and case study are obtained as described in Section 2.2.3. Thresholds, n-CuO paint scores and resulting classification of aggregated scores for the case study are presented in Table 3. Stakeholder share of benefit and costs and its classification are presented in Figure 1.

[Table 3 here]

[Figure 1 here]

The overall picture that emerges from this case study application is that n-CuO paint has high net benefit. The social indicator which has the most significant magnitude in cost category is R&D expenditure. The rationale behind the classification of R&D expenditure as a community cost is that this method analyses the social context for one year, and typically R&D expenditure yields benefits (if at all) over longer periods of time. n-CuO paint is particularly favourable to workers, with high benefits and low costs.

4. Discussion

We propose and apply a method that takes into account both social impact performance and stakeholder preferences in decision-making on nano-enabled products through the Life Cycle. This framework and method offer a flexible structure that can be revised and extended as more knowledge and data on assessment of nano-enabled products becomes available. The simple conceptual framework is also an advantage as it allows value-laden conceptual categorization (i.e. benefits and costs or stakeholder categories) to be easily changed in the analysis.

Quantitative indicators associated with use and end-of-life phase as well as relevant to other stakeholders are currently not available and would be required to make the s-LCA framework comprehensive (Lehmann et al, 2013). Social indicators have been defined in accordance with available country level data in order to enable application of the method. However, these data are not disaggregated in terms of the impact of specific emerging technologies or industrial contexts (e.g. SME/LI), which would allow more precise application of the method. As social impacts as part of sustainability of products acquires greater importance to companies and consumers these issues can be addressed, in a meaningful way, by deploying annual country level surveys to generate more targeted and standardised information.

Measurement of social indicators at company level should also be standardized and done at appropriate levels. In choosing the unit of analysis to apply the method, there should be a match between the decision context, link to product(s) being evaluated and meaningfulness to the company context. A general rule-of-thumb that unit of analysis should be only as fine-grained as it needs to be to support the decision context and as it makes sense from the data generation point of view. Relevant information are needed but on a level, where differences of data makes sense in terms of meaningful interpretation of data. One limitation of the proposed method is that the classification step can be applied only at the company level. For an absolute assessment of two products produced in the same company (e.g. within different product lines, sub-division, etc.), company level data and country level benchmarks are required at this level. In the absence of actual or meaningful data, scaling factors can also be used. For example, for a sub-division level analysis, company level data can be scaled down to sub-division level using sub-division to company ratio of employment and value added. Country-level benchmarks for companies could be divided by average number of sub-divisions per company in that country, if this can be somehow known. Often it makes no sense to go more details of the figures, because the statistics are not assessed on such a detailed level. In contrast to an environmental LCA, where even in one sub-division the environmental impacts of two products might differ significantly, the social indicator data for these products are exactly the same because they use the same facilities.

Due to lack of disaggregated data on SME and LI, employment and value added are used as proxies that are linked to the capacity of the enterprise to create social impacts on account of its size. Several social indicators can be linked to these proxies, and the nature of the association of the social indicator and proxy (i.e. direct or inverse) is also clear. Special attention should be paid in considering the classification results for social indicators for which this relationship is not unambiguous.

5. Conclusions

This paper aims to fill the gap in the quantitative assessment of social impact of nano-enabled products by proposing a method based on s-LCA and MCDA. This method enables the coverage of the entire Life Cycle and value chain, while allowing inclusion of stakeholder preferences to the analysis. This method is applied to the case study of a real industrial product, which facilitates identification of hotspots as well as decision making on the nano-enabled product in absolute terms. Companies can consider various production scenarios and choose the scenarios with better desirable social impacts. Companies seeking to improve the social footprint of their products can also use this method as a starting point to consider most relevant social impacts to achieve this goal. This method will be linked to the outputs of the environmental and economic sub-modules to have an overall sustainability assessment within the SEA module (Subramanian et al, 2016a).

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Tables

Table 1 Social Indicators in SIA sub-module

Worker Benefits	**Worker Costs**
- Social Benefits and Pension	-Strikes and lockout
-Professional training	**-Non-fatal occupational injuries**

-Tertiary education -Female employees -Trade union membership -Collective agreements	
<u>Community Benefits</u>	**<u>Community Costs</u>**
-Employment -Employment to handicapped persons **-Patent applications** - Employees in Research and Development	-Poverty (if product is developed in a developing country) **- Research and Development (R&D) investment** -Child labour (if product is developed in a developing country)

Table 2 Classification of n-CuO Social Indicator Scores

Social Indicator	Low/Medium Threshold	Medium/High Threshold	n-CuO paint score	Classification
Employees covered by collective agreements	3.3E-06	5.0E-06	1.5E-04	HIGH
Employees who are trade union members	3.3E-06	5.0E-06	5.9E-04	HIGH

Female employees who are part of senior management	3.3E-06	5.0E-06	5.46E-05	HIGH
Non-fatal accidents	1.0E-05	1.5E-05	1.6E-09	LOW
Days not worked due to strikes and lockout	1.0E-05	1.5E-05	0	LOW
Employees who are at risk of poverty	3.3E-06	5.0E-06	0	LOW
Child employees	3.3E-06	5.0E-06	0	LOW
Employees with tertiary education	3.3E-06	5.0E-06	3.82-03	HIGH
Contribution to Social Security and Pension	4.2E-06	6.2E-06	7.1E-07	LOW
Employment	1.0E-05	1.5E-05	2.7E-04	HIGH
R&D expenditure	4.2E-06	6.2E-06	6.7E-02	HIGH
Professional Training	3.3E-06	5.0E-06	2.4E-01	HIGH

Table 3 Classification of n-CuO Aggregated Scores

Aggregated Score	Low/Medium Threshold	Medium/High Threshold	n-CuO paint Score	Classification
Cost score	3.1-05	4.6E-05	6.7E-02	HIGH

Benefit score	3.1-05	4.6E-05	2.3E-01	HIGH
Net Benefit Score	0	0	1.7E-01	HIGH

Figures

Figure 1 Stakeholder share of Costs (left panel) and Benefit (right panel).

Cost, Worker Benefits and Stakeholder Benefits are classified as HIGH, and Worker Costs are classified as LOW.