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Selection criteria for suitable indicators for value creation starting with a look at the environmental dimension

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Abstract

This paper presents a set of selection criteria for identifying indicators for sustainable production of the manufacturing industry. Starting from a condensed overview of over 500 general sustainability indicators, such focussing on sustainable production are discussed, including the three dimensions of sustainability and the indicator qualities. Based on the Collaborative Research Centres (CRC) 1026 Framework and with the understanding that manufacturing industries may differ, the authors suggest to use the ABC judgement method - a semi-quantitative systematic method to prioritize indicators based on expert judgement and supporting evidences - to select core and supplemental indicators. Concise questionnaires considering sustainability targets are used and combined with a scoring system to support the decision process. The method can use either top-down indicators (i.e. on the impact level e.g. acidification, climate change) or bottom-up indicators (i.e. on inventory level e.g. energy consumption, recycling rate, volume or weight of solid waste/ hazardous waste). Proof of concept of the proposed approach in a life cycle based case study are presented by three demonstration cases focusing on manufacturing sector i.e. elevator, refrigerator and welding. Based on these cases result, we conclude that this is the first step in the right direction to use the ABC method to identify the suitable impact category sets for conducting LCA studies. The three simple questions that transfer selection criteria, i.e. robustness, relevance, effectiveness, practicality and clear and easy to measure, are found operational and appropriate.

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Keywords: indicators; manufacture; life cycle; top down, bottom up, selection criteria, sustainable production

1. Introduction

“Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony that permits fulfilling the social, economic and other requirements of present and future generations” [1, 2]. Global recognition of sustainability appeared in the early 1970s as the rapid growth of the human population and the environmental degradation associated with increased consumption of resources raised concerns [3]. The definition of sustainable development given by the Brundtland Commission, formally known as the World Commission on Environment and Development (WCED), is a development “that meets the needs of the present without compromising the ability of future generations to meet their own needs” [4]. Despite some proposed sustainability indicator sets for companies and countries [5, 6, and 7], there are currently no scientifically convincing and widely accepted indicators for assessing sustainability, especially for products and manufacturing processes [8, 9, and 10]. As the first step towards a scientifically robust sustainability assessment method, this paper focuses on identifying suitable criteria for tailoring the indicator set for specific products or technologies under the Collaborative Research Centres (CRC) 1026 Framework [11].

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Nomenclature

Top-down –
an approach aiming at a comprehensive consideration of all scientifically relevant aspects of sustainability [12]

Bottom-up –
an approach starting from the currently available data trying to transform them into representative sustainability indicators [12], or
indicators based on appreciation of the preoccupations expressed by stakeholders [13]

Life Cycle Assessment (LCA) -
a holistic, system analytic tool and an established and integral part of the environment management tools [14], according to ISO 14040, LCA is "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" [15]

Depletion of fossil fuel potential –
an impact category relating to decreased fossil fuel for future generations [adapted from 16]

Depletion of mineral resources potential –
an impact category symbolizing decreased mineral resources for future generations [16]

Climate change potential –
an impact category indicating change in the statistical properties of the climate system when considered over long periods of time, regardless of cause [17]

Ozone depletion potential –
an index used to translate the level of emissions of various substances into a common measure to compare their contribution to the breakdown of the ozone layer [18]

Acidification potential –
an impact category indicating change of atmospheric precipitations and the falling "acid rain" forms an acid input which is absorbed by plants, soil and surface waters [34]

Human toxicity potential –
an impact category focusing on effects resulting from direct exposure to chemicals [20]

Photochemical ozone creation potential –
an index used to translate the level of emissions of various gases into a common measure to compare their contributions to the change of ground-level ozone concentration [18]

Water depletion potential –
loss of available water from groundwater and surface water sources [16]

Eutrophication potential –
an impact category considering the enrichment of bodies of water by nitrates and phosphates from organic material or the surface runoff, which increases the growth of aquatic plants and can produce algal blooms that deoxygenate water and smother other aquatic life [18]

1.1. Life Cycle Thinking and Life Cycle Assessment

Life Cycle Thinking (LCT) represents the basic concept of considering the whole product system life cycle from "cradle to grave". It aims to prevent shifting environmental burdens from the individual parts of the life cycle to another. It has been addressed as one of the key principles for sustainability development, e.g. in the Communication on the Integrated Product Policy of the European Union [21]. Based on LCT, LCA is a method to quantify the environmental burdens associated with products. LCA is the state of art method in application related to the environmental dimension of sustainability [8]. In contrast with more narrow methods such as Carbon Footprint (CF), LCA is designed to capture all potential relevant environmental impacts in a systematic way in order to avoid burden shifting among environmental topics. ISO 14044 is the main reference for performing LCA studies [12, 13, 22 and 23]. Figure 1 presents the steps to conduct an LCA study.

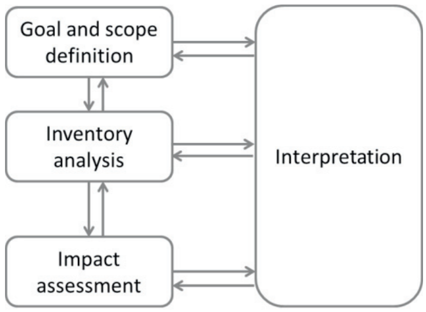

Fig.1 Overview of LCA framework [15]

In the scope definition step in LCA study, practitioners shall define or select the environmental impacts [22]. In practice, this is often still done by (ad hoc) expert judgement without or very limited justification, arguably leading often to a distorted selection, with strong influence on the overall results and recommendations. The authors consider this is an important issue and argue that the selection step of environmental impact categories shall be conducted in a systematic and transparent way. This paper illustrates a suitable systematic approach to select eligible indicators to evaluate environmental sustainability.

1.2. Criteria

The desired characteristics of the framework for Sustainable Development Indicators (SDI) of the OECD, proposed by Hart, are taken into account in the paper. The criteria to select and prioritize indicators are [24, 25]:

- Robustness – indicators must be scientifically sound/defendable. Their calculation should involve no or acceptable/limited subjectivity (i.e. be reproducible) and minor uncertainty (i.e. be sufficiently precise).
- Relevance – indicators must help in measuring progress toward a goal, raise awareness about a critical issue, or help local decision.
- Effectiveness – indicators must point to the right direction and relate to the technical and functional performance.

- Clear and easy to measure – indicators must have (standard) procedure to measure with acceptable effort.
- Practicality – indicators must be applicable with acceptable cost and duration/ time consumption. The following aspects should be met: sufficient data availability (considering data quality, technological broadness and specificity, geographical coverage, age), limited complexity of implementation / needs for experts, sufficient availability of tool support, acceptable duration for development, and others.

2. Methodology

To support the selection of proper impact categories, a semi-quantitative evaluation scheme is established. The aforementioned criteria have been transferred to simple questions. All criteria are considered equally important for selecting these indicators, i.e. with an equal weighting. Figure 2 presents the overview of the current methodology. Currently, the focus is on the environmental dimension of sustainability.

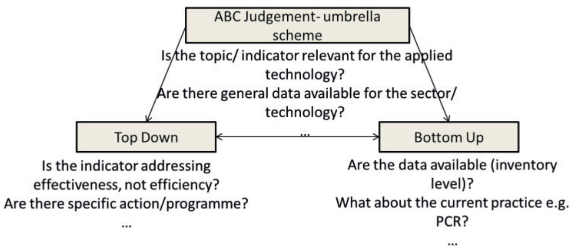

Fig. 2.Overview of ABC method variants

2.1. ABC judgement method

The ABC judgement method is a semi-quantitative, systematic method to prioritize the indicators using expert judgement together with scientific evidences. It is used here to select core and supplemental indicators. Concise questions, based on established sustainability targets, are used and combined with a scoring system or weighting step to support the decision process. Figure 3 presents the steps of ABC judgement method. Examples of questions are:

Generic/ umbrella questions

- Is the topic relevant for the applied technology?
- Are there general data available for the sector/ technology?
- Are there specific actions/programmes towards a sustainable development in respect of the considered indicator in use?

Questions for the top down approach

- Is the indicator addressing effectiveness?
- Does the indicator rely on the robustness of scientific models?
- Are there specific actions/programmes towards a sustainable development in respect of the considered indicator in use?

Three levels are used for this evaluation: fulfilled (A), partly fulfilled (B) and not fulfilled (C). The aim is not to make an absolute evaluation but to rank the prior impact categories/indicators and identify the most suitable one(s). The method can use either top-down indicators (i.e. on the impact level e.g. acidification, climate change) or bottom-up indicators (i.e. on inventory level e.g. energy consumption, waste). Table 1 presents the result of the evaluation of two impact categories of an elevator.

Fig. 3. Step by step of ABC judgement method

Table 1. Result from ABC method of elevator

Question/Environmental impacts	Climate change	Eutrophication
Is the topic relevant for the applied technology?	A	B
Are there general data available for the sector/ technology?	A	A
Are there specific actions/programmes towards a sustainable development in respect of the considered indicator in use?	A	C

2.2. Scaling or weighting

It is trivial to make the subsequent selection if the top impact categories yield AAA results and the subsequent ones BBB or CCC, but often the results are not that clear. The impact categories are prioritised according the scaling of sorting order described in Figure 4. To support a clear and comparable communication of the LCA results, the authors recommend that the first four impact categories should be considered as core impact categories. The rest would be supplementary impact categories. Alternatively, all impact categories that yield results in the sorting order I to III should be the core impact categories and at least IV to VII are supplementary impact categories.

order	SCALING OF SORTING ORDER					
I	AAA					
II	AAB	ABA	BAA			
III	AAC	ACA	CAA			
IV	ABB	BAB	BBA			
V	ABC	ACB	BAC	BCA	CAB	CBA
VI	ACC	CAC	CCA			
VII	BBB					
VIII	BBC	BCB	CBB			
IX	BCC	CBC	CCB			
X	CCC					

Fig. 4. Scaling of sorting order

Instead of scaling, the weighting step can be used to support this decision step as well. The impact categories are prioritised according the weighting step described in Figure 5, where A is equal to 3 points, B equal to 2 points and C equal to 1 point. Also in this example the first four impacts are proposed as very important (weighting results of 1 and 0.83), but the others should not be ignored in a medium and long term based evaluation as well as monitoring scheme.

weigh ting	WEIGHTING OF SORTING ORDER						
1	AAA						
0.83	AAB	ABA	BAA				
0.67	AAC	ACA	CAA	ABB	BAB	BBA	
0.5	ABC	ACB	BAC	BCA	CAB	CBA	BBB
0.33	ACC	CAC	CCA	BBC	BCB	CBB	
0.16	BCC	CBC	CCB				
0	CCC						

Fig. 5. Weighting of sorting order

2.3. Proof of concept

At this stage, a limited number of experts have carried out the evaluation, mainly to test the approach. Along the main focus area of CRC 1026, the first exercise is the manufacturing sector. To ensure the appropriateness and also to take into account the diverse environmental knowledge in different countries, the first three exercises are selected with two product-specific LCA studies and one technology-specific LCA study in different parts of the world. Three experts from both technology and LCA background are invited to join the exercise. Interviews with experts are conducted using preliminary prepared questionnaires for all 14 environmental impact categories along the cause effect chain. The duration of the experts interviews depend on the experts' background, but still they do not last over one or two hours.

After the interviews, the authors conduct the scaling in order to prioritize the environmental impacts. The results from this stage are validated against the completed LCA studies (or the ongoing study, for the welding process).

- Case 1: The elevator: the result is validated through LCA studies from Europe, i.e. Finland [26] and Spain [27], as well as one from USA [28]
- Case 2: The refrigerator: the result is validated through LCA studies from Denmark [29], Japan [30] and Thailand [31]
- Case 3: The welding process: the result is validated through an ongoing life cycle sustainability assessment study in Germany [32] and an LCA study by Dammert [33]

3. Results

3.1. Case 1: Elevator

Table 2 presents the result of the interview with an LCA expert from Technische Universität Berlin (TU Berlin), who conducted the elevator LCA project [27]. The first four impact categories are the same for generic, top down and bottom up approach questions with different degree of fulfilled requirement. For the generic approach, all four impact categories are fulfilled selection criteria i.e. AAA (first order). It means that these four impact categories are robust, relevant, effective, practical and clear, and easy to measure for the case of elevator. The level of confidence is different when questions from top down and bottom up perspectives are used.

For top down approach, only depletion of fossil fuel fulfils all criteria. The depletion of mineral resources and climate change are in the second order, because of the current underlined impact models that are nowadays considered as best available but with high uncertainty. Regarding the ozone depletion potential, the expert considers it as irrelevant for the elevator, since this product and its production contribute to only small amount. The human toxicity is the next impact category in the priority list, because of its relevance [34], but unfortunately, the current method has high uncertainty of the impact pathway model, thus it is not used.

Regarding the bottom up approach, there is no impact category in first order. The depletion of fossil fuel, depletion of mineral resources and climate change are in the second order (AAB), because of their relevance and general data availability situation. The ozone depletions potential and acidification potential are in the fourth order, because these two impact categories are somewhat relevant and the data available is rather accessible.

Table 2. Result from ABC method of elevator

Generic		Top down approach		Bottom up approach	
Order	IC	Order	IC	Order	IC
I	Depletion of fossil fuel	I	Depletion of fossil fuel	II	Depletion of fossil fuel
I	Depletion of mineral resources	II	Depletion of mineral resources	II	Depletion of mineral resources

I	Climate change	II	Climate change	II	Climate change
I	Ozone depletion	III	Ozone depletion	IV	Ozone depletions
II	Acidification	IV	Human toxicity	IV	Acidification

*IC = impact categories

The information in Table 2 is cross checked against the three studies i.e. the study from TU Berlin, KONE and ThyssenKrupp Elevator Americas.

Based on the study conducted by TU Berlin [27], all five impact categories are considered in its study. This is not the case when we compare our result with the LCA study from KONE [26] and ThyssenKrupp Elevator Americas [28], both selecting fossil fuels, climate change, acidification and ozone depletion, eutrophication, and photochemical oxidants as the impact categories and did not consider depletion of mineral resources.

3.2. Case 2: Refrigerator

Table 3 presents the result of the interview with the LCA expert of the refrigerator project, which mostly follow the same approach as the one regarding the elevator.

Table 3. Result from ABC method of refrigerator

Generic		Top down approach		Bottom up approach	
Order	IC	Order	IC	Order	IC
I	Climate change	I	Climate change	I	Climate change
I	Depletion of fossil fuel	I	Depletion of fossil fuel	I	Ozone depletion
I	Depletion of mineral resources	I	Depletion of mineral resources	III	Depletion of mineral resources
II	Ozone depletion	II	Ozone depletion	IV	Depletion of fossil fuel
III	Photochemical ozone creation	III	Eutrophication	IV	Water depletion

We have cross checked the information in Table 3 against the three previous studies from Japan. The relevant impact categories are climate change, depletion of fossil fuel, ozone depletion, depletion of mineral resource [30]. Both Wenzel et al. [29] and Witsalapong et al. [31] concluded in their studies that climate change, ozone depletion, acidification, eutrophication and resources (all) are the selected impact categories. It shows that the first four impact categories selected by the ABC method are also chosen by the other three studies, but with different order of relevance.

3.3. Case 3: Welding process

The selected impact categories have been elaborated only in the top-down approach so far. A proof from bottom-up stands out in this ongoing study. The results from the interview with the technology expert are displayed in table 4. We have cross checked them with the ongoing study. The impact categories: climate change, human toxicity, acidification and photochemical ozone creation are expressed as important impacts.

Table 4. Result from ABC method of the welding processes

Top down approach				
Order	IC	Is the topic/ indicator relevant for the applied technology?	Are there general data available for the sector/ technology?	Are there strategies involvements in- or outside a enterprise?
AAA	Climate Change	A	A	A
AAA	Acidification	A	A	A
AAB	Human toxicity	A	A	B
AAB	Photochemical ozone creation	A	A	B

4. Discussion

This systematic selection process for impact categories is new for the participating LCA practitioners. The proposed ABC method is considered useful for them when they start a project with limited budget and have the option to focus on core impact categories. For technology experts, the method helps them to understand the consequence of their technology better, while the interview is rather time consuming, given the need to first explain many aspects of the environmental impact categories.

For the first four or five impact categories the result of the ABC method appears robust enough, as the cross checking has shown. However, if practitioner would like to conduct LCA study with more than five impact categories, the current version of the method has limitations, as it cannot prioritize due to simplification.

Based on the data, human toxicity is very relevant impact category, however due to lack of available data and the high uncertainty of its model, this impact category is not in the priority list. Therefore, the authors recommend that this issue should also be documented in LCA studies by a statement that the exclusion of human toxicity is due to lack of data and uncertain impact pathway models, but not because of no relevance.

The main impact categories for the manufacturing sector are climate change and depletion of fossil fuel in any case for the studies observed. The depletion of mineral resources impact category is relevant for the elevator However, without the ABC method, the LCA experts not always include this impact category in their study or their product category rules, as shown by the other LCA study [28].

5. Conclusion and outlook

Based on the received feedback, LCA practitioners consider that the ABC method is helpful to select relevant impact categories. Based on these three exercises, the authors conclude that our research is the first step in the right direction to identify the suitable impact category sets to practitioners to conduct LCA studies. The selection criteria were found valid and appropriate.

The applicability of the ABC method should be further tested, as so far it has been applied exclusively to the manufacturing sector. In addition, the current ABC method considers each criterion to be of equal importance, but this needs to be discussed, especially in terms of relevance, practicality and effectiveness.

Moreover, sustainability is more than the environmental dimension and hence, it would be important to expand the scope of this method to include also the social and economic dimensions, as well as to support other life cycle methods.

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References

[1] EPA (2014) http://www.epa.gov/sustainability/basicinfo.htm
[2] Wolf K, Scheumann R, Finkbeiner M., Life Cycle Sustainability Assessment in support of Sustainable Life Styles, 2014, 11th Asia Pacific Roundtable on Sustainable Consumption and Production (11thAPRSCP 2014): "Paving the Way to the Future We Want in Asia and the Pacific" 19-20 May 2014, at Plaza Athenee Bangkok, Thailand
[3] Meadows, D.H., et al., 1972 The Limits to Growth, ed. C.o. Rome., New York, NY: Universe Books.
[4] UN 1987 Report of the World Commission on Environment and Development: Our Common Future
[5] CSD - Commission of Sustainable Development: Indicators of Sustainable Development - Guidelines and Methodologies, New York, 2001.
[6] CSD - Commission of Sustainable Development: http://www.un.org/esa/sustdev/natlinfo/indicators/ isdms2001/table_4.htm, version 25th June 2004.
[7] GRI – Global Reporting Initiative: Sustainability Reporting Guidelines. Boston, 2002
[8] Finkbeiner, M., Schau, E., Lehmann, A., Traverso, M.: Towards Life Cycle Sustainability Assessment. In: Sustainability, Volume 2, Issue 10, pp. 3309-3322, http://www.mdpi.com/2071- 1050/2/10/3309/, last call 15th Dec. 2010.
[9] Finkbeiner, M. 2009 : Vom Umweltschutz zur Nachhaltigkeit. Die Nachhaltigkeitsnutzwertanalyse unterstützt die Verwirklichung eines zentralen Paradigmenwechsel in Politik und Wirtschaft. In: MüllMagazin, Volume 2, pp. 4-9, Rhombos Verlag, Berlin.
[10] SRU - Rat von Sachverständigen für Umweltfragen: Umweltgutachten. Stuttgart, 1998.
[11] http://www.sustainable-manufacturing.net/en_GB
[12] Wolf K. , Chang Y.-J., Scheumann R, Neugebauer S., Lehmann A., Finkbeiner M.. What do we assess for a sustainable society from a manufacturing perspective? 2013Proceedings of 11th Global Conference on Sustainable Manufacturing, September 23-25, Berlin, Germany, ISBN: 978-3-7983-2608-8
[13] Faucheux S., Hue C, O'Connor M. A bottom--up / top--down methodology for Indicators of corporate social performance in the european alluminium industry, 2003
[14] Finkbeiner M., Schau E., Traverso M.. Towards Life Cycle Sustainability Assessment – Integrating Social and Economic Aspects into Life Cycle Assessment
[15] ISO 14040, Environmental Management-Life Cycle Assessment-Principles and Framework. 2006
[16] Chapter 4 Life Cycle Impact Assessment (Accessed on 14th April 2014 http://www.epa.gov/nrmrl/std/lca/pdfs/chapter4lca101.pdf)
[17] IPCC TAR WG1 (2001). Houghton, J.T.; Ding, Y.; Griggs, D.J.; Noguer, M.; van der Linden, P.J.; Dai, X.; Maskell, K.; and Johnson, C.A., ed. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. ISBN 0-521-80767-0 (pb: 0-521-01495-6).
[18] Environmental Product Declaration, KONE EcoSpace™, 2012
[19] Dentener, F., Drevet, J., Lamarque, J.F., Bey, I., Eickhout, B., Fiore, A.M., Hauglustaine, D., Horowitz, L.W., Krol, M., Kulshrestha, U.C., Lawrence, M., Galy- Lacaux, C., Rast, S., Shindell, D., Stevenson, D., Van Noije, T., Atherton, C., Bell, N., Bergman, D., Butler, T., Cofala, J., Collins, B., Doherty, R., Ellingsen, K., Galloway, J., Gauss, M., Montanaro, V., Muller, J.F., Pitari, G., Rodriguez, J., Sanderson, M., Solmon, F., Strahan, S., Schultz, M., Sudo, K., Szopa, S., Wild, O., 2006. Nitrogen and sulfur deposition on regional and global scales: a multimodel evaluation. Global Biogeochemical Cycles 20, GB4003.
[20] Krewitt W., Pennington D.W., Olsen S.I., Crettaz P., Jollie O.. Indicators for human toxicity in Life Cycle Impact Assessment- Position paper for SETAC-Europe WIA2 Task Group on Human toxicity Version: January 7, 2002
[21] European Commission., Communication on Integrated Product Policy. European Commission: Brussels, Belgium, 2003.
[22] ISO 14044, Environmental Management-Life Cycle Assessment-Requirements and Guidelines. 2006
[23] European Commission - Joint Research Centre - Institute for Environment and Sustainability (2010). International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance. First edition March 2010. EUR 24708 EN. Luxembourg. Publications Office of the European Union; 2010.
[24] Hart M.; Guide to Sustainable Community Indicators, Second Edition: 1999
[25] Wolf M-A., Chomkhamsri K., 2012, Selecting the Environmental Indicator for Decoupling Indicators, proceeding in Ecobalance International conference, Japan.
[26] Tonteri, Hannele, Anttila, Anna & Kujanpää Marjukka. The Life Cycle Assessment of KONE EcoSpace Elevator. Research report No VTT-R-06118-09. VTT. Espoo, Finland 2009.
[27] Personal communication with LCA expert relating to LCA of elevator TU Berlin (2013). Life Cycle Assessment of synergy SEAME elevator. Technische Universität Berlin. Commissioned by ThyssenKrupp Elevator AG (unpublished)
[28] Self-declared EPD of elevator. ThyssenKrupp Elevator Americas (2010)
[29] Wenzel H., Hauschild M. and Alting L., Environmental Assessment of Products. Vol.1 Methodology, tools and case studies in product development, pp.319-368, CHAPMAN & HALL, London, (1997).
[30] Personal communication with LCA expert of the LCA study of refrigerator project
[31] Witsalapong S., Chomkhamsri K., Papong S., Yuvaniyama C., Malakul P., Mungcharoen T., 2000 Life Cycle Assessment of Household Refrigerator, Thailand
[32] Personal communication with LCA expert and technology expert of the LCSA study of welding process
[33] Dammert T., Väänänen A., Valkama J.. 2003 environmental issues and ecological profile in electrical and electronics products design, international conference on engineering designiced 03 stockholm, august 19-21, 2003
[34] Pierce, D. (2014). Expanding LEED V4 Material Health Transparency - White paper, Perkins+Will. Available at: http://www.perkinswill.com/