Backgrounder: Recommended Updates to ISO 14044

Prepared for Sub-TAG 5 on Life Cycle Assessment by the US Technical Advisory Group to ISO / TC 207

Technical Review of Life Cycle Impact Assessment Phase, with Specific Recommendations for Updating ISO 14044

1.0 Introduction

1.1. Current LCA Practice

Since its publication in 2006, the ISO 14044 Standard has provided guidance for Life Cycle Assessment (LCA) to help build consensus in practice. It has been particularly useful in guiding the scoping and life cycle inventory (LCI) phases, including addressing elemental flow input/output processes and data quality. The development of Product Category Rules (PCR) per ISO 14025 further enhanced the scoping phase by providing industry sector- and product category-specific guidance on system boundaries and functional unit definition, key assumptions and allocation procedures.

Nonetheless, the life cycle impact assessment (LCIA) phase has drawn sharp criticism from key stakeholders, especially environmental non-governmental organizations (ENGOs), for failure to address a comprehensive set of impacts, and for use of simplistic category indicators in public declarations (e.g., Environmental Product Declarations), comparisons between products, and claims of sustainability based upon LCA. These issues are significant, considering that ISO 14044 states that the "selection of impact categories shall reflect a comprehensive set of environmental issues,"[1] and ISO 14025 states that "all relevant environmental aspects of the product throughout its life cycle shall be taken into consideration and become part of the declaration."[2] Decision-making and mitigation strategies based on LCA depend on careful attention to these requirements.

1.2. Addressing All Relevant Impact Categories

In its organization and structure, ISO 14044 encourages practitioners to follow the phases of LCA in a linear fashion: from scoping to LCI, to LCIA, and finally to interpretation. While this approach may at first appear logical, there are significant unintended consequences. The scoping phase is a logical starting point, but completing the LCI phase before beginning

1 ISO 14044:2006. Section 4.4.2.2.1, page 17.
2 ISO 14025:2006. Section 5.3, page 4

the LCIA has resulted in arbitrarily restricting the impact assessment to the output of inventory results. This linearity has produced a limited scope of impact categories covered in conventional LCAs such that only about a third of the impacts to human health and the Earth's ecosystems and climate from global industrial activities are addressed. While the Standard does state that the assessment process should be iterative, more specific guidance is needed to ensure that this important hurdle is overcome.

One unintended consequence of this linear approach has been the tendency to leave out major impacts linked to specific industries, counter to the intent of ISO 14044. This has unfairly advantaged some materials, products, and services in the marketplace, and disadvantaged others. This problem has become particularly apparent in Environmental Product Declarations (EPDs), claims of sustainability, and claims of full transparency. As a result, stakeholders have questioned the credibility of the EPD approach to selecting category indicators, and the perceived value of LCA has been diminished.[3]

Another concern about the limitations in current LCA practice is the failure to incorporate well-established impact methods and protocols that have been widely published in peer-reviewed journals. These methods and protocols are critical when establishing a comprehensive set of impacts.

This document describes shortcomings of the linear approach, and recommends updates to ISO 14044 to guide completion of LCAs in an iterative fashion and to provide more robust, comprehensive impact assessment and reporting. It builds on elements of the iterative process already embedded in ISO 14044,[4] and adopts key recommendations from the Danish Guidelines and the International Reference Life Cycle Data System (ILCD) Handbook.[5] Finally, it recommends incorporation of well-accepted impact assessment methods and protocols.

1.3 Assuring Environmental Relevance Characterization of Impact Categories

A technical analysis revealed that, in addition to reporting an incomplete set of impact categories, category indicators used by most LCIA methods and LCA software lack the appropriate and required spatial, temporal, intensity and reversibility characterization of midpoints and/or endpoints, and therefore generate results that lack environmental relevance. This paper describes an analytical approach to determine the degree of environmental relevance of any specific category indicator, and recommends that this approach be added to the Standard to provide important required guidance.

1.4 Technical Review of CML-IA Baseline Method

As an example, this document includes the results of a technical review of the indicators

3 For instance, see Sierra Club critique at http://greenwashaction.org/wp-content/uploads/2014/10/EPD-Toxic-Loophole-One-Page.pdf, and http://greenwashaction.org/wp-content/uploads/2014/05/Understanding-EPDs-for-Wood-9-24-13.pdf
4 See Figure 1, Sections 4.2.1, 4.3.1, 4.2.3.3.2, 4.3.3.4, 4.4.2.4, 4.4.4.1, and 4.4.4.2 of ISO 14044.
5 http://eplca.jrc.ec.europa.eu/, ILCD Handbook: General Guide for Life Cycle Assessment

included in the current CML-IA baseline method. This method and its category indicators have been in the marketplace for about fifteen years without significant change. It was chosen for review because it is the most widely used method in the marketplace today, and is the basis of the indicator sets used by many other LCIA models, including the US EPA LCIA model, TRACI.[6] The review found that the CML-IA method neither provides a comprehensive set of impact categories or category indicators, nor meets the test of environmental relevance sufficient to support credible public declarations or claims of sustainability.

In order to overcome these significant shortcomings in current LCA practice, this document focuses on key updates to ISO 14044 that will provide the necessary guidance to improve the overall credibility of LCA results.

2.0. Key Recommendations for Updating the Standard

2.1. Four-Tiered Iterative Process to Establish a Comprehensive Set of Impact Categories

The first key update builds from the ILCD Handbook, which describes the necessity of the iterative process in terms of scoping, inventory, impact assessment and evaluation (Figure 1).

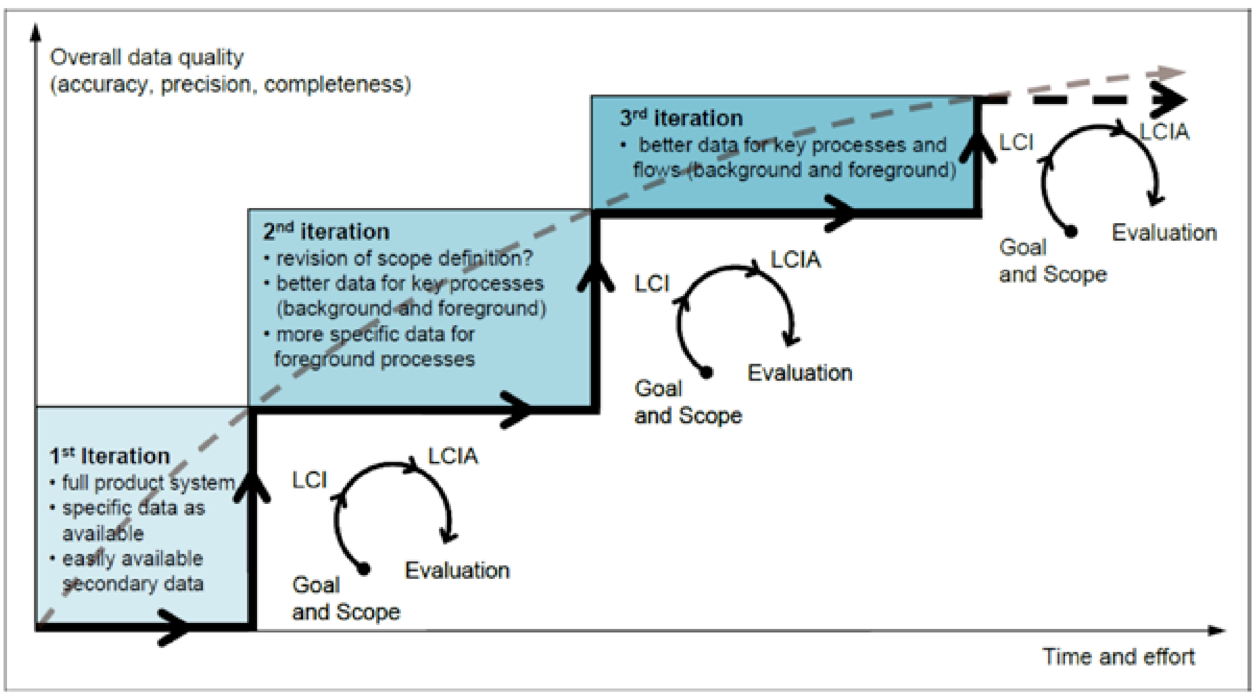

Figure 1. Iterative Process. "Iterative nature of LCA (schematic). LCAs are performed in iterative loops of goal and scope definition, inventory data collection and modeling (LCI), impact assessment (LCIA), and with completeness, sensitivity and consistency checks (Evaluation) as a steering instrument. This is done — with a possible, limited revision of the goal and scope — until the required accuracy of the system's model and processes and the required completeness and precision of the inventory results has been attained." [Caption and figure from Figure 4, 2010 ILCD Handbook, General Guide for Life Cycle Assessment — Detailed Guidance.]

6 Tool for the Reduction and Assessment of Chemical Impacts (TRACI). US EPA. August 5, 2014. http://www.epa.gov/nrmrl/std/traci/traci.html

This paper recommends that the iterative process described in ISO 14044 be refined. Specifically, the iterative process should be applied in four levels (i.e., tiers) of iteration.

Level 1 Iteration: Using "Reverse Effects Characterization" to Establish a Comprehensive Set of Impact Categories

The characterization process starts with "reverse effects characterization" at the impact (i.e., effects) level by characterizing the cumulative, permanent (irreversible) and seasonal midpoints and endpoints that can readily be identified in the peer-reviewed literature and through regulatory processes. Reverse effects characterization is akin to reverse engineering, which starts with the final product and works backward to yield how the product was made, the scale of resources used, etc. In much the same manner, by first establishing the types and scale of such effects, the rough scale of the midpoints and endpoints can be characterized before attempting to attribute by source. Not all impacts to Earth systems are caused by global industrial activities; therefore, only those effects falling within one of the six major effects groupings (Table 1, Section 2.2) either directly or indirectly linked to global industrial activities should be included. (A total of 27 impact categories falling under these six effects groupings have been identified to date, as shown in Table 3, Section 2.3.)

For many impact categories, reverse effects characterization can be used to identify and quantify cumulative, permanent and seasonal midpoint and endpoint loadings typically overlooked in current practice. Only by first characterizing such midpoints can the scale of current impact levels and the mitigation required to reduce their intensity, scale and duration be determined.

For example, according to the United Nations Environment Program (UNEP), planned mitigation of climate pollutants under existing international treaties and national policies, estimated at over $350 billion annually by 2030, will have no significant effect on limiting the rate of climate change until after 2050, as these policies focus almost exclusively on reductions in CO_2 emissions.[7,8] However, UNEP has found that mitigation focused on reducing emissions of black carbon and methane could slow climate change in the near-term by an amount sufficient to delay impending global tipping points by almost two decades – and the cost of these measures is generally much less than comparable CO_2 abatement. Reverse effects characterization – working from the effect backward

7 United Nations Environment Program and World Metrological Organization. Integrated Assessment Black Carbon and Tropospheric Ozone. 2011.
8 Table SPM.2 of IPCC, 2014: Summary for Policymakers, In: Climate Change 2014, Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

– keeps the focus on the effect, making it clear that CO_2 mitigation alone will not alter the short-term trajectory of impacts on the climate system, and that additional major contributors to near-term tipping points must be addressed (Figure 2).

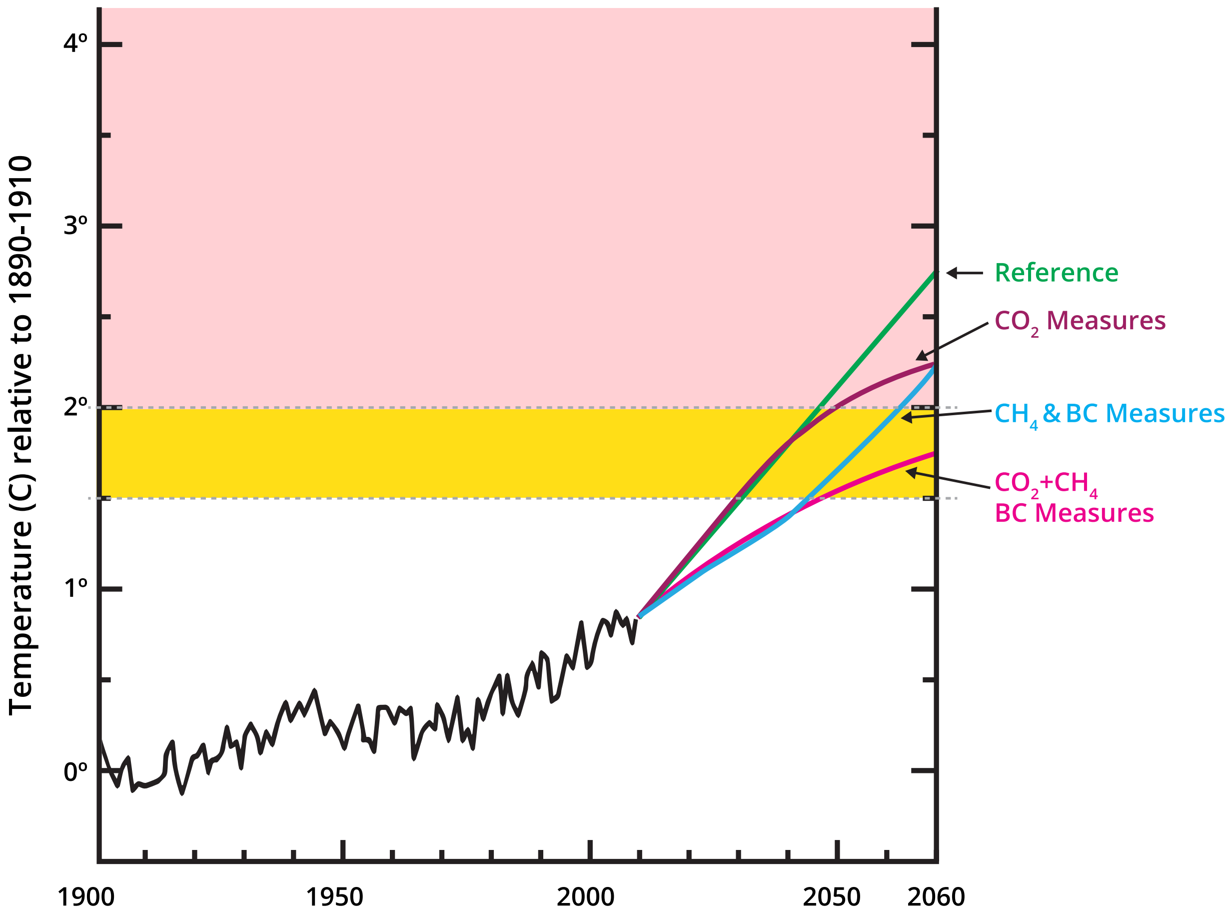

Figure 2. Projected global mean temperature increases based on various scenarios (UNEP / WMO 2011).

Level 2 Iteration: Reverse Effects Characterization to Identify Core Impact Categories by Industry Sector

During the second iteration, reverse effects characterization can be used to readily identify the core impact categories for specific industry sectors. Three examples are presented later in this paper for the wood products, virgin paper and recycled paper sectors. These examples indicate that there are fourteen core impact categories fundamental to wood production, including four major impact categories associated with forestry operations. By contrast, when linear LCI-based LCIA methods were applied to an LCA and EPD prepared for the North American softwood sector, only five impacts were reported (as well as energy consumption), without addressing the major land use impacts of wood production. As a result, the reported findings were considered greenwashing by the ENGO community.[9],[10]

Level 3 Iteration: Study Level Assessment to Yield LCIA Profile

The third level of iteration is focused on determining the impact categories linked to the specific industrial system being studied. This iteration shows the benefit of using the prior iterations in order to prioritize data collection efforts during the LCI phase. At this detailed stage, the LCI data collection process can be more effectively streamlined to focus on inventory data linked to measurable environmental and human health effects, in order to generate an environmentally relevant and comprehensive overall LCIA Profile of the product or organization. (While not detailed in this paper, a new update to open-source LCA software is being developed to show how this iteration can greatly streamline the entire calculation process to the impact profile while increasing its overall environmental relevance.)

Level 4 Iteration: Interpretation

After completing the detailed iterative process yielding the LCIA Profile, life cycle interpretation can be used to set impact reduction goals for the industrial system studied.

The entire iterative process can be continued to document continuous improvements.

2.2. The Six Major "Effects" Grouping Linked to Global Industrial Activities

The term "effects" is often used in the literature to refer to anthropogenic perturbations either to the Earth's pre-industrial natural baseline conditions (i.e., natural ecosystems, climate systems and sustainability of natural resources), or to human health, and represents a more technically refined term than "impacts." Global effects to the major Earth systems from industrial activities can be classified as falling under six major groupings (Table 1).[11]

9 PCR for North American Structural and Architectural Wood Products. Version 1.1 May 2013. FP Innovations. https://fpinnovations.ca/ResearchProgram/environment-sustainability/epd-program/Pages/default.aspx

10 Understanding Environmental Product Declarations (EPDs) for Wood (Current Problems and Future Possibilities). The Sierra Club Forest Certification & Green Building Team. September 24, 2013. Also, The Toxic Loophole in Environmental Product Declarations (EPDs): What you need to know before taking EPDs seriously. Sierra Club, 2014.

11 Steffen, Will, et. al., Planetary boundaries: Guiding human development on a changing planet, Published Online January 15 2015, Science 13 February 2015: Vol. 347 no. 6223 DOI: 10.1126/science.1259855.

Table 1. *Six Major Effects Groupings Impacting Earth's Natural Systems and Human Health Linked to Global Industrial Activities*

Major Effects Groupings	Documentation of the Major Ecosystems, Climate Systems and Human Health Endpoints
Biotic and Abiotic Resource Depletion	Well-documented evidence of limitations to availability of natural resources. This group represents thousands of distinct environmental mechanisms, all with similar but unique endpoints.
Global and Regional Climate System Impacts	Well-documented oncoming 2035, 2050 and 2100 tipping points as reported in IPCC's Fifth Assessment Report (2013) and other major consensus documents. This group of impact categories is complex. The global climate change impact category should be calculated against all three of these critical tipping points to provide an accurate picture of the studied system's impacts. Regional hot spots within this group are a critical new series of impact categories with distinct environmental mechanisms, but with climate change endpoints that place them in this grouping.
Ocean Ecosystem Impacts	The impact categories in this group all have the same overall endpoint (the ocean ecosystem), although most of the impact categories involve regional endpoints. The justification for this group of impacts is highlighted by the recent major study in Science that current practices will increase the probability of overall oceanic ecosystem collapse by the year 2100.
Terrestrial and Freshwater Ecosystem Impacts (from Emissions)	http://www.nytimes.com/2015/01/16/science/earth/study-raises-alarm-for-health-of-ocean-life.html?smid=li-share&
Terrestrial and Freshwater Ecosystem Impacts (from Land Use and Conversion)	Well-established endpoint with established impact categories within current general LCA practice.
Human Health Impacts (from Chronic Exposure to Hazardous Chemicals)	Well-documented ecosystem damage from land use such as wood harvesting and mining. This group of impact categories captures the level of overall disturbance to a single ecosystem. Only by addressing all of the impact categories within this group can land use impacts be fully assessed. That is, the combination of results across all four impact categories captures the overall impacts on this single endpoint.
Human Health Impacts (from Chronic Exposure to Hazardous Chemicals)	Well-documented human health endpoints from both emissions and untreated hazardous wastes. Several impact categories have been established from LCA methods. Because of the complex nature of the environmental mechanisms (see Tables 2 and 3), these impact categories often spin off multiple category indicators, reflecting the unique nature of the fate, transport and exposure risks of each chemical and each hazardous waste stream.

Once the major effects groupings to the Earth's natural baseline conditions are identified, they can be linked to specific impact categories with distinct and separate environmental mechanisms into a comprehensive set of impact categories by specific endpoints, as shown in Table 3 (Section 2.3 below).

Because the six groupings are limited to impact categories associated with industrial activities, they exclude many impacts to human health and ecosystems that have other causal sources (e.g., diet). More detailed discussion of selected groupings and their impacts follows.

2.2.1. Ocean Impact Grouping

While much attention has centered on how to establish land use related impacts, the oceans are now under assault by major impact vectors that threaten the entire ocean ecosystem. Therefore, establishing this grouping is very important to the overall credibility of LCA. A major study on impacts to the ocean ecosystem highlighted seven impact categories linked to global industrial activities that are driving oceanic ecosystems toward collapse by 2100. These distinct impacts have unique environmental mechanisms, but share a common endpoint and so are grouped together in the Oceanic Ecosystem Impacts group (Table 3).

While some of the impact categories have been previously been listed by various LCA methods, other impact categories listed in this background have been included based upon readily available physical evidence, such as the plastic trash accumulating in the oceans (e.g., the Great Pacific Garbage Patch, shown in Figure 3, estimated to be twice the size of the state of Texas, is causing major damage to coral reefs and ocean life in general). Since LCA is a cradle-to-grave assessment, this particular end-of-life issue linked directly to plastic containers and packaging must be included in the comprehensive set of impact categories.

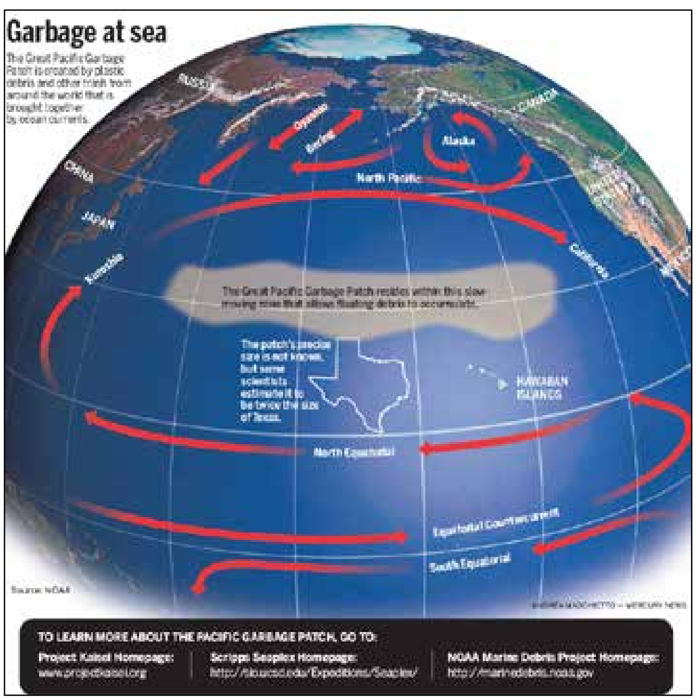

Figure 3. Left: The Great Pacific Garbage Patch, now twice the size of the state of Texas. Source: NOAA, as reprinted in "Researchers set sail for the Great Pacific Garbage Patch," San Jose Mercury News, Paul Rogers, August 3, 2009. Right: Photo by Steven Guerrisi.

2.2.1.1. The Serial Ocean Impact Categories of Carbon Dioxide Emissions

While current LCA methods address both the direct and serial impacts associated with nitrogen oxide (NO_x) emissions (see further discussion under Section 2.3 below), the serial impacts associated with carbon dioxide (CO_2) have typically been excluded. These serial impacts are linked to ocean acidification and ocean warming, which could contribute to the potential collapse of important aspects of the ocean ecosystem by 2100, according to NOAA and a wide body of scientific literature.[12] Table 2 describes the rationale for addressing these serial impacts separately so that all major impacts can fully be accounted for, and so that their mitigation can be prioritized to match the scale of current and projected carbon dioxide emission rates (now exceeding 35 billion tons of CO_2 yearly).

Table 2. *Well Established Serial Impacts of Carbon Dioxide*

Serial CO_2 Impact Categories	Distinct Environmental Mechanisms
Ocean Acidification	The oceans are acidifying at a rate faster than at any time within the last 300 million years. At the current pace, the acidity of the oceans will triple by 2100. Acidification is affecting all oceans worldwide. Large portions of polar oceans will become corrosive to shelled organisms by as soon as 2030, and suitable habitat for corals could disappear by 2050.[13] This impact category is caused by the conversion of carbon dioxide into carbonic acid in seawater, and the resulting reduction of pH and Aragonite saturation. This distinct environmental mechanism should not be commingled with the climate change impact categories.
Ocean Warming	This impact category represents a distinct serial environmental mechanism of heat transfer from the atmosphere into the oceans. While sharing the same radiative forcing midpoint, the endpoints of this impact category are different from climate change impacts. Impacts from increases in ocean temperatures, such as coral bleaching and species impacts, are not linked to climate change.

2.2.2. Terrestrial and Fresh Water Ecosystem Impacts (from Land Use and Conversion) Grouping

While some conventional LCA methods have suggested that land use impacts can be addressed by a single impact category (e.g., ReCiPe, IMPACT World), these methods are not being used in practice and there is no peer-reviewed literature incorporating such aggregated impact categories. In contrast, this recommended grouping of impact categories, which reports disturbances to various distinct biomes

12 http://www.sciencemag.org/content/347/6219/1255641.full
13 IGBP, IOC, SCOR (2013). Ocean Acidification Summary for Policymakers - Third Symposium on the Ocean in a High-CO2 World. International Geosphere-Biosphere Programme, Stockholm, Sweden.

and each key species' habitat, provides a credible way to assess the disturbance of specific ecosystems undergoing land use or conversion. World Wildlife Fund (WWF) has posted 28 critical impact biomes that are threatened by industrial activities.[14] (The term "biome" is widely used by professional field ecologists in reporting large landscape disturbances.)

Figure 4. Accountability for Land Use. This image shows the irreversible clear cut of ancient redwood forest biomes in Northern California, which occurred while certified as "sustainably managed".

2.2.3. Data to Support Reverse Effects Characterization

Reverse effects characterization takes advantage of the wide availability of environmental impact assessment data and literature that have documented the major impacts to human health and the environment linked to global industrial activities. In many cases, because the Earth's systems are now significantly impacted and expected to worsen, many of these impact categories are increasingly regulated by government agencies and have become the focus of voluntary certifications.

2.3. Establishing a Comprehensive Set of Impact Categories

Each of the six major effects groupings includes a set of the impact categories that, when combined, link the overall impacts to the Earth's natural baseline condition for that group's endpoints. Table 3 and Figure 5 present the classification of specific impact categories under each grouping. (For more detail, see Appendix A.)

2.3.1. Distinct Environmental Mechanisms

Each distinct impact category meets the following criteria, consistent with the requirements of ISO 14044, and represents a distinct environmental mechanism:

14 See WWF Wildfinder database: http://www.worldwildlife.org/science/wildfinder/. See also http://www.worldwildlife.org/biomes

- Stressors, midpoints, and endpoints are observed, and their conditions measured, in the context of a distinct environmental mechanism for a given impact category. Impact categories with no observed stressors, midpoints, or endpoints, for which conditions cannot be measured, are not included.[15]

Table 3. *Impact Categories Derived from Effects Characterization*

Biotic/Abiotic Resource Depletion Impacts
Energy Resource Depletion
Water Resource Depletion
Minerals and Metals Resource Depletion
Biotic Resource Depletion
Global and Regional Climate System Impacts
Global Climate Impacts
Regional Climate "Hot Spot" Impacts
- Arctic[16]
- Black carbon (Central India)[17]
Ocean Ecosystem Impacts
Ocean Acidification
Ocean Warming
Marine Biome Disturbance
Marine Eutrophication
Key Species Loss
Persistent, Bioaccumulative, and Toxic Chemical Loading
Cumulative Plastic Loading
Terrestrial and Freshwater Ecosystem Impacts (from Emissions)
Regional Acidification
Stratospheric Ozone Depletion
Freshwater Ecotoxic Exposure Risks
Freshwater Eutrophication
Terrestrial Eutrophication
Terrestrial/Freshwater Ecosystem Impacts (from Land Use and Conversion)
Terrestrial Biome Disturbance
Freshwater Biome Disturbance
Wetland Biome Disturbance
Key Species Habitat Disturbance
Human Health Impacts (from Chronic Exposure to Hazardous Chemicals)
Ground Level Ozone Exposure Risk
PM 2.5 Exposure Risk
Ambient Air Exposures Risk
Indoor Air Exposures Risk
Ingestion Exposures Risk

15 Ionizing radiation, an impact category included in some LCAs, is an example of an impact category that has no observed midpoints or endpoints under normal industrial conditions. This impact category measures the exposure to ionizing radiation from nuclear power plants to surrounding populations. However, no measurable ionizing radiation that could cause measurable risk is emitted from normal nuclear plant operations. Any risks are instead associated with catastrophic releases resulting from breaches of containment of radioactive waste, primarily from spent nuclear fuel.

16 Two proposed impact categories Arctic Vortex-Negative Phase and the ODC Arctic/Antarctic Vortex Enhancement are to be added after technical expert support is attained from subject matter experts.

17 This will be expanded to include up to four additional impact categories of regional climate change after technical expert support is attained from subject matter experts, related to hot spots of brown clouds as described by UNEP in the following four regions: East Asia; Southeast Asia; Southern Africa; and Amazon Basin. See UNEP Regional Assessment Report with Focus on Asia: Atmospheric Brown Clouds. 2009.

Figure 5. Comprehensive Impact Categories

- The environmental mechanism can be described and modeled.
- All impacts must be included, whether directly linked to causal stressors or indirectly linked through serial environmental mechanisms. A serial environmental mechanism is described in ISO 14044, clause 4.4.2.3, as a sequential impact caused by the same (group) of stressor(s). For example, NO_x emissions are actually a complex mixture of different but related compounds that, when combined, remove ozone from the atmosphere but then produce more ozone within the same general airshed, depending upon the oxidation state of specific NO_x. The same NO_x molecules can then combine with moisture in the air to form strong acids that cause regional acidification. This same molecule can then be converted in soil and cause eutrophication to surrounding water bodies. It is common practice in LCA to classify NO_x into multiple impact categories because of the serial nature of the environmental mechanisms associated with these emissions.

Many of the listed impact categories are regulated by local, regional, and/or national governmental agencies. Some major impact categories, such as climate change and ozone depleting chemicals, are the subject of international treaties. Natural resource-related impact categories are included based upon well-established government resources linked to their reserve bases, current and projected use rates, and degrees of renewability and recycling.

Twenty-seven major global and regional impact categories are identified in this paper, but the final reference list should be subjected to stakeholder input to determine whether to include additional reference impact categories. Likewise, additional impact categories may be needed to address impacts uniquely linked to a specific product system or localized effects.

Deviations from the Earth's natural baseline conditions can be positive or negative. Some stressors can reduce specific impact levels while at the same time causing other major impacts. For example, ozone depleting chemicals (ODCs) deplete the stratospheric ozone layer, thus increasing harmful UV radiation. At the same time, ODCs cool both poles by removing ozone, a very strong climate forcer, thus significantly reducing regional radiative forcing. Both positive and negative impact categories should be included in the reference list because LCA is designed to report all deviations from natural baseline conditions. Such comprehensive reporting is vital for LCA trade-off analysis and informed decision-making.

2.3.2. Establishing the Set of Core Impact Categories by Sector

Once the reference list of impact categories is established, the same iterative process can be used to establish the list of core impact categories by industry sector in a straightforward manner. For example, Table 4 below shows how the reference list is used as a starting point to identify the core impact categories for North American softwood, virgin paper, and recycled paper.

In contrast to the comprehensive list of impact categories identified through the iterative process, as shown above, the currently published EPD for all North American softwood production addresses only five impact categories. However, at least nineteen impact categories should be screened for any wood product, regardless of whether the specific operation is involved with all of the listed default impact categories. Default lists of impact categories for basic materials such as wood should be included in a normative annex to ISO 14044, given the history of EPDs published by some industries. Similarly, the EPDs for all construction products (normative requirements of ISO 21930) are currently required to report only five impact categories, even though the full range of impacts associated with construction materials includes more than 20 of the impact categories from the reference impact category list. ISO 21930 states:[18]

> 8.2.2 Declaration of environmental impacts, use of resources and generation of waste
> The following environmental information shall be included in the EPD.
> 8.2.2.1 Environmental impacts expressed in terms of the impact categories of LCIA
> - climate change (greenhouse gases);
> - depletion of the stratospheric ozone layer;
> - acidification of land and water sources;
> - eutrophication;
> - formation of tropospheric ozone (photochemical oxidants)

Such examples make it clear that a more comprehensive set of impact categories should be included in ISO 14044 to guide future practice. Given inconsistencies and the lack for formality in the EPD development process to ensure that a comprehensive list of impact categories is included, ISO 14044 should expand its requirements and protocols for the use of LCA to support public claims and similar applications. Such updates should include guidance for establishing impact categories based upon reverse effects characterization and the formal iterative process, as described in this paper, when using LCA to support declarations or claims of sustainability.

18 ISO 21930:2007, Section 8.2.2.

Table 4. *Deriving the Core Impact Categories for Three Industry Sectors from the Reference List*

Reference List of Impact Categories	Core Impact Categories		
	North American Softwood	North American Virgin Paper	Recycled Paper
Biotic/Abiotic Resource Depletion Impacts			
Energy Resource Depletion	X	X	X
Water Resource Depletion	X	X	X
Minerals and Metals Resource Depletion			
Biotic Resource Depletion	X	X	
Global and Regional Climate System Impacts			
Global Climate Impacts	X	X	X
Regional Climate "Hot Spot" Impacts			
- Arctic	X	X	X
- Black carbon (Central India)			
Ocean Ecosystem Impacts			
Ocean Acidification	X	X	X
Ocean Warming	X	X	X
Marine Biome Disturbance			
Marine Eutrophication	X		
Key Species Loss			
Persistent, Bioaccumulative, and Toxic Chemical Loading	X	X	X
Cumulative Plastic Loading			
Terrestrial and Freshwater Ecosystem Impacts (from Emissions)			
Regional Acidification	X	X	X
Stratospheric Ozone Depletion			
Freshwater Ecotoxic Exposure Risks	X	X	
Freshwater Eutrophication	X		
Terrestrial Eutrophication			
Terrestrial/Freshwater Ecosystem Impacts (from Land Use and Conversion)			
Terrestrial Biome Disturbance	X	X	
Freshwater Biome Disturbance	X	X	
Wetland Biome Disturbance	X	X	
Key Species Habitat Disturbance	X	X	
Human Health Impacts (from Chronic Exposure to Hazardous Chemicals)			
Ground Level Ozone Exposure Risk	X	X	X
PM 2.5 Exposure Risk	X	X	X
Ambient Emission Exposure Risk			
Indoor Emission Exposure Risk			
Ingestion Exposure Risk	X	X	X

2.3.3. Impact Categories Addressed by the CML-IA Baseline Method

In addition to inconsistencies within the ISO 14044 Standard, the lack of sufficient guidance has affected LCA practitioner methods. The CML-IA baseline method is a good example. It provides general descriptions for several impact categories consistent with effects characterization, and is a good starting point to build consensus towards updating ISO 14044. However, this method addresses only 12 impact categories (Table 5), or less than half of the total impact categories from the reference list. This method's claim of conformance to ISO 14044 further illustrates the need to include the list of reference impact categories in ISO 14044.

The CML-IA method also demonstrates the limitations of relying on the linear approach to LCA, strictly using LCI results as the basis for determining impact categories. For example, the method does not adequately incorporate the critical element of irreversibility, such as in the area of climate change, whereas scientific consensus projects that the Earth is facing three major climate tipping points, with the first threshold to be crossed by 2035. Nor does the method account for regional climate hot spots such as the Arctic, or fully characterize the impacts to the ocean ecosystem associated with industrial impacts. Similarly, CML-IA reports marine ecotoxicity impacts, but excludes the six other major impact categories that affect the world's ocean ecosystems.

Whereas the endpoints associated with emissions-related impacts are typically described in terms of the receiving environment, for resource depletion, the cause-effect chain is based on the condition of reserve base compared to the amount of net use (and any relevant recycling loops) until the material is lost to the system and becomes waste. However, since ISO 14044 does not currently provide specific guidance for how to model the distinct environmental mechanisms for resource depletion, practitioners have been left with the challenge of determining methods for doing so. In its treatment of resource depletion, the CML-IA baseline method for "depletion of abiotic resources – elements" does not recognize that the depletion of each resource has a unique environmental mechanism. Instead, CML-IA aggregates disparate resources under a single impact category with a single category indicator, despite the fact that the resources and their reserve bases are widely variable. For example, the rate of depletion of rare earth minerals that are in short supply cannot be compared to the depletion of iron ore, where significant recycling supplies nearly 60% of the steel required for production in the United States. In fact, once these resources are placed back into their unique category indicators, it becomes clear that each rare earth mineral has its own important and unique conditions, requiring its own characterization. ISO 14044 does not provide sufficient detail to prevent inappropriate aggregation in calculating or reporting the depletion of either biotic or abiotic resources.

Table 5. *Completeness of CML-IA Baseline Impact Categories*

Endpoint Characterization-Derived Impact Categories	CML-IA Baseline Method LCI-Derived Impact Categories
Biotic/Abiotic Resource Depletion Impacts	
Energy Resource Depletion	Addressed
Water Resource Depletion	Not addressed
Minerals and Metals Resource Depletion	Not addressed in accordance with the ISO 14044
Biotic Resource Depletion	Not addressed
Global and Regional Climate System Impacts	
Global Climate Impacts	Addressed
Regional Climate "Hot Spot" Impacts	
- Arctic	Not addressed
- Black carbon (Central India)	Not addressed
Ocean Ecosystem Impacts	
Ocean Acidification	Not addressed
Ocean Warming	Not addressed
Marine Biome Disturbance	Not addressed
Marine Eutrophication	Not addressed
Key Species Loss	Not addressed
Persistent, Bioaccumulative, and Toxic Chemical Loading	Addressed
Cumulative Plastic Loading	Not addressed
Terrestrial and Freshwater Ecosystem Impacts (from Emissions)	
Regional Acidification	Addressed
Stratospheric Ozone Depletion	Addressed
Freshwater Ecotoxic Exposure Risks	Addressed
Freshwater Eutrophication	Addressed
Terrestrial Eutrophication	Addressed
Terrestrial/Freshwater Ecosystem Impacts (from Land Use and Conversion)	
Terrestrial Biome Disturbance	Not addressed
Freshwater Biome Disturbance	Not addressed
Wetland Biome Disturbance	Not addressed
Key Species Habitat Disturbance	Not addressed
Human Health Impacts (from Chronic Exposure to Hazardous Chemicals)	
Ground Level Ozone Exposure Risk	Addressed
PM 2.5 Exposure Risk	Not addressed
Ambient Emission Exposure Risk	Addressed
Indoor Emission Exposure Risk	Not addressed
Ingestion Exposure Risk	Addressed

3.0. Key Inconsistency in Current ISO 14044 Standard

A key inconsistency within the current Standard lies between Section 4.4.2.2.2, which recommends endpoint effects characterization, and the statement within the Standard that the output of the impact phase is limited to reporting only "potential environmental impacts." Specifically, the current ISO 14044 Standard includes the following statements:

> **Introduction:**
> LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave).
>
> > ***Footnote 2:*** *The "potential environmental impacts" are relative expressions, as they are related to the functional unit of a product system.*
>
> **LCA Definition (3.2):**
> Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.
>
> **LCIA definition (3.4):**
> The phase of life cycle assessment aimed at understanding and evaluating the *magnitude and significance* of the potential environmental impacts for a product system throughout the life cycle of the product. ***[Italics added for emphasis]***

The Danish Guidelines and the ILCD Handbook have provided specific guidance on how to establish midpoint characterization methods along with formal midpoint characterization factors for several impact categories (as described further below).

This inconsistency in ISO 14044 has dissuaded developers of commercial LCA software and LCIA methods such as the CML-IA baseline method from incorporating more advanced, necessary midpoint/endpoint characterization to meet the recommendations of ISO 14044 Section 4.4.2.2.2. While historically this inconsistency may not have been a major issue, the fact that LCA is being increasingly used for public claims now makes this a higher priority. The statements limiting the output to only "potential" impacts should be updated to include midpoint characterization and modeling of actual, ongoing impact levels to meet the public disclosure requirements of the Standard.

4.0. Establishing the Environmental Relevance of Category Indicators

4.1. Elements Used to Determine to Environmental Relevance

In addition to recommending specific updates to the Standard by clarifying the overall iterative process, this paper also recommends an analytical framework to determine the degree of environmental relevance of category indicators. These updates will provide the guidance needed to conform to the spatial, temporal, intensity and reversibility elements required in ISO 14044 Section 4.4.2.2 and its subsections.

As described in Section 4.4.2.2.2, the environmental relevance of category indicators is the degree of linkage between stressors and the condition of category endpoint(s) within the cause-effect chain. This degree of linkage is determined through spatial, temporal, intensity and reversibility characterization of the linked midpoints or endpoints. Consistent with the example provided in ISO 14044, the degree of environmental relevance is described within this paper as high, moderate, or low, depending upon the category indicator's representation of the current or projected condition of the endpoint(s). The Danish Guidelines provide a general method for classifying the degrees of environmental relevance for a given category indicator that was further refined (see below) for this evaluation (Figure 6).

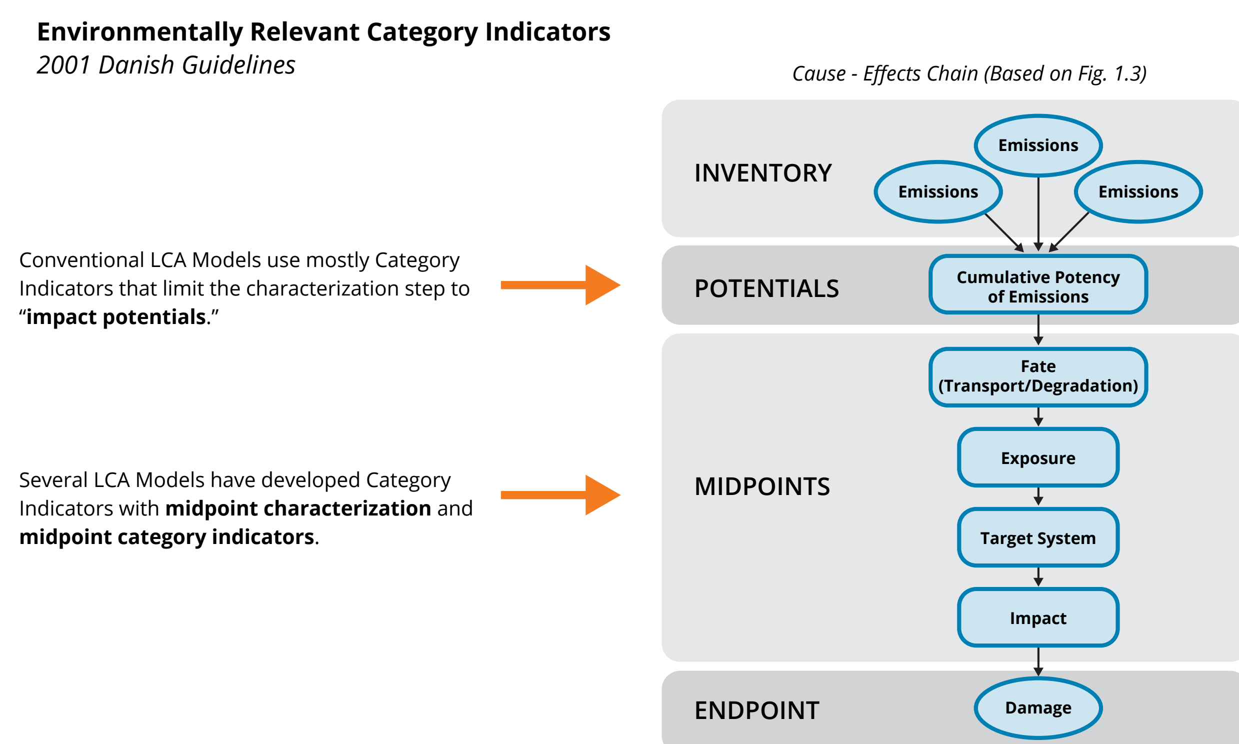

Figure 6: Danish Guideline Analytic Method for Determining Environmental Relevance

Specifically, ISO 14044 Section 4.4.2.2.4 requires that the environmental relevance of category indicators must include the following elements:

a. The condition of category endpoint(s);

b. The relative magnitude of the assessed change in the category endpoint(s);

c. The spatial aspects of the assessed change in the category endpoint(s) (such as area and scale);

d. The temporal aspects of the assessed change in the category endpoint (such as duration, residence time, persistence, timing, etc.);

e. The reversibility of the assessed change in the category endpoint(s);

f. The uncertainty of the linkages between the category indicators and the category endpoints.

While ISO 14044 does not explicitly include or define midpoints in Section 4.4.2.2.2, the Danish Guidelines show that elements a. - f. can be applied to midpoints in the same manner as they apply to endpoints in establishing the degrees of environmental relevance.

4.2. Impact Categories With Unique and Multiple Category Indicators

While an impact category represents the overall environmental mechanism related to a specific endpoint such global climate change, many impact categories have many distinct regional biophysical impact pathways that require characterization by specific location in order to meet ISO 14044 Section 4.4.2.2.2 recommendations. For example, while regional acidification impacts all proceed along the same general impact pathway, the amount that will deposit in a specific exceedance area will vary by the conditions within a given region. Once the unit process indicator is separately calculated to incorporate the corresponding regional conditions, combining the individual unit process results into a single summary of regional acidification for the product can be justified. For other impact categories, such as loss of key species habitats, to meet the requirements of environmental relevance, multiple category indicators with separate indicator results may be required to represent the overall impact categories of various unique but related endpoints.

4.3. "Potency Potential" Characterization Factors (PP-CF)

Potency potential characterization factors are applied to stressors in the cause-effects chain, and are well established and in wide use. However, these characterization factors lack sufficient linkage to midpoints and endpoints since they represent only the "potential" of an elementary flow (e.g., an emission) to cause impacts. These characterization factors imply the worst-case assumption that all elementary flows have the potential to cause impacts, even when damage to the target endpoint would not be expected.

This ambiguity has the advantage of avoiding liability because these potential factors cannot prove actual impacts. While this advantage is not generally discussed, it has been one of the principal reasons why these oversimplified characterization factors are favored by some LCA users, and one of the principal factors resulting in misleading EPDs in the marketplace. The problem with depending exclusively on potency potential characterization factors is that the resultant category indicator results are not based on any of the elements of environmental relevance required under ISO 14044 Section 4.4.2.2.4, and therefore are not suitable for use for public declarations or comparative assertions according to ISO 14044 (Section 4.4.5 requires environmental relevance for indicators used in comparisons).

Potency potential characterization factors have a wide range of confidence levels, depending upon the elementary flow and the category indicator in question. For example, the regional acidification category indicator, which normalizes the relative strengths of all strong acid emissions compared to sulfuric acid, is known with precision. At the same time, most emissions of sulfur occur as sulfur dioxide, which converts to a weak acid in the atmosphere. In order for sulfur dioxide emissions to cause damage to the surrounding environment, they must first be converted to sulfur trioxide by sunlight and water droplets. This conversion is seasonal, and sulfur dioxides emitted from coal plants in the northern climates produce only weak acids. However, the potency potential characterization factor in current use ignores that this critical conversion rate varies by region and time of year.

Other category indicators using these factors incur similar errors depending on regional conditions. For example, smog formation “potential” characterization factors are based upon VOC emissions and their individual potential to produce ground level ozone relative to methane. This is calculated using photochemical oxidation chemical potential (POCP) factors that specify the equivalent amount of ozone formed per amount of each VOC emission. These factors have two fundamental problems built into their use as LCIA characterization factors: 1) in many airsheds, NO_x is the limiting pollutant that determines the formation of ozone levels for the region, thus making the type and amount of VOC emissions irrelevant; and 2) even in VOC-limited receiving environments in which it is appropriate to use POCP values, such values can vary depending on the specific regional airshed. LCIA method developers used these factors because they were available and provided an easy way to aggregate VOC emissions, but this application of off-the-shelf equivalency factors is inappropriate. Most of the potency potential factors suffer from similar oversimplified assumptions and can be corrected only by midpoint characterization and stricter adherence to the actual biophysical impact pathways of the environmental mechanisms.

4.4. Midpoint/Endpoint Characterization Factors (M-CF; E-CF)

This characterization step is largely ignored by current LCIA methods. The Danish Guidelines have outlined a straightforward method to determine the degree of environmental relevance of a category indicator (Figure 7). Once the cause-effect chain has been modeled, the environmentally relevant elements (spatial, temporal, intensity and reversibility) can be applied to determine whether and how each element applies to the impact category.

For example, regional acidification impacts are specific to areas where exceedance of threshold is measurable. Consequently, acidification would warrant regional spatial characterization in order to meet that element of environmental relevance.

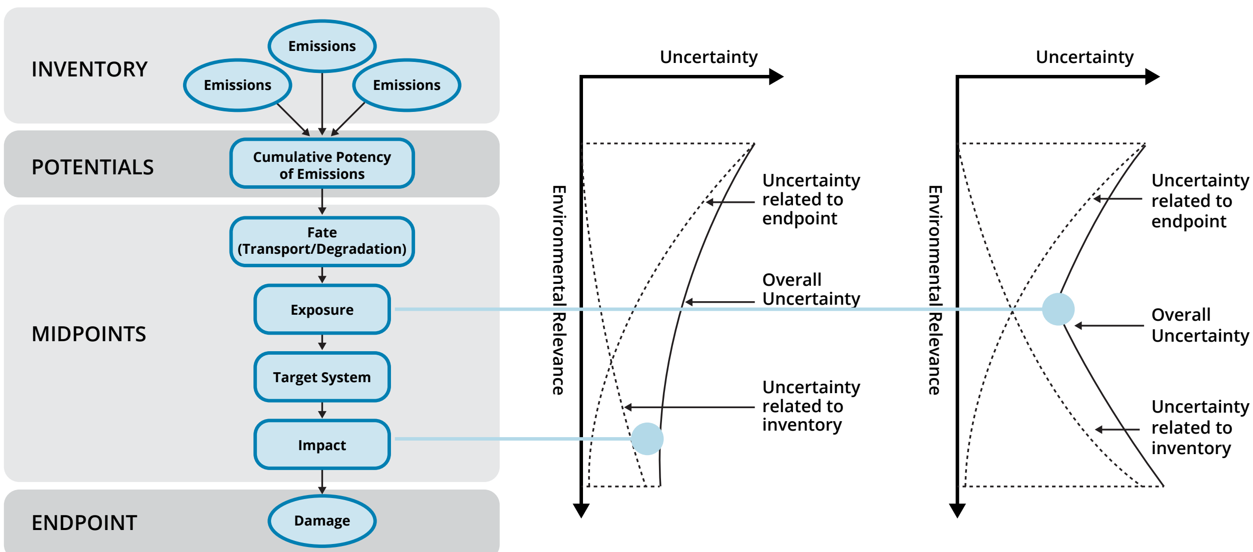

Figure 7: Danish Guidelines Method for Selecting Category Indicators with the Lowest Overall Uncertainty

The technique for establishing formal midpoint characterization factors that adhere to all of elements of ISO 14044 Section 4.4.2.2.4 is well established by the Danish Guidelines, and has been used to establish several category indicators with a high degree of environmental relevance. For example, the EDIP regional acidification category indicator calculates the fraction of total emissions that actually deposits in areas exceeding the critical load of strong acids. The method recommends using the RAINS air dispersion model to calculate fate and transport, which generates an accurate indicator result with a high degree of environmental relevance. While such characterization is not required for internal LCA modeling, it is essential for public claims.

Using the Danish Guidelines, it is possible to provide qualitative confidence intervals for levels of required characterization (i.e., low, medium, high). If the category indicator characterization step does not meet any of the necessary elements of environmental relevance[19], then it has a zero confidence level.

4.5. Reversibility of Endpoints

Characterizing the conditions of reversibility is required by the environmental relevance clause of ISO 14044. There are two fundamental factors of reversibility/ irreversibility for endpoints and midpoints that are required to meet this element of environmental relevance.

- **Exceedance of Threshold**
  Exceedance-of-threshold mapping has been established for several regional impact categories such as ground level ozone, regional acidification, aquatic eutrophication and PM 2.5. Such mapping will also be available through the open source LCA software, which will allow users to easily incorporate this characterization into their indicator results. This tool is increasingly being used in general practice to increase the overall accuracy and relevance of the LCIA indicator results. This critical characterization function greatly enhances the mapping of real (rather than potential) impact hot spots.
- **Incorporating Projected Global Tipping Points**
  While exceedance of threshold for regional impacts can have varying degrees of reversibility, the planet is facing major global tipping points in global climate and oceanic ecosystems that will cause irreversible changes lasting for a millennium. The IPCC AR 5 (with a high degree of confidence) specifically states that the initial GMT tipping point of +1.5° C is projected to occur as soon as 2035. Given that these changes are expected as soon as within twenty years, all LCIA methods and category indicators should be required to account for and report all impact categories associated with such tipping points.

4.6. Environmental Relevance of CML-IA Baseline Category Indicators

The inconsistent guidance in ISO 14044 related to the output of LCIA profiles, limiting impact assessment to measuring only “potential impacts” while at the same time requiring environmental relevance, has hindered the effort to develop environmentally relevant indicators in LCA practice. For instance, an evaluation of the CML-IA baseline method, based on the background documents available on the CML website, shows that 11 out of 12 category indicators were developed with

19 The Regional Air Pollution Information and Simulation Model; http://www.eolss.net/Sample-Chapters/C15/E1-47-15.pdf

no environmental relevance (see Table 6 and Appendix B).[20] As can be readily seen in the matrix evaluation, no formal midpoint characterization was included in its algorithms, precluding determination of the degree of environmental relevance.

4.7. The Reporting of Trivial Impact Levels

A common misapplication of the ISO 14044 Standard is the reporting of trivial indicator results. Such reporting creates the impression that the indicator results have physical meaning and are significant. For example, users of the CML-IA category indicators are currently reporting extremely small amounts that could not conceivably affect an endpoint. One practitioner has used this set of indicators to report 10^{-11} kg of ozone depleting chemical (ODC) emissions for the Environmental Footprint of concrete. If the entire production of North American concrete were scaled to this indicator result, the scaled result would still be lower than the amount of ODC found in a single old refrigerator. Most readers of such an EPD have no idea that these amounts could not possibly affect the stratospheric ozone layer and are misled into considering them as environmentally relevant and meaningful. This can lead to the false prioritization of investment towards impact reduction efforts that may not have any meaningful impact (i.e., a case where investments are made to reduce ODC emissions for a product where this impact is not relevant).

Table 6. *The Environmental Relevance of the CML-IA Baseline Category Indicators[21] – Two Indicators (Acidification Potential and Global Warming Potential)*

CML Baseline Category Indicators	Represents Distinct Environmental Mechanism	Potency Potential Characterization Factors – Confidence Interval	Environmental Relevance (ER) Characterization Requirements				Environmental Relevance –Confidence Interval	Degree of Environmental Relevance of Indicator
			SPATIAL	TEMPORAL	INTENSITY	REVERSIBILITY		
Acidification potential	Well-established mechanism of terrestrial and fresh water body acidification	Acid equivalencies based on SO_2 eq. Confidence Interval ± 50%. Factor does not include conversion rates of SO_2 to SO_3 that are dependent on regional conditions and global soils databases (e.g., Harmonized World Soil Database[22]).	The CML indicator does not provide disposition mapping in order to determine the fraction of acid releases depositing in areas of exceedance. This requirement can be met using the RAINS and HYSPLIT dispersion software.	The CML indicator ignores seasonally dependent conversion rates of SO_2 into SO_3 and seasonal dependence of transport of strong acids into water bodies. This requirement can be met using the RAINS and HYSPLIT dispersion software.	The CML indicator does not characterize the intensity of the acidification in the areas of exceedance. This requirement can be met using the RAINS and HYSPLIT dispersion software and global soil characteristics databases.	The CML indicator does not characterize the reversibility of impacts involved in this mechanism, in which areas in exceedance can take centuries to recover.	Zero	No Environmental Relevance.
Global Warming Potential (GWP-100 years)	Well-established mechanism of global climate change	GWP is based on 100-year time horizon CI = ± 40%[23]	None required	The CML indicator's GWPs represent an integration of both PP-CFs and M-CFs. The CML category indicator has arbitrarily selected a 100-year time horizon that ignores the IPCC AR 5 time horizon tipping points of 2035, 2050, and 2100.	The CML indicator's GWPs ignore the oncoming intensity of endpoints coming by 2035 as reported by IPCC AR 5.	The CML indicator's GWPs do not factor in the fact that the planet will go through an irreversible change within 20 years that is projected to last for thousands of years.	Zero	No Environmental Relevance.[24]

20 An operational guide to the ISO standards (Guinée et al.) - Part 3: Scientific background (Final report, May 2001). http://cml.leiden.edu/research/industrialecology/researchprojects/finished/new-dutch-lca-guide.html
21 A more complete analysis of CML category indicators is provided in Appendix B, "The Environmental Relevance of the CML Baseline Category Indicators."
22 http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/index.html
23 IPCC Fifth Assessment Report, Chapter 8, 2013.
24 IPCC Fifth Assessment Report, Technical Summary, 2014.
25 IPCC Fifth Assessment Report, Technical Summary, 2014.

5.0. Recommended Updates to ISO 14044

Overall the current ISO 14044 sections providing guidance on the LCIA phase are clear and well written. The Standard was written during a period in which life cycle scoping and LCI protocols dominated practice. During the past decade, LCA has grown in importance for public declarations (EPDs) and claims of sustainability, and LCA is touted as raising the bar of transparency and offering a roadmap to sustainability. However, current LCIA methods are largely based upon the same assumptions used in the CML-IA baseline method, with similarly limited impact categories and category indicator lists. Only those impacts derived directly from the LCI phase are reported, with little or no environmental relevance, and trivial results are reported without informing the user of the lack of scale to the corresponding endpoint.

The following updates would provide the basic guidance needed to ensure that ISO 14044-based public claims follow the original intention of providing full transparency of all environmental and human health impacts associated with any industrial activity, to support more informed decision-making. Specific guidance on changes to clauses to be amended is provided in N504 and N505.

1. Update the Standard to include a more detailed iterative approach that incorporates reverse effects characterization. This should include detailed guidance for each of the four iterative steps described in this paper, including the approach for identifying relevant impact categories, which can be linked to effects caused by a given industrial activity.
2. Provide more guidance for approaching LCA through an iterative process building on what is provided in the ILCD Handbook and Danish Guidelines. This would support much more comprehensive, balanced, and cost-effective LCA studies for public declarations and claims of environmental sustainability. A more detailed iterative process, as outlined in this paper, should be the basis for updating ISO 14044 guidance.
3. Establish a table listing the reference impact categories and groupings shown in Tables 1 and 3 that will bring full transparency to LCA, and require LCIA methods referencing ISO 14044 to state clearly which impact categories are included.
4. Modify ISO 14044 Section 4.4.2.2.4 to describe the elements of both midpoint and endpoint characterization should be included for category indicators used for the impact categories provided in the reference impact category and groupings list above.

5. Expand the output options for LCIA profiles to include the modeling and accounting of current and projected site-specific, region-specific and global-specific measurable impact levels based upon midpoint/endpoint characterization to meet the recommendations of ISO 14044 Section 4.4.2.2.2.
6. Provide a new clause specifying the analytical framework for determining the degree of environmental relevance for category indicators used in LCIA methods.
7. Add a specific definition for midpoints and add the term “midpoints” to the environmental relevance clause.
8. Add language to clarify what is meant by a distinct “environmental mechanism” that encompasses all impact categories and includes resource depletion categories.
9. Provide an informative annex that shows the range of current category indicators and their current degrees of environmental relevance, by method (e.g., CML-IA baseline method, ReCiPe, IMPACT World).
10. Provide guidance for appropriate reporting of trivial indicator results.
11. Provide guidance for claims of “environmental sustainability” based upon LCA. Claims of overall sustainability based solely upon ISO 14044 constitute a significant misuse of the Standard since such claims are expected to include both social and economic parameters as well as environmental performance. Failure to provide the distinction between full sustainability and environmental sustainability will be met with significant resistance.
12. Require inclusion and reporting of impact categories linked to the oncoming climate tipping points. Any claims of environmental sustainability should require that entities provide proof that they have completely mitigated such tipping point impacts through established market mechanisms.
13. Remove weighting as an optional element of LCIA, as this is inconsistent with the effects characterization framework.