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LIFE CYCLE APPROACH-BASED METHODS – OVERVIEW, APPLICATIONS AND IMPLEMENTATION BARRIERS

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Abstract: Companies operating in the circular economy face the challenge of inclusion parameters related to the life cycle of products in the area of decision-making and communication with the stakeholders. At the same time, life cycle approach-based methods, including LCA, carbon footprint, and environmental footprint, are dynamically developed. The purpose of this article is to recognize the possibilities and applications, as well as barriers to the implementation of three group of methods – life cycle assessment, carbon footprint and environmental footprint.

Keywords: life cycle assessment, LCA, circular economy, carbon footprint, environmental footprint.

1. Introduction

The concepts of Sustainable Development, Life Cycle Thinking and Life Cycle Management increasingly dictate the conditions of business operations. This can be seen both in the creation of legal regulations regarding various environmental aspects and their mandatory inclusion in the design and manufacturing of products (e.g. Ecodesign directive (Directive 2009)), as well as in the use of these aspects to increase competitiveness and improve various areas of activity (see Karlsson and Luttropp, 2006).

LCM can be applied in all organizations - from a very small-scale local vendor, to large and multinational companies (Sonnemann et al., 2015). Indeed, for years, international corporations have been tapping into the economic opportunity associated with incorporating environmental aspects into the company's strategy (Wimmer et al., 2010). In turn, their partners in the value chain, often from the SME sector, in particular, upstream partners (that means companies from cradle to gate, e.g. material suppliers), are also forced to report relevant environmental indicators in relation to the life cycle (Baran, 2016).

Analysis of environmental aspects through the life cycle using methods such as life cycle assessment and derivative methods makes public the characteristics of the product or enterprise involved in environmental issues described as impact categories (Baran, and Janik, 2013; Baran et al., 2016).

2. Overview of life cycle approach-based methods

In business practice, tools that take into account the life cycle of products are increasingly reached for. Among these are:

- Life Cycle Assessment LCA (including Life Cycle Assessment of products and Organizational Life Cycle Assessment O-LCA),
- Carbon Footprint CF (including Product Carbon Footprint PCF and Corporate Carbon Footprint CCF),
- Environmental Footprint EF (including Product Environmental Footprint PEF and Organization Environmental Footprint OEF).

The life cycle environmental assessment methodology can apply to both the product and the organization, albeit, the method of analysis is different in each of these cases. While both approaches interpenetrate, the basis for data collection is different. In the case of product analysis, the collected data relate to a specific functional unit – for example, a given product with specific characteristics, manufactured according to a given technology. In the case of organization analysis, the approaches are more diverse, but there is a division into direct and indirect impacts – in the value chain. The scope of organization analysis can be broader than the analysis performed in terms of the product.

The methods listed at the outset – the most important methodological issues are reviewed below.

2.1. Life Cycle Assessment LCA – product approach

Life cycle assessment is compilation and evaluation of the inputs, outputs and the potential environmental impacts of product system throughout its life cycle (ISO 14040).

LCA consists of the following stages (ISO 14040, 14044):

- Goal and scope definition – choice of functional unit, which can be, e.g. a specific product. In addition, the boundaries of the analysed environmental system are determined.
- Inventory analysis – involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. Data of each unit process within the systems boundary can be classified under major headings, including: energy inputs, raw

material inputs, ancillary inputs, other physical inputs; products, co-products and waste; emissions to air, discharges to water and soil, and other environmental aspects.

- Impact assessment – transforming the collected data into impact category indicators, according to the procedures defined in (ISO 14040). In general, this process involves associating inventory data with specific environmental impact categories and category indicators, thereby attempting to understand these impacts. Issues such as choice, modelling and evaluation of impact categories can introduce subjectivity into life cycle impact assessment LCIA phase. One of subjective issues is choice of LCIA method – for example ILCD 2011 Midpoint+, IMPACT 2002+, CML-IA, ReCiPe (SimaPro Database, 2019). Analyses are as a rule carried out using professional programs like SimaPro or GaBi. The main difference between the methods is the use of different impact categories and environmental mechanisms for individual impact categories. The assessment of the potential environmental impact expressed for individual impact categories based on environmental mechanisms (the causal chain attributing a given emission to the impact category) is the result of many studies of physical, chemical, biological and physicochemical properties of substances in various environmental reservoirs (water, soil, air).
- Interpretation – findings from the inventory analysis and the impact assessment are considered together. The phase should deliver results that are consistent with the defined goal and scope and which reach conclusions, explain limitations and provide recommendations.

2.2. Organizational life cycle assessment O-LCA

According to (ISO/TS 14072), organizational LCA is a compilation and evaluation of the inputs, outputs and potential environmental impacts of the activities associated with the organization adopting a life cycle perspective.

O-LCA consists of the following stages (Guidance on Organizational, 2015):

- Goal and scope of the study – among others, determining of reporting organization and consolidation method – control (operational, financial) or share equity, reporting flow and system boundary.
- Inventory analysis – the inventory should consist of all inputs (e.g. energy, water and materials) and outputs (e.g. products, co-products, waste and emissions to air, to water and to soil) connected with the activities involved in the provision of the reporting flow (the reporting flow links the different units in the value chain with the product portfolio of the reporting organization) and considering the system boundary definition. For direct activities, the inventory shall include all inputs and outputs (for example, generation of energy resulting from combustion of fuels in stationary sources (e.g. boilers, furnaces and gas turbines); physical or chemical processing (e.g. from manufacturing, processing

and cleaning)). Regarding the value chain, it is recommended to consider all the inputs and outputs from indirect activities that are included in the system boundary (for example, extraction, production and distribution of purchased raw materials, electricity, steam and heating energy; end-of-life (EoL) treatment of products sold).

- Impact assessment – basically the same approach as that of product LCA. Once the inventory is compiled, translating the inputs and outputs into environmental impacts should be done with one of the existing impact assessment methods (e.g., ReCiPe, CML 2002, EDIP and LIME). As with product LCA, two obligatory steps are performed – classification and characterization – and it is optional to apply normalization, aggregation and weighting.
- Interpretation – the fourth step of an O-LCA dealing with interpretation and uncertainty is analogous to that of LCA of product.

2.3. Carbon Footprint of Products CFP

Carbon footprint of products is an analysis conducted in accordance with GHG Protocol (Greenhouse Gas Protocol. Product, 2011), ISO standard (ISO 14067), or PAS 2050 (PAS 2050). Companies shall account for carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), perfluorocarbons (PFCs), and hydrofluorocarbons (HFCs) emissions to, and removals from, the atmosphere.

CFP consists of the following stages (ISO 14067):

- Goal and scope definition – the overall goal of conducting a CFP study is to calculate the potential contribution of a product. At this stage, the functional unit (or declared unit for partial CFP) is selected. In addition, the boundaries of the analysed environmental system are determined.
- Inventory analysis – the qualitative and quantitative data for inclusion in the life cycle inventory shall be collected for all unit processes that are part of the system under study. Companies shall collect data for all processes included in the inventory boundary (Greenhouse Gas Protocol. Product, 2011).
- Impact assessment – in the LCIA phase of a CFP study, the potential climate change impact of each GHG emitted and removed by the product system shall be calculated by multiplying the mass of GHG released or removed by the 100-year GWP given by the IPCC in units of kg CO_2e per kg emission.
- Interpretation – the life cycle interpretation phase of a CFP study shall comprise the following steps: a) identification of the significant issues based on the results of the quantification of the CFP in accordance with LCI and LCIA phases; b) an evaluation that considers completeness, consistency and sensitivity analysis; c) the formulation of conclusions, limitations and recommendations.

2.4. Corporate carbon footprint CCF

Corporate carbon footprint is currently the most popular measure of life cycle environmental aspects used by enterprises. CCF, like CFP, covers the accounting and reporting of the six greenhouse gases covered by the Kyoto Protocol (Kłos, 2014; Kulczycka and Wernicka, 2015). ISO 14064-1 and identifies three types of emissions: a) direct emissions (scope 1); b) energy indirect emissions (associated with purchases of electricity and heat) (scope 2); c) other indirect emissions (scope 3) (Greenhouse Gas Protocol, 2004; Greenhouse Gas Protocol. Corporate Value Chain, 2011).

CCF analysis begins with selecting and applying the consolidation method (equity share), then the initial assumptions are developed, and operational boundaries are determined. Subsequently, inventory analysis is made for the above-mentioned categories (Greenhouse Gas Protocol, 2004; Greenhouse Gas Protocol. Corporate Value Chain, 2011):

- Direct GHG emissions (including direct emissions from stationary combustion; direct emissions from mobile combustion; direct process related emissions; direct fugitive emissions; direct emissions and removals from Land Use, Land Use Change and Forestry (LULUCF);
- Energy indirect GHG emissions (including indirect emissions from imported electricity consumed; indirect emissions from consumed energy imported through a physical network (steam, heating, cooling, compressed air);
- Other indirect GHG emissions and removals (including energy-related activities not included in direct emissions and energy indirect emissions; purchased products; capital equipment; waste generated from organizational activities; upstream transport and distribution; business travel; upstream leased assets; investments; client and visitor transport; downstream transport and distribution; use stage of the product; end of life of the product; downstream franchises; downstream leased assets; employee commuting; other).

The carbon footprint calculation consists of steps repeated for each of the categories listed above (ISO 14069):

- Identification of GHG sources and sinks,
- Selection of activity data (according to best, minimum or intermediate scenario),
- Selection of emission factors,
- Impact assessment in relation to GHG released or removed by the 100-year GWP given by the IPCC in units of kg CO_2e per kg emission,
- Interpretation.

2.5. Product environmental footprint PEF

The product environmental footprint is a life cycle assessment (LCA) based method to quantify the environmental impacts of products (goods or services). It builds on existing approaches and international standards and details methodological issues. The overarching purpose of PEF information is to enable to reduce the environmental impacts of goods and services - taking into account supply chain activities (from extraction of raw materials, through production and use and to final waste management). This purpose is achieved through the provision of detailed requirements for modelling the environmental impacts of the flows of material/energy and the emissions and waste streams associated with a product throughout its life cycle.

The rules provided in the PEF method enable to conduct PEF studies that are more reproducible, comparable and verifiable, compared to existing alternative approaches. However, comparability is only possible if the results are based on the same Product Environmental Footprint Category Rules (PEFCR). The development of PEFCRs complements and further specifies the requirements for PEF studies (Zampori, 2019b). Recommendations for a specific product group distinguishes PEF from classical LCA.

PEF study consists of the following stages (Zampori, 2019b):

- Goal and scope definition – the aims of the study are defined, namely, the intended application, the reasons for carrying out the study and the intended audience. Main methodological choices are made in the scope phase, for example, the exact definition of the functional unit, the identification of the system boundary, the selection of additional environmental and technical information, main assumptions and limitations.
- Inventory analysis – involves the data collection and the calculation procedure for the quantification of inputs and outputs of the studied system. Inputs and outputs concern energy, raw material and other physical inputs, products and co-products and waste, emissions to air/water/soil. Data collected concern foreground processes and background processes. Data are put in relationship to the process units and functional unit.
- Impact assessment – LCI results are associated to environmental impact categories and indicators. This is done through LCIA methods, which first classify emissions into impact categories and then characterize them to common units (e.g. CO_2 and CH_4 emissions are both expressed in CO_2 equivalent emissions by using their global warming potential). Examples of impact categories are climate change, acidification or resource use. The end of life of products used during the manufacturing, distribution, retail, the use stage or after use shall be included in the overall modelling of the life cycle of the organization. Specific for PEF is using the Circular Footprint Formula CFF that is a combination of "material + energy + disposal".

- Interpretation – results from LCI and LCIA are interpreted in accordance to the stated goal and scope. In this phase, most relevant impact categories, life cycle stages, processes and elementary flows are identified. Conclusions and recommendations can be drawn, based on the analytical results.

2.6. Organisation Environmental Footprint OEF

The Organisation Environmental Footprint is a Life Cycle Assessment (LCA) based method to quantify the environmental impacts of organisations: this includes companies, public administrative entities and other bodies. The OEF method builds on existing approaches and international standards. OEF information is produced for the overarching purpose of seeking to reduce the environmental impacts of organisations, taking into account supply chain activities (from extraction of raw materials, through production and use, to final waste management). This purpose is achieved through the provision of detailed requirements for modelling the environmental impacts of the flows of materials and energy, and the emissions and waste streams associated with the product portfolio of an organisation, throughout its life cycle. The OEF is complementary to other assessments and instruments, such as site-specific environmental impact assessments or chemical risk assessments. At organisational level, the importance of the environmental impacts occurring in the supply chain is increasingly recognised. Standards and methods were created, such as the GHG Protocol Corporate Standard and its sectoral guidance or Global Reporting Initiative indicators. At EU level, the EMAS Sectoral Reference Documents include guidance on indirect impacts, highlighting also the use of LCA-methods for evaluation of the respective product portfolio (PP). The rules provided in the OEF method enable to conduct OEF studies that are more reproducible, comparable and verifiable, compared to existing alternative approaches. However, comparability is an option only if the results are based on the same set of Organisation Environmental Footprint Sector Rules (OEFSR) and if the performance is normalized against a reference system (e.g. yearly turnover with reference to the product portfolio). The development of OEFSRs complements and further specifies the requirements for OEF studies (Zampori, 2019a).

OEF study consists of the same stages as PEF. The most important issues and differences are detailed below (Zampori, 2019a):

- Goal and scope definition – definition of the reporting unit (RU): description of the organisation and the product portfolio.
- Inventory analysis – an inventory of all material, energy and waste inputs and outputs and emissions into air, water and soil for the product supply chain shall be compiled as a basis for modelling the OEF. Direct activities are that occurring within the organisational boundary, and, therefore, are owned and/or operated by the organisation (e.g. site-level activities). Indirect activities refer to the use of materials, energy and emissions associated with goods/services sourced from upstream, or occurring

downstream, of the organisational boundary in support of producing the product portfolio.

- Impact assessment – includes four steps: classification, characterisation, normalisation and weighting (like in classical LCA). Impact categories are the same as in PEF. Specific for PEF is using the Circular Footprint Formula CFF that is a combination of "material + energy + disposal”.
- Interpretation.

3. Application areas of selected methods

ISO 14040 standard includes several examples of company related LCA applications, among others, product development and improvement, strategic planning, public policy making, marketing, environmental management systems and environmental performance evaluation, environmental labels and declarations, integration of environmental aspects into product design and development (design for environment), inclusion of environmental aspects in product standards, environmental communications, quantification, monitoring and reporting and entity and project emissions and removals, and validation, verification and certification of greenhouse gas emissions. Table 1 shows life cycle approach-based methods applications. The most useful methods for specific applications were indicated by marking with a ‘+’. For example, all methods can provide support to environmental management and environmental management systems, and comparisons of results to the benchmark of the product category is possible with PEF due to the fact that within this method, methodological guidance for a specific group of products is defined.

Table 1.
Life cycle approach-based methods applications

	APPLICATIONS	LCA	CFP	PEF	O-LCA	CCF	OEF
Internal applications	support to environmental management and environmental management systems	+	+	+	+	+	+
	support for product design minimising environmental impacts along the life cycle	+	+	+			
	identification of environmental hotspots	+	+	+	+	+	+
	environmental performance improvement and tracking	+	+	+	+	+	+
	optimisation of processes along the life cycle of a product	+	+	+			
	optimisation of processes along the supply chain				+	+	+
	strategic planning	+	+	+	+	+	+

Cont. table 1.

External applications	responding to investors' information requests				+	+	+
	responding to customers and consumers demands	+	+	+			
	sustainability or environmental reports	+	+	+	+	+	+
	marketing	+	+	+	+	+	+
	responding to requirements of environmental policies at EU level or at the level of the individual member states						+
	cooperation along supply chains to optimise the product along the life cycle	+	+	+			
	identification of significant environmental impacts common to a sector						+
	identification of significant environmental impacts common to a product group	+	+	+			
	comparisons and comparative assertions when the performance of the product portfolio is normalized against a reference system						+
	comparisons and comparative assertions against the benchmark of the product category followed by a grading of other products according to their performance versus the benchmark			+			
	green procurement (public and corporate)	+	+	+	+	+	+
	public policy making	+	+	+	+	+	+

Source: own work based on (ISO 14040; Zampori, 2019a, 2019b; ISO/TR 14062; Lewandowska, 2011; Lewandowska et al., 2012; Michalski and Białecka, 2010; Piekarski et al., 2013).

Internal and external applications of life cycle management tools imply possible benefits that can be consolidated into four areas (elaborated on basis of Background Report, 2006):

1. Reputation and image improvement:
   - Improve of public image and general relations to stakeholders;
   - Increase and maintain shareholder value;
   - Product branding ("green");
   - Work towards being a sustainable business and be at the forefront of competitors.
2. "Sustainable" products:
   - Sustainable manufacturing processes in all parts of the business chain (measured by EMS, environmental performance indicators, green accounts);
   - Extended product life time and technological efficiency (better quality products);
   - Low environmental impacts in the product life cycle (measured by e.g. LCA);
   - Lowest possible health impacts in the product life cycle (measured by LCIA or "Risk Assessment"). Improvements of occupational safety and health conditions throughout the whole life cycle;
   - Lowest possible use of non-renewable resources in the whole life cycle (measured by LCI);
   - Lowest possible economic costs to consumer and society in the whole life cycle (measured by LCC, "green taxes" or cost-benefit analysis);

- High “Eco-efficiency” (measure of relation between environmental impacts and economic costs);
- Designed for disassembling and reuse/recycling (screening LCA);
- Preferable usage of renewable and recycled materials Preparation for “Take back systems”;
- Best social conditions for workforces (social responsibility).

3. Being proactive: preparation for supplier, customer, and government mandates:
   - Be at the edge of and prepared for present or future legislative developments, e.g. introduction of Integrated Product Policy and “take back legislation”.
4. Ability to implement programs with a focus on sustainability and beyond the production fence:
   - Product stewardship programmes;
   - Programmes for development and design of new products;
   - Supply chain management, supplier evaluation. Communication in the value chain;
   - Environmental product declarations;
   - Corporate Social Responsibility Programme;
   - Marketing activities.
5. Preparation for advanced international and national programs:
   - Prepared to join various eco-labelling schemes (increased visibility, image and sale);
   - Possibility to get a “Dow Jones Sustainability Index” (increased shareholder value);
   - Possibility to serve in “green” public procurement programmes (increased sales).
   - Possibility of participation in international programmes – e.g. Carbon Disclosure Project CDP, EcoVadis, Circular Economy.

4. Barriers of life cycle approach-based methods implementation

Among the largest barriers related in putting into place life cycle-based methods, enterprises point towards high time and cost consumption of conducting analysis, difficulties in accessing relevant data and trainings (Cichy and Szafraniec, 2015; Wolniak, 2017).

Barriers to using LCA lead to lost opportunities for improved environmental decisions. Potential concerns that affect the use of LCA methods include the aspects pointed out in Table 2 with considering possible solutions.

Table 2.
Barriers of life cycle approach-based methods implementation

Barriers	Description	Considering possible solutions
Resource requirements	- Required know-how - Time consumption - High costs	- Outsourcing of life cycle approach expertise, acquiring the know-how from outside - Searching for external financing options - Estimation and comparing the costs and benefits of external and internal expert LCA services
Data requirements	- Difficult data collection procedures (in practice) - The need for internal training to collect good site-specific quality data - Inconsistent data - external and internal - Lack of internal procedures for collecting life cycle data - data are not available at the needed level (e.g. geographic, process) - The range of LCI databases vary in design, format, and quality - Data not available in the value chain	- Joining in developing databases with data that have been vetted within the industry - Development and implementation of internal procedures and data collection systems adapted to the needs of LCA
Increasing number of methodologies, standards and programs containing methodological recommendations	- The problem with determining the appropriate methodological approach needed in a given situation	- Developing know-how - Trainings
Limited guidance	- Problems with the application of complicated methodological procedures in available programs (e.g. concerning recycled content) - Methodology in continuous dynamic development	- Employees trainings - Developing cooperation with partners in the value chain – especially with suppliers and clients
Uncertainties over implementation of results	The results of an LCA may suggest a change in a company's operations. Dedicated competence groups within an organization are somewhat reluctant to effect changes - and particularly changes that do not evolve from activities within the group itself	- Implementation appropriate knowledge management approach to life cycle-based activities - Stimulating LCA understanding in the HR area
Validity	Power of and value provided by LCA would increase significantly if it were validated – additional costs and requirements	- Analysis of the possibilities of validity and selection of the best solution
Scientific basis	Life-cycle studies that do not follow the steps of a traditional LCA may be criticized as lacking scientific support	- Cooperation with science - Development of internal know-how
Transparency	Existing standards and guidance provide some guidelines, which, if followed, will ensure consistency, but for some issues, the standards are silent or ambiguous, leaving room for the use of an extensive range of methods. Many of these methods lack transparency on core methodological issues, making it difficult to compare them with other methods	- Organization needs initial analysis before conducting LCA-based analysis - Adaptation of the used methodology to the needs

Cont. table 2.

Absence of perceived need	Many companies do not see how lifecycle thinking can be applied to their specific operations - or even the benefits of doing so. Many potential users are unaware of how life-cycle approaches can aid in decision making. Documentation of performance improvements can be tedious and resource intensive, but may be necessary to verify the results of changes resulting from life-cycle thinking.	Options for integrating or at least considering LCA analytical approaches and results in conjunction with other environmental and decision making tools will be needed to show how LCA can contribute to improved decisions.
Organizational structures	Often, life-cycle practitioners are functionally a part of a company's environment, safety, and health division – separated or disconnected from the process design and product development departments. Thus, the knowledge of the life-cycle practitioners is not shared with developers, and the developers may not be aware of how life-cycle thinking can be integrated into design and development.	- Introduction of a new department dealing with sustainable development - Appropriate department empowerment because many internal parties need to work together to implement LCA-related projects by providing the required resources for the sustainability initiative including time and educational resources - Participating actively in setting up the strategic sustainability goals of the organization - Communicating explicitly throughout the organization regarding the sustainability aims in an effective and clear manner - Involving actively the employees with regard to ideas and suggestions for the use of life cycle approaches

Source: own elaboration based on (Life Cycle Thinking, 2007; Wolniak, 2019; Zarębska and Dzikuć, 2013).

5. Conclusion

Currently, the life cycle based methods are in the process of dynamic development. In particular, this applies to the area of data availability in specialized databases and as part of the developed environmental footprint methodology that brings standardization of methodological solutions (e.g. consistency in the LCIA methodology used).

The developed methodology and numerous case studies do not help enterprises in the operationalization of knowledge about possible applications. This article outlines the possibilities of using the most advanced and commonly used methods based on the LCA approach. Both product and organizational approaches were discussed (particularly important due to the relatively frequent use of CCF). Barriers to method implementation were also indicated.

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