Methods for the Assessment of Environmental Sustainability of Packaging: A review.

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Abstract

Growing awareness for environmental issues and stricter legislation increases the pressure on producers to address these issues. In particular, packaging is under scrutiny, because it is perceived as a major contributor to waste streams and resulting environmental problems.

This review provides an overview of the existing tools used to assess the environmental impacts of packaging. While a full life cycle assessment (LCA) is an appropriate tool to assess the impacts of a well-established product, simplified LCA allows a quick and less detailed assessment during, for example, the design phase of a certain product. Furthermore, scorecards are capable of addressing pre-selected environmental aspects of packaging. Whenever applying simplified LCA or scorecards, the inevitable trade-off between accuracy and user-friendliness has to be considered. Nevertheless, a careful selection of the indicators to be assessed and a good understanding of the packaging system allow results to be meaningful even with these simplified tools.

Keywords

Packaging, Life Cycle Assessment, Streamlined Life Cycle Assessment, Simplified Life Cycle Assessment, Ecodesign Tools, Scorecards, LCA, SLCA

1. Introduction

Methods to assess the environmental impact of packaging have gained increasing interest over the last decades. In particular, packaging is an often-studied Life Cycle Assessment (LCA) topic (Franklin et al., 1974; Ayres, 1995; Falkenstein Wellenreuther & Detzel, 2010, Detzel & Mönckert, 2009; Gasol, Farreny, Gabarrell & Rieradevall, 2008; Belboom, Renzoni, Verjans, Léonard & Germain, 2011; Humbert, 2009; Odabasi, 2016; Verghese, Horne & Carre, 2010). The first packaging LCA study was undertaken in the late 1960s and was commissioned by Coca Cola (Franklin & Hunt, 1996). Procter & Gamble assessed the environmental impacts of their laundry detergent packaging in the early 1990s (Verghese, Lewis, Lockrey & Williams, 2013, p. 174-175). The holistic life-cycle approach provides several advantages, because it avoids the risk of shifting environmental burdens from one life cycle stage to another by evaluating all life cycle stages. By assessing several different environmental impact categories, the risk of shifting the burden from one environmental topic to another can be minimized (Flanigan, Frischknecht & Montalbo, 2013). LCA has become an integral part of the industrial decision-making process (Dorn, 2016). The increased use of LCA has boosted demand for streamlined and tailor-made LCA-based-tools (The Consumer Goods Forum, 2011). This trend derives from the fact that for many years packaging has been center stage in political and consumer campaigns to address perceptions of unsustainable consumerism in Western society (Verghese, Lewis & Fitzpatrick, 2012). Ocean littering for example has become a major environmental concern, and packaging is an important contributor to marine plastic debris (Lavers & Bond, 2017; Jambeck et al., 2015; Ingrao, Gigli & Siracusa, 2017; United Nations Environment Programme (UNEP), 2016). On the other hand, intelligent packaging can contribute to product sustainability since it prevents product damage. Particularly food loss can be significantly reduced by suitable packaging (Gutierrez, Meleddu & Piga, 2017; Verghese et al., 2013). Optimized packaging often provides environmental advantages. The reason is that the benefits of prevented food waste are often higher than the environmental impacts of production or optimization of the packaging involved (denkstatt, 2014). This example makes clear that for a good understanding of the environmental impacts the packaging should not be analyzed separately from the contained product to avoid burden shifting (Grant, Barichello & Fitzpatrick, 2015). A reduction of packaging material, which would lead to increased product damage, would be counterproductive (denkstatt, 2014). The influence of packaging attributes on recycling and food waste behavior should also be taken into account (Wikström, Williams & Venkatesh, 2016). This publication, nevertheless, focuses on the assessment of environmental impacts of packaging alone, since packaging-assessment is the first step of the overall assessment process.

The packaging value chain is increasingly complex (Dominic, 2013). It consists of many players, in particular raw material producers, packaging converters, the consumer goods industry, retailers, consumers and disposal companies. Assuming that each actor shares some commitment to the goal of sustainability, they cannot simply look at the impact of their own actions to achieve the greatest sustainability gains, but must see in what way they can support other players along the value chain (European Organization for Packaging and the Environment (EUROPEN), 2011).

TABLE 1 shows that the different tools and methods have to meet different standards regarding accuracy and usability depending on the user's requirements. The choice of an environmental assessment tool and the indicators to be evaluated depends on what is going to be compared, where in the packaging design process the assessments are being applied, how the results are being used and where in the supply chain they are being applied (The Consumer Goods Forum, 2011).

The aim of this review is a comparison of existing methods to assess the environmental impact of packaging. In particular, this review is intended to support environmental and packaging professionals in their search for an appropriate assessment tool.

2. Comparison of Environmental Assessment Methods and Tools

To date various methods and tools have been developed and introduced to measure the environmental impact of packaging. These possibilities exhibit specific advantages but, in some cases, also disadvantages. The present section, therefore, aims to present key methods and tools, which can be classified into conventional LCA, simplified (or streamlined) LCA (SLCA) and scorecards.

2.1. Life Cycle Assessment (LCA)

The most advanced and simultaneously precise method of assessing the environmental impacts of a given system is a fully executed LCA according to the internationally accepted standards, ISO 14040 and ISO 14044. Recapitulated, LCA compromises the compilation and evaluation of material and energetic inputs and outputs in additional to (potential) environmental impacts of a certain product (e.g. packaging) or process, and considers not only certain conditions, but the entire life cycle. This cycle covers the stages raw material extraction and acquisition, energy and material production, manufacturing, use, end of life treatment and final disposal. Moreover, when conducting an LCA, it is further of the utmost importance to allow full traceability by giving information on the intention for carrying out the study, system boundaries, assumptions, data quality, data sources and allocation procedures. In the case of a fully executed LCA, a mandatory critical review further ensures reliability and scientific validity of the results (ISO, 2006). A considerable amount of literature has been published on LCA (Chen, Yang, Yang, Jiang & Zhou, 2014; Estrela, 2015; McManus & Taylor, 2015). In-depth information on how to set up an LCA can be found elsewhere and is not part of this review. Standard textbooks, for example, are provided by Klöpffer and Grahl (2014) and Guinée, de Bruijn, van Duin and Huijbregts (2004). There are also several software solutions currently available on the market, which facilitate the execution of a full LCA. The most commonly known and used are GaBi, SimaPro, Umberto and openLCA (Lüdemann and Feig, 2014). It is important to note, that these software solutions allow the use of several impact assessment methods and the integration of different Life Cycle Inventory databases, which can cause divergent results to some extent (European Commission, 2010, thinkstep, 2017; ecoinvent, 2017). In particular, in the field of packaging, a considerable number of LCAs have been conducted with, in some cases, far-reaching consequences. A specific example is the comparative LCA in the field of beverage packaging, commissioned by the German Federal Ministry for the Environment, which was the basis for the German deposit system on disposable packaging (single-use deposit) (Schonert et al., 2002). Despite the meaningful results of a fully executed LCA, the broad application of LCA is frequently hampered by several factors. These are primarily the extensive data acquisition and preparation as well as the herewith associated cost intensive undertaking of such an analysis. Additionally, expert knowledge is mandatory, which in combination with the aforementioned factors causes particularly small and medium enterprises to outsource such activities to consultants and technical offices (The Consumer Goods Forum, 2011).

2.2. Simplified (or Streamlined) LCA (SLCA)

Against the above mentioned background, a growing demand for easy to use SLCA tools, which can be used without extensive training, is perceptible worldwide. This is, for instance, underlined by the United Nations Environment Programme (UNEP) report “An Analysis of Life Cycle Assessment in Packaging for Food & Beverage Applications”, which points out that a detailed LCA may not be required for every type of decision to be made about packaging design, manufacturing or governmental policy making. This emphasizes the importance of a qualitative consideration of the broader life cycle in decision making and SLCA tools for directional analyses (Flanigan et al., 2013). Over recent decades, innumerable SLCA tools have entered the market to accompany these developments. Rousseaux et al. (2017), for example, reviewed and categorized 629 eco-design tools and developed an "Eco-tool-seeker".

Regarding packaging, there are several available tailor-made SLCA tools available, for example PackageSmart, COMPASS, Bilan Environnemental des Emballages (BEE) or Packaging Impact Quick Evaluation Tool (PIQET). These tools allow the analysis of all life cycle stages of a product. However, the possibilities to customize and create new Life Cycle Inventory datasets are limited. Another drawback, when compared to full LCA tools such as GaBi, is that highly complex product systems cannot be modeled or assessed and that the number of impact assessment methods and indicators is limited. Thus, the inevitable trade-off between accuracy and user-friendliness has to be kept in mind when considering the use of an SLCA tool. For example, SLCA tools offer the possibility to easily gain LCA information easily and on the basis of this support decision making. The benefit of such tools is, therefore, always closely related to the accuracy needs and the particular decisions to be supported (Verghese et al., 2010).

Throughout the stage of product design, SLCA information about the impacts of various materials, processes and life cycle phases can be used in refining the product design. This approach is also known as *"eco-design"* (Hetherington, Borrion, Griffiths & McManus, 2014; Rodrigues, Pigosso & McAloone, 2017). At this stage, the application of a full LCA is not appropriate, since the final product details are not yet known and the costs involved would be prohibitive.

SLCA tools typically use pre-defined LCA-steps prompting only for inputs which are easily obtainable (The Consumer Goods Forum, 2011). Simplification occurs at the level of Life Cycle

Inventory and/or Life Cycle Impact Assessment leading to reduction of the complexity of the modeling process, the data collection efforts and the set of impact categories while facilitating the communication of the results (Arzoumanidis, Salomone, Petti, Mondello & Raggi, 2017).

The SLCA tools reviewed in the present publication are consistently web-based tools with a high degree of user-friendliness. Generally only a basic understanding of life cycle thinking is needed to obtain meaningful results. A good understanding of the assessed product system, however, remains a prerequisite. In most cases, the user interface allows the creation and management of projects, for which certain properties can be specified and they often allow for a general comparative assessment of different scenarios or assumptions. Within a brief period, usually less than a day, a non-LCA-specialist can learn to model packaging systems, compare scenarios and make an environmental impact assessment. Video tutorials as well as free trial versions are available.

The following subsections focus on certain of the SLCA tools used in the context of packaging. A compilation thereof is depicted in Table 2 and the applied method for comparison was testing trial versions.

2.2.1. Packaging Impact Quick Evaluation Tool (PIQET)

The goal of PIQET is to determine the potential environmental impacts associated with the packaging system of a packaged consumer good. Users can create a project, name it and model a packaging system inside this project. The functional unit selected for analysis in PIQET is one kilogram of product on a pallet (packed, including the packaging end-of-life) delivered to a retailer. The modeling of the packaging system consists of assigning certain materials, manufacturing processes, transport and end-of-life scenarios to the different levels of the packaging system. Interestingly, PIQET uses a classification of packaging levels which differs from the standard nomenclature. In PIQET there are five packaging levels. Sub-retail and retail unit correlate with the conventionally known primary packaging, merchandising unit with secondary packaging, and traded unit with tertiary packaging. PIQET allows one to conduct a simplified cradle-to-grave LCA. It is possible to vary the recycled content of the packaging material and to analyze different end-of-life scenarios. There is only one impact assessment method implemented in PIQET (with 19 different indicators for categories such as global warming, ozone depletion, land use etc.). The different life cycle stages, which can be assessed in PIQET include material, conversion, filling, wholesale, retail, consumer and end-of-life. Reports and charts with the impact assessment results can be easily generated. In PIQET, simplification takes place at the level of Life Cycle Inventory and Life Cycle Impact Assessment (Life Cycle Strategies Pty Ltd, 2017). An overview of PIQETs functionalities is given by Verghese et al. (2010).

2.2.2. PackageSmart

PackageSmart was developed to allow packaging engineers to rapidly assess new and existing package designs. It is owned by the company EarthShift Global LLC and the structure differs slightly from PIQET. After creating a project, a “package” is defined. The package is the whole system, including primary, secondary and tertiary packaging. The package consists of assemblies, the assemblies themselves consist of subassemblies, and the subassemblies are composed of inventories. An assembly could be, for example, a PET bottle with cap and label. A subassembly could be the PET bottle, which consist of inventories such as polyethylene terephthalate, moulding etc. The assemblies can be assigned to the different packaging levels (primary, secondary, tertiary). A functional unit has to be defined, which is called “Consumer Meaningful Unit of Measure”. PackageSmart allows one to conduct a simplified cradle-to-grave LCA. It is possible to vary the recycled content of the packaging material and to analyze different end-of-life scenarios. The user can choose between various impact assessment methods. Alongside with different LCA indicators, the cube efficiency (percent of volume in a transport unit occupied by the product) of the packaging can be calculated. Reports and charts depicting the impact assessment results can be easily generated. In PackageSmart, simplification occurs only at the level of life cycle inventory, but not at the level of life cycle impact assessment, due to the fact that the user has to choose between different impact assessments methods (EarthShift Global LLC, 2017).

2.2.3. Comparative Packaging Assessment (COMPASS)

COMPASS stands for COMparative Packaging ASSessment. It was developed by the Sustainable Packaging Coalition and is owned by the company TRAYAK LCC. The structure is similar to PIQET and PackageSmart, although the terminology differs. In the project, one can specify primary, secondary and tertiary packages. The three levels of packages can be combined into one packaging system. Each package consists of components. The components consist of inventories. A component could be, for instance, a plastic bag, and inventories would be in this case the plastic material used (e.g. low-density polyethylene) and the conversion process (e.g. film extrusion). COMPASS does not only allow for the assessment of life cycle metrics (for example: green house gas (GHG) emissions, aquatic toxicity etc.), but also the calculation of so called “non-life-cycle based attributes”, including recycled content, sourcing (percentage of certified raw materials) and solid waste. It is also possible to assess health issues. The program checks the packaging for materials of concern. There are three different categories for these materials: C (carcinogen), R (reproductive toxicant) and PBT (persistent, bioaccumulative and toxic). Three lists of substances of concern are integrated into COMPASS (Annex 1 to 6 of the EU REACH regulation, the Toxic Substances Control Act Concern List published by the US EPA and the list of the Californian

Authorities). In COMPASS, simplification takes place at the level of Life Cycle Inventory and Life Cycle Impact Assessment (Trayak LLC, 2017).

2.2.4. Bilan Environnemental des Emballages (BEE)

BEE is a free-to-use online SLCA tool, which allows the modeling of packaging systems. Materials and processes can be assigned to primary, secondary and tertiary packaging. Distribution, which is called *"Downstream Transportation"*, can also be specified. BEE allows the calculation of six environmental impact indicators, namely global warming potential, abiotic resources depletion, air acidification, water consumption, fresh water as well as marine eutrophication. The datasets account mainly for the French industry, but it is also possibly to select, for example, electricity grid mixes for some other countries as well. Simplification takes place at the level of Life Cycle Inventory and Life Cycle Impact Assessment. The online tool is available in French and in English (Eco-Emballages, 2017).

2.2.5. Instant LCA Packaging™

Instant LCA Packaging™ is a web-based SLCA tool, which allows the user to compare eco-design scenarios for packaging. It was developed for non-expert users. The software is owned by the Intertek Group plc (Intertec Group plc, 2017). RDC Environment, an environmental consultancy, which was acquired by Intertec, offers services such as customization or database development for Instant LCA Packaging™ users (Business Wire, Inc, 2011). This software is not reviewed here, since no trial version is available.

2.2.6. IK-Eco-Calculator

This SLCA tool for the assessment of plastic packaging was developed by the German Industry Association for Plastic Packaging (IK Industrievereinigung Kunststoffverpackungen e.V.). The tool can be used by members of the association and is only applicable for the German industry

(Möller, Köhler & Moritz, 2016). This software is not reviewed here, since no trial version is available.

2.2.7. EasyLCA

EasyLCA is a software developed by Henkel to make product packaging more sustainable. The tool allows comparison between different packaging types. Their environmental impact can be analyzed during all life cycle stages (Henkel AG & Co KGaA, 2014). This software is not reviewed here, since no trial version is available.EcodEX®

The software EcodEX® is owned by the company Selerant. It is a user-friendly, web-based SLCA tool, which is not packaging-specific. Although, it allows the environmental impact assessment of all different types of consumer goods. The packaging can be easily modeled on the three levels primary, secondary and tertiary packaging. EcodEX® makes it possible to assess the product together with the packaging. It can be connected with existing Enterprise Resource Planning sytems. Five environmental indicators can be calculated, namely global warming potential, land use, water, ecosystem quality - impact 2002+ and non-renewable energy. It is based on the ecoinvent database (Selerant S.r.l., 2017).

2.3. Non-LCA software tools

There are several software tools on the market, which facilitate the evaluation of the environmental performance of packaging, although they do not follow the life cycle approach.

2.3.1. Superpac

Superpac is a packaging optimization software, which is owned by PCS Packaging Software Ltd. It can be extended with a CO_2 software module that can be used to calculate the carbon emissions generated by different packaging solutions (PCS Packaging Software Ltd., 2017). It is, technically speaking, not an SLCA tool, since only one indicator (carbon emissions) is assessed and it is not possible to model the full life cycle.

2.3.2. RecyClass

Plastic Recyclers Europe, a Brussels-based association of European plastic recyclers, developed this web-based tool, which evaluates the technical recyclability of the packaging given the current best available technology. The user will gradually approach a rating result by answering questions related to the package. A scale resembling the energy efficiency rating from "A" to "F" is used. A package easy to recycle will receive an "A" rating, while an "F" will indicate that incineration is the only feasible option. The RecyClass tool is only suitable for packaging which is made of plastic, is free from dangerous substances and does not consist of bio- or oxo-degradable plastics. This free-to-use online tool is easy to use and does not require expert knowledge (Plastic Recyclers Europe, 2017).

2.4. Scorecard

Next to LCA and SLCA, Scorecards offer the possibility to assess the achievement of certain ecological goals, such as improved recyclability or the reduction of greenhouse gas emissions. In doing so, scorecards can serve as a tool for implementing a sustainability strategy (Hansen & Schaltegger, 2017).

To measure certain achievements, one has to define indicators and metrics. An indicator represents an issue or characteristic an organization wants to measure. A metric is the method used to express an indicator. Metrics are often computational or quantitative, but can also be a qualitative assessment of an indicator. An example for an indicator would be "*greenhouse gas emissions"* and the corresponding quantitative metric would be *"x kg CO_2 equivalents per kg packaging"*. An example for an indicator with a qualitative metric would be *"chain of custody",* expressed with the answer *"unknown"* or *"known"* or *"source-certified"* (O'Dea, 2009). These indicators can be derived from an LCA but others, such as *"cube efficiency"* or *"recycled content"*, are easier to retrieve. The complexity of a scorecard depends on the choice of the indicators. The Consumer Goods Forum developed a guideline "Global Protocol on Packaging Sustainability 2.0" (subsequently abbreviated as GPPS) which gives an overview of relevant indicators and the corresponding metrics (The Consumer Goods Forum, 2011).Table 3 shows the GPPS indicators, which are relevant from an environmental point of view.

A scorecard for measuring the sustainability of packaging can be composed of the indicators listed in Table 3. Since the quality and significance of a scorecard is determined by meaningful and appropriate indicators, attention should be paid when it comes to selection thereof (The Consumer Goods Forum, 2011). Choosing too few or inappropriate indicators, for example, carries the risk of simplification and of overlooking of relevant environmental issues, while choosing too many indicators, holds the risk of excessive effort to complete the scorecard, which, ultimately, could decrease the acceptance of the scorecard. In general, scorecards are used for controlling company-internal goals and achievements, and also for communication and control of suppliers. A common example would be a retailer or a major company, which is interested in the way their suppliers address sustainability of their products (Wal-Mart Stores, Inc., 2006). The following subsections present a few examples for scorecards. These case studies have been chosen due to their typical setup and their scope.

2.4.1. Case Study: Woolworths

Woolworths Australia developed a scorecard to measure and control the reduction of the environmental impacts of packaging. Woolworths Australia is a signatory of the Australian Packaging Covenant and made the commitment to review all in-scope products (brand owned by

Woolworths) against Sustainable Packaging Guidelines (SPG). The SPG must be applied to all new and refurbished private label packaging. In the case of the Woolworths scorecard, most of the indicators concern material composition of the packaging. In most cases the metrics are simple YES or NO answers. Other important indicators are *"recycled content of packaging"*, *"responsible sourcing"* and *"recyclability of packaging"*. Suppliers of in-scope products (private labels, exclusive and controlled brands) have to prove their compliance to the SPG (Woolworths, 2011). Further information as well as the Woolworths scorecard and packaging sustainability guidelines can be retrieved from the Woolworths vendor website (Woolworths, 2017).

2.4.2. Case Study: Wal-Mart

In 2006, Wal-Mart released a packaging scorecard, which asks suppliers to provide information about greenhouse gas emissions, material value, product/packaging ratio, cube utilization, transportation, recycled content, recovery value, renewable energy and innovation. Suppliers have to register via the Wal-Mart Sustainability Hub and provide details. As of 2017 the packaging scorecard is embedded in the broader Sustainability Index (Wal-Mart, Inc., 2016). The "Sustainable Packaging Playbook" is a guidebook for suppliers to improve packaging sustainability. It focuses on three priorities, namely optimized design, source sustainability and recycling. Wal-Mart asks suppliers to improve their Sustainability Index score and provides an overview of sustainable packaging best practices (Wal-Mart, Inc., 2016).

2.4.3. Case Study: World Wide Fund for Nature (WWF)

The WWF developed a paper scorecard. This scorecard can be used by companies to ensure that their paper suppliers meet certain sustainability criteria. Overall the WWF paper scorecard consists of ten questions, structured in three sections. These sections are recycled fibre, virgin fibre as well as greenhouse gases, water pollution and waste. The supplier can choose between different various options and so gain points. The score from the single questions can be added to an overall result (WWF, 2007). Certain parts of the WWF paper scorecard are used by Nestlé (Nestlé, 2013).

3. Discussion

The present review aimed to compare the different methods available to assess the environmental impacts of packaging. The appropriate use of one of these methods depends on the company's environmental strategy and the defined goals. If a producer intents to attain a detailed understanding of a product, it is necessary to conduct a full, externally reviewed LCA. Also, if a company wishes to use the environmental data for external communication or for comparative assessment of different products, there is no way to bypass LCA. It is costly to conduct an LCA and requires expert knowledge. This limits the use of LCAs as an environmental assessment method.

SLCAs allow for a quick assessment of different packaging. The SLCA tools reviewed are particularly user-friendly. They are particularly valuable during the design process, due to the fact that different scenarios can easily be compared from an environmental point of view. It is important, however, to know the limitations of these SLCA tools since they only allow the modeling of standard packaging solutions. If, for example, new and innovative polymers are used as raw materials, they might not be representable in the SLCA tool. The underlying Life Cycle Inventory datasets cannot be modified, and detailed modeling of complex life cycles is not feasible. The user has to be aware of the risk of simplification and of the trade-off between accuracy and usability. The use of an SLCA tool does not replace a full LCA. Arzoumanidis et al (2017) reported that the assessment of the same product system, modeled with different SLCA tools, can lead to contrasting results, because of different databases, modeling assumptions and impact assessment methods. This finding implies that SLCA tools should be used only for internal scenario comparison. It is problematic to compare the environmental performance of different products calculated with different tools without a good understanding of the used methodology.

Scorecards are management tools to measure the achievement of defined goals. Typically, sustainability scorecards are forms, which have to be completed by contractors or suppliers of large companies. Time and effort depend largely on the selected indicators. If life cycle-indicators are part of the scorecard, then a quantitative assessment has to be made before completing the scorecard. Often, scorecards consist mainly of questions which are relatively easy to answer. Many companies use sustainability scorecards as an environmental management tool. The use of scorecards makes sense, if there is an environmental strategy with quantifiable and measurable goals behind it.

A serious weakness of the scorecard approach is that often the results of the different indicators are aggregated into one single environmental indicator, or, in the case of Wal-Mart, into an overall sustainability score. From a scientific point of view it is problematic because the aggregated result cannot be validated (Carroll, 2007). The weighting of the different indicators always implies a certain degree of subjectivity and is based on more or less robust assumptions (Ahlroth, 2014). The European Organisation for Packaging and the Environment (EUROPEN) criticized the Wal-Mart approach because of flaws in the data and logic. EUROPEN led a lobby in Brussels against a European Parliament proposal for a “Packaging Environmental Indicator” (Carroll, 2007).

The increasing number of tools makes the choice of the most appropriate tool more difficult for companies, resulting in a growing demand for classification of the tools and guidance (Rousseaux et al., 2017). Additionally, the rapid growth in “similar-but-different” tools raised concerns among member states of the European Union, since the proliferation of methods and approaches makes it unnecessarily complicated and expensive to make environmental claims regarding the environmental performance of products. Therefore, the member states mandated the development of a European method for the calculation of the environmental footprint of products to the European Commission (Galatola & Pant, 2014). This approach is called Product Environmental Footprint or PEF. The PEF is a multi-criteria measure of the environmental performance of a good or a service throughout its life cycle. Product Environmental Footprint Category Rules (PEFCRs) include specific rules, guidelines and requirements that aim to develop "type III environmental declarations" for any product category. "Type III environmental declarations" are quantitative, LCA-based claims of the environmental aspect of a certain good or service (European Commission & Joint Research Center, 2012). To date, working groups with stakeholders from industry, academia and administrative bodies are developing PEFCRs. PEFCR will not only define the calculation methods, but also prescribe the use of certain background datasets. PEFCR drafts for many different product categories have been submitted to the European Commission, but to date they have not yet been approved (European Commission, 2017). Additionally, there is a PEF Packaging Working Group, which was set up to provide guidance on packaging related modeling and data issues in the ongoing PEF pilot phase (European Commission, 2016). Elaborated PEFCRs would open up the possibility of developing PEF compliant software tools for different product categories, including packaging. Perhaps, the Product Environmental Footprint (PEF) initiative will bring more harmonization into the confusing LCA landscape, although Finkbeiner (2014) raised serious concerns about this issue. According to Finkbeiner, there is a risk that the PEF will end up such as many other "footprint" initiatives and even increase the confusion and proliferation. It has to be stated, that some of the critical issues have been addressed during the pilot phase.

The results of this review show that the choice of the “right” tool largely depends on the questions asked, on the position in the packaging value chain and on the available resources of the organization (The Consumer Goods Forum, 2011).

Another important finding is that the selection of appropriate indicators is of utmost importance, regardless of the method (LCA, SLCA or Scorecard) used. If, for example, a packaging scorecard focusses on recycling indicators alone, there is a risk of ignoring important environmental issues. For some materials such as aluminum, recycled content is a clear winner over virgin content from an environmental perspective since both scrap collection and reprocessing require far less energy than virgin content production. For others, the outcome is not as clear-cut, either due to the use of renewable energy in virgin material production, inefficient material recovery systems, or due to other reasons (Hermes, 2014). An exclusive focus on carbon emissions implies the risk of shifting the environmental burden from global warming to other environmental impact categories (Finkbeiner, 2009). This finding is supported by a number of studies, which have found that the production of biofuels results in shifting the environmental burden of greenhouse gas emissions to land use change and eutrophication (Taheripour & Tyner, 2012; González-García & García-Rey, 2013).

The choice of indicators should be guided by the general principles of sustainable packaging. Several studies and guidelines have been published on this topic (e.g. Verghese et al., 2012; Jedlicka, 2009; Australian Packaging Covenant, 2010). The indicators themselves also need further development. In the case of packaging, the environmental impact category of marine littering has become a very serious concern, but there is no quantitative indicator to characterize the contribution of a packaging to marine littering.

4. *Conclusion & Recommendations*

This review has given an account of and the reasons for the widespread use of packaging-specific environmental assessment tools in industry. The use of these tools is likely to increase during the coming years. In the EU, a certain harmonization can be expected due to the development of the PEF.

Several limitations to this review need to be acknowledged. Not all of the available packaging-specific SLCA tools could be tested, since trial versions were not available in some cases. The scorecards were reviewed only on the basis of a few examples, since the majority of packaging scorecards are used internally and are, therefore, not publicly available.

In a future investigation, the results of the above-mentioned tools for the life cycle of a given packaging system should be directly compared. Further research should be undertaken on new, polymer-based, packaging materials which hold an increasing share of the market, since there is a lack of complete and up-to-date datasets for environmental assessment tools. Further studies should focus on the selection of the most meaningful environmental indicators for packaging solutions and on the refinement of these indicators. Last but not least, the impact of the PEF initiative shall be closely observed and particularly the results of the PEF Packaging Working Group will have the highest relevance for both packaging and sustainability professionals in Europe.

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Conflict of interest

The authors declare to have no conflict of interest.

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TABLE 1 Overview of the three principal methods to assess environmental impacts of packaging, adapted from GPPS (The Consumer Goods Forum, 2011).

Method for the assessment of packaging	**Application field**	**Advantages**	**Drawbacks**
Full LCA (LCA)	A detailed assessment of a product, which can be used for marketing purposes.	Robustness, flexibility Can support marketing claims after external peer review	More costly and long, requires expert knowledge
Streamlined LCA (SLCA)	SLCA can be used as a supportive tool during the design phase.	Quick, low cost,consistent, can be used by non-experts	Low flexibility No capacity to capture specificities Limited possibility to support environmental claims
Scorecards	Management tool to control the suppliers compliance to certain sustainability criteria	Allows retailers and big companies to easily compare their suppliers	Risk of over-simplification Important sustainability aspects might be overlooked, if inappropriate indicators have been chosen

TABLE 2 Overview of reviewed packaging-specific SLCA tools

Software solution	Underlying databases	Impact assessment methods	Life cycle stages	References
Packaging Impact Quick Evaluation Tool - PIQET	Ecoinvent Australia LCA Database BUWAL 250 ETH-ESU 96 IDEAMAT IVAM Database	Australian impact assessment method developed by RMIT University Melbourne	- Material - Conversion - Filling - Wholesale - Retail - Consumer - End-of-Life	Life Cycle Strategies Pty Ltd, 2017 Verghese, Horne, Carre, 2010
PackageSmart Life Cycle Assessment Software	Ecoinvent US LCA database	CML EDIP 2003 EPD (2013) IPCC TRACI	- Materials - Conversion - Distribution - End-of-Life	EarthShift Global LLC, 2017
COMPASS - Comparative Packaging Assessment	Ecoinvent US LCI	Life cycle metrics developed by the Sustainable Packaging Coalition (SPC)	- Manufacture - Conversion - Distribution - End-of-Life	Trayak LLC, 2017
BEE - Bilan Environnementat des Emballages	Ecoinvent PlasticsEurope SYPAL	Six indicators, preselected and partly developed by Eco-Emballages	- Material production - Manufacturing - Transportation - End-of-Life	Eco-Emballages, 2017

TABLE 3 Packaging sustainability indicators and the corresponding metrics as proposed by GPPS (The Consumer Goods Forum, 2011).

Indicator	Metric
NON-LCA Environmental Attributes	
Packaging Weight and Optimization	Weight per packaging constituent, component or system and demonstration of optimization as described by EN 13428 or ISO/CD 18602.
Packaging-to-Product Weight Ratio	Weight of all packaging components used in the packaging system per functional unit.
Material Waste	Mass per packaging constituent, packaging component, or packaging system.
Recycled Content	Recycled material share of total quantity of material used per packaging constituent, packaging component or packaging system.
Renewable Content	a) The percent by weight an the material level according to the amendment to ISO 14021. b) The percent by weight on carbon level according to ASTM D6866.
Chain of Custody	Unknown, known or sourced-certified.
Assessment and Minimization of Substances Hazardous to the Environment	Meeting the requirements of EN 13428 or ISO 18602 on heavy metals and dangerous/hazardous substances.
Production Sites Located in Areas with Conditions of Water Stress or Scarcity	Number or percent of facilities located in an area identified as a stressed or scare water resource area.
Packaging Reuse Rate	a) Reusable – Yes or No according to EN 13429 or ISO/CD 18603. b) Average Reuses
Packaging Recovery Rate	a) Recoverable – Yes, meeting criteria or No. b) Recovery rate [% wt.] with respect to total weight of packaging placed on the market per recovery option.
Cube Utilization	Percent of volume in a transport unit occupied by the product (%).
Life Cycle Indicators - Inventory	
Cumulative Energy Demand (CED)	CED = Cumulative Energy Demand Renewable + Cumulative Energy Demand Nonrenewable [MJ/FU].
Freshwater Consumption	Volume of fresh water consumed per functional unit [m3/FU].
Land Use	[m2 × years / FU] calculated as the sum of all elementary flows of the type land occupation at the inventory level.
Life Cycle Indicators - Impact	
Global Warming Potential (GWP)	Mass of CO_2 equivalents [kg CO2 eq/FU].

Ozone Depletion	Mass of CFC-11 equivalents [kg CFC-11 eq/FU].
Toxicity, Cancerous	Potential relative to a reference substance, e.g. [kg C_2H_3Cl eq/FU or kg C_6H_6 air eq/FU].
Toxicity, Non-Cancerous	Potential relative to a reference, e.g. toluene, expressed as mass equivalents, e.g. [kg toluene eq/FU].
Particulate Respiratory Effects	Mass of PM10 equivalents [kg PM10 eq/FU].
Ionizing Radiation	Mass of kg U235 equivalents [kg U235 eq/FU].
Photochemical Ozone Creation Potential (POCP)	Mass of non-methane volatile organic compound equivalents [kg NMVOC eq/FU].
Acidification Potential	Mass of SO_2 equivalents [kg SO2 eq/FU].
Aquatic Eutrophication	Phosphorous equivalents in freshwater [kg P eq/FU]. Nitrogen equivalents in saltwater [kg N eq/FU].
Freshwater Ecotoxicity Potential	Ecotoxicity potential relative to a unit of mass of a reference substance, e.g. 1,4-Dichlorobenzene [kg 1,4 DB eq/FU].
Non-Renewable Resource Depletion	Relative to a reference substance e.g. a) kg antimony equivalents/FU or b) Person reserve [kg/FU].