Life Cycle Assessment (LCA): Discussion on Full-Scale and Simplified Assessments to Support the Product Development Process

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Abstract

The environmental impacts observed throughout a product life cycle are, to a large extent, determined during its development phase, especially on the initial stages of product development process. These stages are characterized by a high level of uncertainty, environmental performance improvement potential and by the unavailability of quantitative and detailed data of the product for performing full-scale LCAs, since it is still under development. Companies are more than ever recognizing the need for adopting a systemic view of the environmental impacts in the first stages of product development but, the complexity and slowness of full-scale LCA studies coupled with the lack of technical expertise of the designers to apply LCA, prevents the use of the results in the decision making process of product development. In order to overcome this problem, a large amount of ecodesign practitioners and academics has developed simplified methods and tools to assess the environmental impacts in the product life cycle. In this context, the main goal of this study is to discuss the use of full-scale and simplified LCA in product development process context and present an overview of the so called simplified LCA, obtained during a systematic literature review on ecodesign methods and tools.

Keywords: *Life Cycle Assessment (LCA), Simplified Life Cycle Assessment (S-LCA), Ecodesign, Product Development Process (PDP).*

1 Introduction

Over the years, it become clear that the state of the environment in some areas has improved locally, but the general picture is still bleak and getting worse as regards the more regional and global impacts (Hauschild et al., 2005). Industry has a key role to play in this scenario, particularly concerning the environmental improvement of products (goods or services).

According to the Commission of the European Communities (2001), products are fundamental to the wealth of our society and the quality of life we all enjoy. The rising consumption of products, however, is directly or indirectly also the source of most of the pollution and depletion of resources our society causes'. Products affect the environment at many points in the value chain from raw material extraction to waste management, and these environmental effects result from interrelated decisions made at various stages of a product's life cycle (Baumann et al., 2002).

The environmental impacts observed throughout a product life cycle are, to a large extent, determined during its development phase (Graedel & Allenby, 1995). The integration of environmental factors into design is an emerging trend known as ecodesign, design for (the) environment (DfE) or life-cycle design (LCD).

Ecodesign is a proactive management approach which directs product development towards environmental impacts reduction along its life cycle, without compromising other criteria such as performance, functionality, aesthetics, quality and cost (Weenrn, 1995; Johansson, 2002). It can be defined as the systematic introduction of environmental concerns into the New Product Development (NPD) process throughout the application of specific methods (Baumann et al., 2002; Nielsen & Wenzel, 2002).

Methods and tools have been developed for integrating environmental considerations in the product development process. Many industries have developed their own schemes over the years, and throughout the 1990'ies a number of publicly funded methodology projects had the aim of developing more generally applicable approaches to design for environment (Hauschild et al., 2005).

When optimizing the environmental performance of whole systems instead of single elements, substantially higher improvements regarding environmental sustainability can be reached. In this sense, products have to be designed considering all phases of their life cycles (from raw material extraction to end of life), and the product development process should take into account the function delivered by the product (Vezzoli & Sciama, 2006). This key advantage of thinking in systems is required and promoted by Life Cycle Assessment (LCA) (Bey & McAloone, 2006).

LCA is gaining acceptance due to the hard task of helping industries in quantifying the environmental aspects and potential impacts of the life cycle of a product system. Although LCA methodological framework is established by the International Organization for Standardization – ISO (ISO 2006a; 2006b), which makes it an internationally accepted and adopted technique, full-scale LCA is also recognized to be complex, costly and highly quantitative especially during the initial stages of the product development process, when detailed information about the product is still not available and crucial decisions which defines the product environmental performance must be taken). Moreover, Vezzoli & Sciama (2006), in a survey conducted in 2000 with Italian design experts, highlighted a general lack of environmental competencies on staff; e.g. few design centers know what a Life Cycle Assessment (LCA) is and fewer are those who make use of it.

Thus, considering: (1) the need for adopting a systemic view of the environmental impacts in the first stages of product development,(2) unavailability of quantitative and detailed data on initial phases, (3) complexity and slowness of full-scale LCA studies, which prevents the results use in the decision making process of product development, and finally, (4) lack of technical expertise of the designers to apply LCA, the main goal of this study is to discuss the use of full and simplified LCA in product development process context and present an overview of the so called simplified LCA, obtained during a systematic literature review.

2 Methodology

The identification and classification of ecodesign methods and tools were obtained by means of a systematic literature review. The systematic review is the way by which the researcher can map the existing and previous developed knowledge and initiatives in a specific research area. Besides the analysis of previous discovery, techniques, ideas and ways to explore topics, the systematic review also allows the evaluation of information relevance to the issue, its synthesis and summarization (Biolchini et al, 2005; Brereton et al, 2007).

The phases of a systematic review correspond to problem formulation (identification of the goal of the review, target and context, beneficed areas and expected results), data collection (identification of the relevant databases, keywords and strings), data evaluation (application of the inclusion/exclusion criteria for the selection of the relevant studies and representation standardization), data analysis and interpretation (synthesis of the studies and definition of the criteria for classification) and presentations and conclusions (registration of the studies and methods and tools, analysis of the classification and determination of the state of the art) (Biolchini et al, 2005; Brereton et al, 2007)

The main goal of this systematic review was the determination of the state of the art in ecodesign methods and tools. The target of the systematic review, according to its context, can be explained by the non-achievement of the ecodesign potential benefits due to the lack of systematization of ecodesign methods and tools. It was obtained 560 studies, including papers, thesis, dissertations, publications, books and books reviews along the systematic review. It was made an initial studies selection, that was then analyzed according to the inclusion/exclusion criteria (studies that presented the development, application or review on ecodesign methods and tools). It was then performed a study review to certify that relevant studies has not been excluded. The valid studies were then analyzed in order to extract the relevant information about the ecodesign methods and tools.

As a result of the systematic literature review, 105 ecodesign methods and tools were identified and classified according to 13 criteria (Pigosso et al, 2010). A subset of 19 methods and tools, which includes the traditional full-LCA and the so called simplified LCA, will be presented in this paper.

3 Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is the globally recognised analytical tool for quantifying environmental impacts of the whole life cycle of goods and services. It evolves all successive stages of a product system, ranging from extraction of raw materials and energy needed to manufacture, use and distribution until the final disposition of the product, which may include recycling of materials and components, and other ways of treatments post-consumption (Azapagic, 1999). The LCA methodological framework is defined by ISO 14040 and 14044 standards (ISO 2006a; 2006b), which describe the minimum requirements for its use and performance.

The holistic system's perspective which is applied in LCA enables the company to disclose the 'problem shifting' which occurs when solutions to (environmental) problems at one place in a product's life cycle create new problems elsewhere in the life cycle (Hauschild et al., 2005).

Keoleian (1993) explores the practical application of life cycle assessment (LCA) to product system development, and, according to this author, many organizational and operational factors limit the integration of the three LCA components (inventory analysis, impact assessment and improvement assessment) with product development. He states that appropriate environmental information must be supplied to decision makers throughout each stage of the development process to achieve this goal and, LCA can serve as a source of this information, but informational requirements can vary as the design moves from its conceptual phase, where many design choices are possible, to its detailed design and implementation.

As demonstrated by Alting et al. (2007), the possibility to influence the environmental performance of a product is bigger in the product development stages, but in this stages the knowledge about the product is lower (quantitative information is not available) They also substantiate the need for both analysis (LCA) and synthesis tools which are applicable at the early stages of product development. Industry's efforts must be based on a combination of analytical tools for analyzing the impacts of products and focusing on the most important impacts, and synthesis tools for designing and developing new products with an improved environmental performance.

According to Manzini & Vezzoli (2002), auxiliary tools for sustainable design are evolving and expanding their potential and their effectiveness in relation to criteria for reducing the environmental impact in the whole life cycle of products. Among the guidelines listed by these authors is the integration of (more or less) simplified LCA to the phases of product development. The practical use of environmental LCA methods and software tools in industry has revealed the need for simplifications for many applications. Hence, streamlined life cycle assessment methods have been derived from experience with the complex full methods (Hauschild et al., 2005).

Simplified LCA (S-LCA), also known as Streamlined LCA, emerged as an efficient tool to evaluate the environmental attributes of a product, process, or service's life cycle (Graedel & Saxton, 2002).

The aim of simplifying LCA is to provide essentially the same results as a detailed LCA, i.e. covering the whole life cycle but in a superficial way (e.g. using qualitative and/or quantitative generic data), followed by a simplified assessment, thus reducing significantly the expenses and time expended. It should still include all relevant aspects, but good explanations can, to some extent, replace resource-demanding data collection and treatment (Schmidt & Frydendal, 2003). The assessment should focus on the most important environmental aspects and/or potential environmental impacts and/or stages of the life cycle and/or phases of the LCA and give a thorough assessment of the reliability of the results (Christiansen et al., 1997).

Full-scale LCA is traditionally quantitative. However, it is recognized that where quantification is not possible (for reasons of time or cost, for example), qualitative aspects can - and should - be taken into account (Guinée, 2001). According to Graedel & Saxton (2002), S-LCA is not meant to be a rigorous quantitative determination, however, but rather a tool for identifying environmental 'hot spots' and highlighting key opportunities for effecting environmental improvements.

It is not complicated to apply quantitative and detailed LCAs to simple products, such as packaging, since they consist of few components or types of material and information on most of the commonly used materials is available (and, if necessary, it is easy and fast to collect it). But it not the same when complex products are in scene. For more complicated products, as a television, a complete LCA may prove to be very resource demanding and at the same time not very precise, because the number of possibilities is very high and the database on 'not so common' materials is limited and, in these cases, S-LCAs are more helpful, especially in the early stages of product development (Jensen et al., 1997). In the case of improvements in already existing product systems, the use of (full) LCA may become easier, once data from a reference system can be used (with a well-known life cycle).

Streamlined approaches and other ecodesign methods and tools, such as design checklists and matrixes, are essential. The practical use of these tools in product development also depends on the nature and complexity of the product system (e.g. new *vs.* established), the product development cycle (time-to-market constraints), availability of technical and financial resources, and the design approach (integrated *vs.* serial) (Keoleian, 1993). These factors influence the role and scope of LCA in the product development. Effective communication and evaluation of environmental information and the integration of this information with cost, performance, cultural and legal criteria will also be critical to the success of design initiatives based on the life cycle framework (Keoleian, 1993).

4 Ecodesign methods and Tools: Simplified LCA

This section presents the simplified LCA methods and tools identified during the systematic literature review, including a summary of how they work. It is important to notice that these methods and tools presents a life cycle perspective and provides an analysis or comparison of the environmental impacts associated to a product using or providing qualitative or semi-quantitative data (Table 1).

Table 1. Simplified LCA methods/tools

Ecodesign method/tool	**Summary**	**Criteria for assessment**	**Approach**
ABC Analysis (Byggeth & Hochschorner, 2006)	The tool is used to assess environmental impacts of a product. The product is evaluated on 11 different criteria and classified as: A (problematic, action required), B (medium, to be observed and improved), C (harmless, no action required).	Includes social requirements, environmental impact, environmental costs and risks of accidents	Qualitative
Green Design Tool(Kassahun et. al, 1995; Poyner & Simon, 1995)	The tool is based on analysing 'top level greenness attributes' of a product, providing to the designer an overview of the environmental status of product design. It can be applied using the basic concept of the product.	Reusability, label, internal joints, material variety, material identification, recycled content, chemical usage, additives, surface finishes, external joints and hazards level of material	Semi-quantitative
Design Abacus (Bhamra & Lofthouse, 2007)	Design Abacus can be used to rate a product on social, economic and environmental areas, in both the analysis and planning of a design. It helps you identify design goals, compare many design variables and compare different product designs across the product life-cycle.	Defined by the user (example: energy, material, usability, cost, life span, end of life)	Qualitative
DfE Matrix *(*Yarwood & Eagan, 1998)	The matrix provides an indicator to environmental impact of a product by the answer of 100 questions that address a wide range of design and environmental topics. The questions embraces the consideration of potential environmental impacts caused by the manufacture, use and disposal of the product. In addition, the matrix highlights areas of concern and provides manufacturers with ideas and options for resolving those environmental concerns.	Materials, energy use, solid residue, liquid residue, gaseous residue.	Semi-quantitative
Eco-Compass technique (Sun et. al, 2003)	Eco-Compass technique is used to evaluate the environmental impact of an existing product. Combining the cost and benefit, a product's life locus tree can be built up and the environmental impact of a product is assessed on the performance of process, life phases, and different life locations of a product using these eight indices.	Mass intensity, energy intensity, health and environmental potential risk, revalorization, resource conversation, and service extension	Semi-quantitative

ECODESIGN Checklist Method (ECM)(Wimmer, 1999)	The tool points out purposefully redesign tasks in order to increase the environmental performance of a product. Based on a holistic view of the product in three analysis levels (part-, function-, and product level) the method shows clearly, where the weak points of a product are and how to realize reuse, recycling of parts, where to integrate, omit or create functions and where to reduce consumption or increase efficiency, usability of the whole product.	Usability of product (customer's needs oriented), low consuming product (using phase), low resource consumption and avoiding waste (manufacturing phase),durable product, reuse of product-parts, recycling of product-materials	Semi-quantitative
Ecodesign Web (Bhamra & Lofthouse, 2007)	Ecodesign Web provides a quick way of helping designer to identify which areas of the product you should be focusing on to improve its environmental performance. It works by comparing seven design areas with each other to identify a 'better than'/ 'worse than' output.	Materials selection, materials usage, distribution, product use, optimal life, end of life	Qualitative
Eco-indicator 99 and Eco-it (PRé Consultants, 2000)	The Eco-indicator of a material or process is a number that indicates the environmental impact of a material or process, based on data from a life cycle assessment. The higher the indicator, the greater the environmental impact. The absolute value of the points is not very relevant as the main purpose is to compare relative differences between products or components. Eco-it is the tool used to calculate the Eco-Indicator.	Materials, production processes, transport processes, energy generation processes, disposal scenarios	Semi-quantitative
Eco-Products Tool(Namikawa, 2005)	It is defined as "Eco-Product" those products that achieve at least 2 on a scale of 0 to 5 for each of the eight criteria, as well as an average score of 3 or higher. The environmental efficiency index shows the value created while controlling environmental impacts and resource consumption.	Resource reduction, product longevity, resource recycling, ease of disassembly, ease of processing, environmental safety, energy conservation and provision of information	Semi-quantitative
Environmental Design Strategy Matrix (EDSM) Lagerstedt, 2003)	The matrix identifies some design strategies based on characteristics of products at the different life-cycle stages.	Life-cycle length, energy consumption, resource consumption, material requirement, configuration and disposal route.	Qualitative
Environmental Effect Analysis (EEA)(Lindahl, 1999)	The purpose of the EEA method is to identify and evaluate potential environmental impacts in all lifecycle phases of the investigated product in a systematic way. Furthermore the purpose also is to make that in an early phases of the design process in order to take corrective and preventive actions to minimize the environmental burden	Not defined (most significant environmental aspects)	Qualitative
Environmental Efficiency Potential Assessment method (E2-PA)(Nagata et al., 2001)	E2-PA is a decision making tool specifically designed to support eco-design of products. The conceptual basis came from Eco-Efficiency and is characterized by its assessment policy, which evaluates the environmental performance as the potential environmental impacts of the product.	Material intensity, energy intensity, hazardous material intensity, recovery intensity, duration intensity, utility intensity, waste intensity, pollution intensity	Semi-quantitative
Green Design Advisor (GDA) (Ferrendier et al, 2002)	The GDA tool provides a direction of improvement, as well as the design features with the highest improvement potential and shows	number of materials; mass; recycled content; recyclability; toxicity; energy use; time for	Semi-quantitative

	the weak points, as well as good design features. Additional design guidelines exist; however, there are no automatically generated design alternatives.	disassembly; disposal cost	
MECO Matrix (Hochschorner, 2003)	MECO provides an estimative of environmental impact to each phase of product life cycle. The information on the studied product/ system is first structured in the MECO chart. The analysis with the chart can be followed by a more detailed LCA, making a gradual evaluation of the product. All inflows and outflows must be considered for one category at a time based upon the functional unit and the chosen life cycle phase.	Materials, Energy, Chemical and Others	Semi-quantitaive
MET Matrix ((Byggeth & Hochschorner, 2006)	The purpose of the tool is to find the most important environmental problems during the life cycle of a product, which can be used to define different strategies for improvement. The environmental problems should be classified into the categories	Material cycle (M), Energy use (E), Toxic emissions (T)	Qualitative or Quantitative
Methodology based on MCDM techniques to Identifying the greatest environmental impact value (Bastante-Ceca et al, 2006)	The method help to identify the life cycle stage with the highest environmental impact value, where ecodesign principles should be successfully applied, improving the accuracy of tools such as matrices without going as far as the complexity of tools such as the Life Cycle Assessment.	Not defined	Semi-quantitative
Philips Fast Five Awareness (Byggeth & Hochschorner, 2006)	The tool is used to judge and compare different product concepts towards a reference product.	energy, recyclability, hazardous waste content, durability/reparability/preciousness, alternative ways to provide service.	Qualitative
The Environmentally Responsible Product Assessment Matrix (ERPA) (Hochschorner, 2003)	The central feature of ERPA assessment is a 5x5 matrix. One dimension is the life cycle stages and the other is environmental concern. The method can be used to evaluate products, processes, facilities, services or infrastructure. Each element of the matrix is assigned a rating from 0 (highest impact) to 4 (lowest impact), according to a checklist. The rating is based on the seriousness but also on whether possibilities of reducing impacts have been utilized or not.	Materials choice, energy use, solid residues, liquid residues and gaseous residues	Semi-quantitative

5 Final Remarks

Designing products with better environmental performance is a necessary action for industries to ensure competitive and environmental advantages. However, the systematic incorporation of environmental considerations during product development process (ecodesign) is not an easy task, especially in the early stages, in which there is a lack of information about the product (but the degrees of freedom to take actions for improvements are greater).

LCA is a technique developed to study the environmental influence of a product system. However, in some cases, as for complex products, the application of full LCA is hampered by several factors, including lack of data and other resources. Time is also a factor that prevents the application of LCA during the first stages of the product development process (PDP).

In order to overcome the difficulties for applying full-scale LCA during PDP, it was developed a large amount of Ecodesign methods and tools to support the simplified assessment of the life cycle environmental impacts, called S-LCA. In this paper, it was presented 19 simplified LCA ecodesign methods and tools which were identified during a systematic literature review. A general summary of the method or tool were provided, including the criteria used for the assessments and the approach adopted.

A survey on the effective use of these methods and tools by industry should be conducted in future works. Databases development, especially for Brazil, is of great value to facilitate and promote LCA performance for decision-making purposes concerning products.

Extreme improvements towards sustainable products can be explored by the incorporation of services in the economy, and, in this sense, broadening the application of S-LCA to Product-Service Systems is a tendency to be researched.

6 References

Alting, L., Hauschild, M., Wenzel, H., 2007. Life Cycle Engineering and Management. In: Seliger, G. (Ed.), Sustainability in Manufacturing: recovery of resources in product and material cycles. Springer-Verlag, Berlin, pp. 31-67.

Azapagic, A., 1999. Life cycle assessment and its application to process selection, design and optimization. Chemical Engineering Journal 73, pp. 1-21.

Baumann, H., Boons, F., Bragd, A., 2002. Mapping the green product development field: engineering, policy and business perspectives. Journal of Cleaner Production 10 (5), pp. 409-425.

Bey, N., McAloone, T., 2006. From LCA to PSS: Making leaps towards sustainability by applying product/service-system thinking in product development. Proceedings of the 13th CIRP International Conference on Life Cycle Engineering (LCE 2006).

Bhamra, Tracy; Lofthouse Vicky. 2007. Design for sustainability: a practical approach. Gower Publishing, England.

Biolchini, J.; Mian, P. G.; Natali, A. C. C.; Travassos, G. H, 2005, Systematic Review in Software Engineering. Rio de Janeiro.

Brereton, P.; Kitchenham, B. A.; Budgen, D.; Turner, M.; Khalil, M., 2007, Lessons from applying the systematic literature review process within the software engineering domain. In: The Journal of Systems and Software.

Byggeth, S.; Hochschorner, E., 2006. Handling trade-offs in Ecodesign tools for sustainable product development and procurement. Journal of Cleaner Production, 14, 1420-1430.

Christiansen, K. (Ed.), 1997. Simplifying LCA: Just a cut? SETAC, Brussels.

Commission of the European Communities, 2001. Green paper on integrated product policy. http://eur-lex.europa.eu/LexUriServ/site/en/com/2001/com2001_0068en01.pdf Last accessed January 2011.

E. Hochschorner and G. Finnveden, 2003. Evaluation of two simplified life cycle assessment methods, Int J LCA **8**, pp. 119–128

Ferrendier, S., Mathieux, F., Rebitzer, G., Simon, M., Froelich, D., 2002. Ecodesign Guide (ECOLIFE Thematic Network) - Environmental Improved Product Design Case Studies of the European Electrical and Electronics Industry.

Graedel, T., Saxton, E., 2002. Improving the Overall Environmental Performance of Existing Telecommunications Facilities. International Journal of Life Cycle Assessment 7 (4), pp. 219-224.

Graedel, T.E., Allenby, B.R., 1995. Industrial ecology. Prentice Hall, New Jersey.

Guinée, J., 2001. Life Cycle Assessment: An operational guide to the ISO standards.http://cml.leiden.edu/research/industrialecology/researchprojects/finished/new-dutch-lca-guide.html Last accessed January 2011.

Hauschild, M., Jeswiet, J., Alting, L., 2005. From Life Cycle Assessment to Sustainable Production: Status and Perspectives. CIRP Annals - Manufacturing Technology 54 (2), pp. 1-21.

ISO – International Organization for Standardization. ISO 14040: Environmental management – Life cycle assessment – Principles and framework. Geneva: ISO copyright office, 2006a.

ISO – International Organization for Standardization. ISO 14044: Environmental management – Life cycle assessment – Requirements and guidelines. Geneva: ISO copyright office, 2006b. 47p.

Jensen, A.A., Hoffman, L., Møller, B.T., Schmidt, A., 1997. Life Cycle Assessment: a guide to approaches, experiences and information sources. dk-TEKNIK Energy & Environment, Denmark.

Johansson G., 2002. Success factors for integration of ecodesign in product development. Environmental Management and Health 13 (1), 98-107.

Kassahun, B.; Saminathan, M.; Sekutowski, J.C., 1995. Green design tool, Electronics and the Environment, 1995. ISEE., Proceedings of the 1995 IEEE International Symposium on ,118-125.

Keoleian, G.A., 1993. The application of life cycle assessment to design. Journal of Cleaner Production 1 (3-4), pp. 143-149.

LAGERSTEDT, J. 2003. Functional and enviromental factors in early phases of product development - Eco Functional Matrix. Kungliga Tekniska högskolan. [S.l.].

M. Lindahl, 1999. E-FMEA - A New Promising Tool for Efficient Design for Environment, ecodesign, pp.734, First International Symposium on Environmentally Conscious Design and Inverse Manufacturing.

Manzini, E., Vezzoli, C., 2002. O desenvolvimento de produtos sustentáveis: os requisitos ambientais dos produtos industriais. EDUSP, São Paulo.

Nagata, K.; Nohtomi, M.; Aizawa, M.; Asaoka, K.; Usami, C.; 2001. The development of the Environmental Efficiency Potential Assessment method, Environmentally Conscious Design and Inverse Manufacturing, 2001. Proceedings EcoDesign 2001: Second International Symposium on , vol., no., pp.820-825.

Nielsen, P.H., Wenzel, H., 2002. Integration of environmental aspects in product development: a stepwise procedure based on quantitative life cycle assessment. Journal of Cleaner Production 10 (3), pp. 247-257.

O. Namikawa, 2005. Development of the evaluation tool that integrate "Design for Environment" and "Eco-efficiency" at Hitachi," ecodesign, pp.240-241, 2005 4th International Symposium on Environmentally Conscious Design and Inverse Manufacturing.

Pigosso, D. C. A.; Rozenfeld, H.; Seliger, G. 2010. Ecodesign Maturity Model: criteria for methods and tools classification. Global Conference on Sustainable Manufacturing. Abu Dhabi.

Poyner, J.R.; Simon, M., 1995. Integration of DFE tools with product development, Clean Electronics Products and Technology, 1995. (CONCEPT), International Conference on , 54-59.

PRé Consultants, 2000. Eco-indicator 99 Manual for Designers", Ministry of Housing, Spatial Planning and the Environment, The Hague, The Netherlands.

Schmidt, A., Frydendal, J., 2003. Methods for calculating the environmental benefits of 'green' products. In: Erdmenger, C. (Ed.). Buying into the environment: experiences, opportunities and potential for eco-procurement. dk-TEKNIK Energy & Environment, Denmark.

Sun, J., Han, B., Ekwaro-Osire, S., and Zhang, H.-C., 2003. Design-for-Environment: Methodologies, Tools, and Implementation, Integrated Design and Process Technology, Austin, Texas, pp. 375-386.

Vezzoli, C., Sciama, D., 2006. Life Cycle Design: from general methods to product type specific guidelines and checklists – a method adopted to develop a set of guidelines/checklist handbook for the eco-efficient design of NECTA vending machines. Journal of Cleaner Production 14 (15-16), pp. 1319-1325.

Weenrn, J.C., 1995. Towards sustainable product development. Journal of Cleaner Production 3 (1-2), pp. 95-100.

Wimmer, W.; 1999. The ECODESIGN checklist method: a redesign tool for environmental product improvements, Environmentally Conscious Design and Inverse Manufacturing, 1999. Proceedings. EcoDesign '99: First International Symposium On , vol., no., pp.685-688.

YARWOOD, J. M.; EAGAN, P. D., 1998. Design for the Environment - Toolkit. Minnesota Office of Environmental Assistance. Minnesota, p. 72.