DTU Library

Characterization of the State-of-the-art and Identification of Main Trends for Ecodesign Tools and Methods: Classifying Three Decades of Research and Implementation

Pigosso, Daniela Cristina Antelmi; McAloone, T. C.; Rozenfeld, H.

Published in:
Indian Institute of Science. Journal

Publication date:
2015

Document Version
Publisher's PDF, also known as Version of record

Journal of the Indian Institute of Science
A Multidisciplinary Reviews Journal
ISSN: 0970-4140 Coden-JIISAD

REVIEWS

Characterization of the State-of-the-art and Identification of Main Trends for Ecodesign Tools and Methods: Classifying Three Decades of Research and Implementation

D.C.A. Pigosso[1]*, T.C. McAloone[1] and H. Rozenfeld[2]

Abstract | Ecodesign is a proactive management approach that integrates environmental considerations in product development and related processes (such as purchasing, marketing and research & development). Ecodesign aims to improve environmental performance of products throughout their life cycle, from raw material extraction and manufacturing to use and end-of-life. Over the last three decades, an intense development of new ecodesign methods and tools could be observed, but uptake by the industry remains a challenge. The purpose of this research is to perform a review of existing ecodesign tools and methods through a systematic literature review linked to bibliometric analyses, in order to explore the state of the art of ecodesign methods and tools and identify trends and opportunities in the field for the next decade.

1 Introduction

Products are essential for wealth of the society and for desired quality of life. However, the growing consumption of products is also directly or indirectly at the root of most of the pollution and depletion of resources society causes.[1] Every product, in some way or the other, causes environmental impacts, from the extraction of raw material and its production and use to the management and final disposal of waste.[2]

Ecodesign, a proactive approach to environmental management, involves the consideration of environmental issues in the product development process in order to minimize environmental impacts throughout the product's life cycle, without compromising other essential criteria such as performance, functionality, asthetics, quality and cost.[3,4]

In the last decades, several ecodesign methods and tools (any systematic way to deal with environmental issues during the product development process) were developed to evaluate environmental impacts, revealing potential problems and conflicts and facilitating the choice between different aspects through the comparison of ecodesign strategies.[2,5–8] Although several ecodesign methods and tools exist, they are still not used systematically in the development of new products.

The objective of this research is to perform a review of ecodesign tools and methods through a systematic literature review linked to bibliometric analysis, in order to explore the state-of-the-art of the ecodesign field and identify trends and opportunities.

The next section describes the methodology employed in the systematic literature review and bibliometric analysis. Section 3 describes the main results of the bibliometric analysis and is followed by Section 4, which discusses the major results in terms of the evolution of ecodesign methods and tools. Section 5 highlights the trends for ecodesign tools and methods in the next decade. Final remarks and conclusions are presented in Section 6, followed by the bibliographic references.

Environmental impacts: Changes to the environment, whether adverse or beneficial, wholly or partially, resulting from an organization's activities, products or services.

Ecodesign: Approach that integrates environmental considerations into product development in order to minimize environmental impacts across the product's life cycle.

Product's life cycle: Comprises the stages of a product life, often defined as raw material extraction, manufacturing, use & maintenance, and end-of-life.

[1]DTU, Denmark.
[2]USP, Brazil.
*danpi@dtu.dk

2 Methodology

Given the objective of exploring the state-of-the-art of ecodesign methods and tools, the research performed can be characterized as exploratory.[9] The main technical procedure employed in the research was a systematic literature review, which was combined with bibliometric analysis.

Exploratory research: Type of research adopted to explore a given research field. It often results in the development of concepts, classifications and definitions.

Research work involving systematic reviews follows a well-defined sequence of methodological steps, according to a previously developed protocol.[10,11] The systematic review model comprises three phases, namely: (1) planning (Section 2.1), (2) execution (Section 2.2), and (3) analysis of the results[11] (Sections 2.3). Bibliometric analysis was employed as a tool to support the analysis of the results.

2.1 *Planning*

The focus of interest of the systematic review, i.e. the research objective of the review, was the exploration of the state of the art of research dealing with ecodesign methods and tools.

Bibliometric analysis: Enables the observation of the state of science and technology through the overall production of scientific literature, at a given level of specialization (OECD, 1997).

The database selected in this review is the ISI Web of Science. The criterion employed to evaluate the data sources was their international scope in the area of research and availability of data for the bibliometric analyses.

The selection of keywords and logical terms was performed iteratively. To begin with, there was a set of 21 articles that were extracted from the initial keywords. As the review proceeded, new keywords emerged and were added to the initial set, resulting in new searches in the databases using the newly included keywords.

The main terms or keywords employed were: (“ecodesign” or ”eco-design” or “design for environment” or “sustainable product development” or “sustainable product design” or “life cycle design” or “life-cycle design” or “green product” or “green design” or “environmental product design” or “sustainable product development”) and (“tool” or “method” or “framework” or “model” or “technique” or “procedure” or “guideline”).

The results were refined based on three main criteria: language (English), type of study (journal papers) and knowledge areas (engineering, environmental sciences ecology, business economics, materials science and operations research management science).

The studies to be included in the scope of the review were selected by applying the study inclusion/exclusion criteria. The selected papers were the ones that presented the development of ecodesign methods and/or tools, case studies of their application, and review studies.

2.2 *Execution*

The execution phase (2) involves searching for studies in databases using the pre-established review protocol, developed in the planning phase (Section 2.1).

The identification of studies in the selected databases was carried out in May and June 2015 and resulted in a total of 530 journal articles. Applying the inclusion/exclusion criteria (presented in Section 2.1.3), 350 studies dealing with ecodesign methods and tools were selected. The articles that did not fulfill the inclusion criteria were then reviewed to ensure that no relevant articles were excluded.

2.3 *Analyses of the results*

The selected studies were synthesized by extracting the relevant information in combination with a bibliometric analysis.

Bibliometric analysis is currently applied to a wide variety of fields and its application in scientific research is increasing exponentially. In order to perform the bibliometric analysis, the VantagePoint bibliometric software was employed.

In addition to the bibliometric analyses, the 350 papers were divided and analyzed according to the publication year in four groups: 1) 1993–1995; 2) 1996–2000; 3) 2001–2005; 4) 2006–2010 and 5) 2011–2015. The main topics were identified based on the analysis of each individual paper. The analysis of the results (Phase 3) are presented in sections 3 (bibliometric results) and 4 (evolution of ecodesign methods and tools as a knowledge area).

While the literature review enables an understanding of the evolution of the knowledge area over time, it provides limited evidence on trends and future research topics. In order to identify the trends for ecodesign tools and methods, the understanding of the literature review was complemented by the authors’ tacit knowledge on the topic, their participation into conferences and related events (which often presents up to date research topics), accompaniment of political discussion in an international context and experience with ecodesign implementation in manufacturing companies. While this brings a high level of subjectivity, the authors believe the analysis can provide relevant insights to researchers in the field.

3 Bibliometric Results

This section presents the bibliometric results obtained in this research (Table 1).

3.1 *Number of papers per year*

In order to identify the evolution of the knowledge area over the years and its current relevance, the first analysis performed in this study was the annual distribution of the identified papers (Figure 1).

The values obtained indicate that there is a growing interest in developing and applying ecodesign methods and tools for the development of products with better environmental performance. The last 5.5 years (from 2010 to June/2015) account for 64.3% of the published papers over the last 22 years. The year with the highest amount of published papers is 2014, with 55 papers.

Based on the identified trend, it is expected that the number of papers will continuously increase in the coming years, indicating a continuous focus on the development of new methods and tools and their application in industry.

Table 1: Bibliometric analyses performed in this research.

Number of papers per year
Number of papers per author
Number of papers per Institution
Number of papers per Journal
Most used keywords
Most cited papers
Most cited references

3.2 *Number of papers per author*

The studies correspond to the work of 852 authors in total, which results in an average of 2.4 authors per paper. Figure 2 presents the 11 most productive authors of the sample of papers analyzed in this research.

Sixteen of the sixty papers by the 11 most productive authors were published in the Journal of Cleaner Production and five on the Journal of Engineering Design. In total, the papers were published in 20 different journals.

The distribution of the other authors in relation to the number of papers published are: 35 authors with 3 papers; 125 authors with 2 papers and 681 authors with 1 paper. With the increase in number of authors in the recent years, there is an indication of expansion of the knowledge area.

3.3 *Number of papers per Institution*

The sample of 350 papers selected in this research involve a total amount of 385 institutions. Figure 3 presents the 12 most influential institutions (with five or more papers in the sample).

From the 12 institutions, six are in Europe (3 in France, 2 in the United Kingdom and 1 in Denmark), five are in Asia (3 in Taiwan, 1 in Hong Kong and 1 in India) and one is in South America (Brazil).

An analysis of the full sample indicates that institutions from 44 countries were involved in the research. The papers published in the analyzed sample per country are presented in Table 2.

An analysis of the most popular journals for each country shows that while the Journal of Cleaner Production is the most popular one for

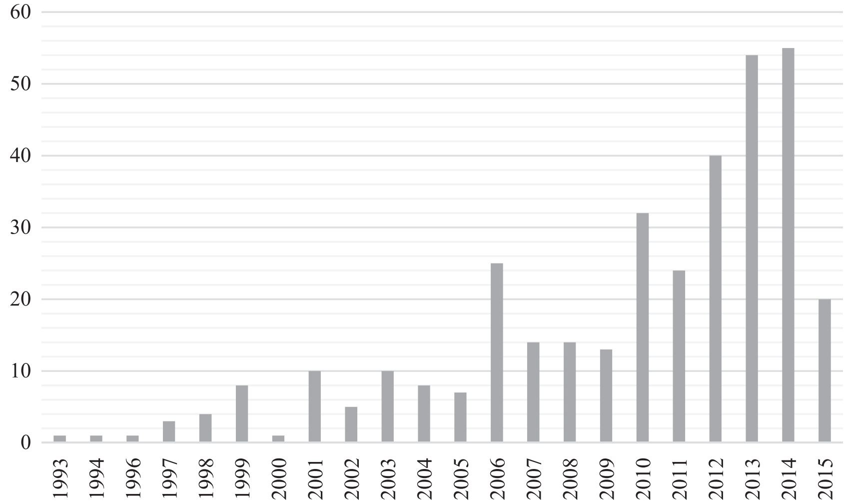

Figure 1: Annual distribution of selected papers.

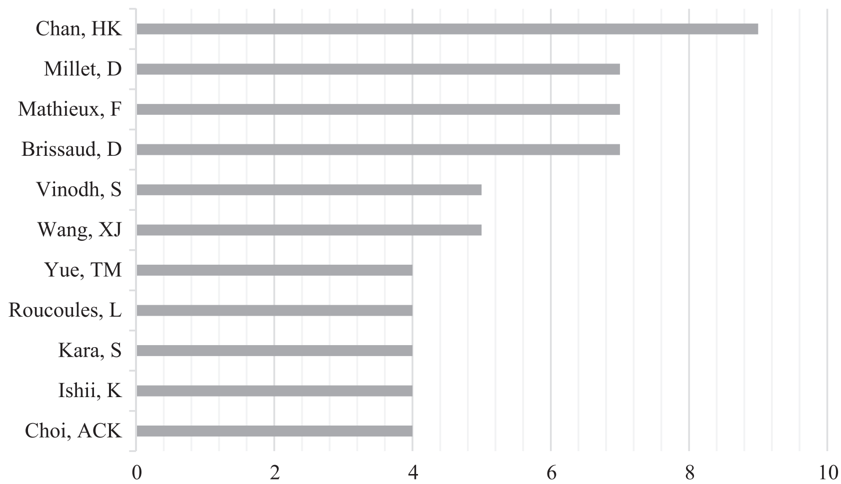

Figure 2: Most productive authors in the analyzed sample.

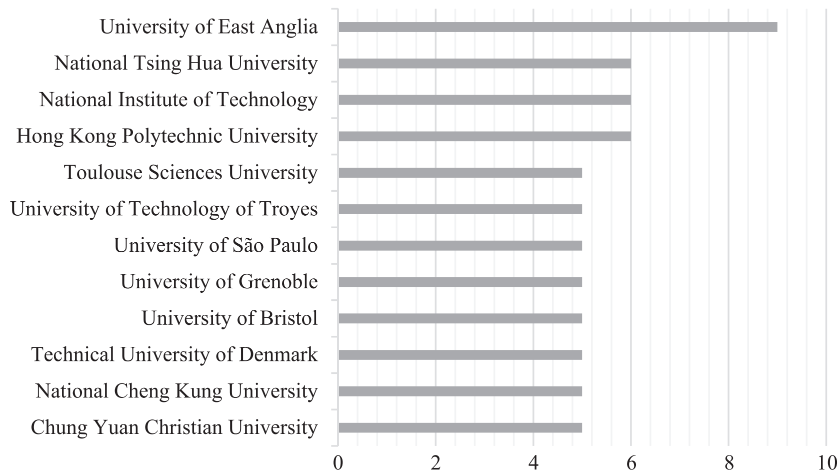

Figure 3: Most influential institutions in the sample.

most of the countries (including USA, France, Taiwan, England and China), the Journal of Life Cycle Assessment is more popular in Germany, Austria and Spain. The European Journal of Operations Research seems to be preferred by researchers from Canada.

3.4 *Number of papers per journal*

One hundred different journals were recorded, indicating the high multidisciplinary level of the knowledge area. Table 3 presents the number of papers published in the most recurrent journals of the sample.

The Journal of Cleaner Production started publishing ecodesign related papers in 2002. Over the last years, the number of ecodesign related published papers has systematically increased. 2014 is the year in which the highest number of ecodesign related papers has been published—17 papers.

The International Journal of Life Cycle Assessment published the first ecodesign-related paper in 2001, and inconsistent publication can be seen over the years (e.g. 2013 accounted for 6 published papers, while only one paper was published in 2014).

The Journal of Engineering Design had the first ecodesign related paper published in 1994 and had not published any paper in the area from 1995 to 2005 and in 2009–2010. Nevertheless, an increase trend in publishing ecodesign related papers can be observed in the last 4 years.

The Journal of Industrial Ecology seems to be expanding the scope for publishing ecodesign related papers: in 2014, 5 papers were published. The same can be observed in the Business Strategy

Table 2: Number of papers published per country.

Country	# Papers	Country	# Papers
USA	49	Singapore	4
France	39	Belgium	3
Taiwan	37	Greece	3
England	34	Poland	3
China	31	Switzerland	3
Germany	25	Wales	3
Italy	23	Ireland	2
Sweden	19	Luxembourg	2
Canada	16	Mexico	2
Japan	16	New Zealand	2
Spain	16	Thailand	2
Australia	15	Turkey	2
South Korea	15	Fiji	1
Brazil	9	Indonesia	1
Denmark	9	Iran	1
India	9	Israel	1
Malaysia	9	Latvia	1
Portugal	8	Oman	1
Netherlands	7	Romania	1
Austria	5	Scotland	1
Finland	4	Slovenia	1
Norway	4	Tunisia	1

and the Environment and International Journal of Production Economics.

3.5 *Most used keywords*

The most used keywords from the 1048 different keywords identified in the sample are presented in Figure 4.

Words commonly used synonymously with ecodesign can be observed in the list of most common keywords (design for environment, sustainable product development, life cycle design and eco-innovation). Other keywords that indicate the overall context for the study can also be observed, including sustainability, product design, product development, design and sustainable development).

On the other side, a high number of keywords dealing with specific areas of ecodesign are identified: Life Cycle Assessment (as a tool to measure the environmental performance), recycling and remanufacturing (as end-of-life strategies).

3.6 *Most cited papers*

350 papers from the sample received a total of 1988 citations (average of 5.7 citations per paper). The most cited papers are presented in Table 4.

Ten out of the twenty most cited papers were published in the Journal of Cleaner Production. The others were published in 10 different journals. Most of the most cited papers were published in 2006 (4 papers).

3.7 *Most cited references*

The 350 papers that comprise the sample analyzed in this research summed up 10514 cited references. The 10 most cited references are presented in Table 5.

4 Evolution of Ecodesign Methods and Tools as a Knowledge Area and Major Achievements

The evolution of the ecodesign methods and tools field over the three decades was analyzed in order to 1) identify the main topics addressed by the papers; and 2) identify the evolution of the topics addressed throughout the years. In total, 30 main topics related to ecodesign methods and tools were identified. The results of the analysis are summarized in Table 6.

Recycling: Recovery of materials in the end-of-life so as to make them suitable for use in manufacturing processes as raw material

Remanufacturing: End-of-life strategy that conserves the product components and bring the product back into an "as new" condition by carrying out disassembly, overhaul, and replacement operations

Table 3: Most recurrent journals in the analyzed sample.

# Papers	Journal
89	Journal of Cleaner Production
28	International Journal of Life Cycle Assessment
12	Journal of Engineering Design
12	Journal of Industrial Ecology
9	International Journey of Production Research
9	Material Design
8	International Journal of Advanced Manufacturing Technology
7	Journal of Mechanical Design
7	Resources, Conservation and Recycling
6	Expert Systems with Applications
6	International Journal of Computer Integrated Manufacturing
5	CIRP Annals - Manufacturing Technology
5	International Journal of Precision Engineering Manufacturing
5	Journal of Electronics Manufacturing
5	Robotics and Computer Integrated Manufacturing
4	Advanced Engineering Informatics
4	Business Strategy and the Environment
4	International Journal of Production Economics
4	Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture

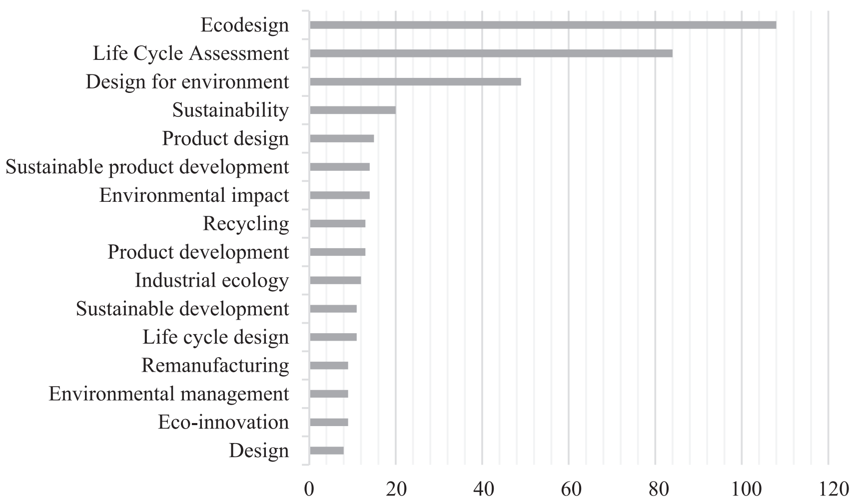

Figure 4: Most used keywords.

The early-nineties were characterized by papers dealing with the serviceability as a way to increase the environmental performance of products and in the first reviews of existing tools to integrate environmental issues in product development. Major achievements during this period were related to the transition from a preventive approach, focused mainly on end-of-pipe attitudes, to a more proactive approach, which aimed at integrating environmental issues in the product development process, and therefore, minimizing the impacts at its source.

It was not before the late-nineties, however, that the ecodesign knowledge area started to

Table 4: Most cited papers in the analyzed sample.

# of citations	Title	Reference
109	Developing sustainable products and services	12
105	EcoDesign and The Ten Golden Rules: generic advice for merging environmental aspects into product development	13
87	Design for the environment: A quality-based model for green product development	14
86	A strategic design approach to develop sustainable product service systems: examples taken from the 'environmentally friendly innovation' Italian prize	15
84	Linear programming in disassembly/clustering sequence generation	16
78	Service Engineering: a novel engineering discipline for producers to increase value combining service and product	17
77	Evaluating the environmental impact of products and production processes: A comparison of six methods	18
76	Eco-innovation and new product development: understanding the influences on market performance	19
72	Ecodesign of automotive components making use of natural jute fiber composites	20
71	Managing 'green' product innovation in small firms	21
61	Handling trade-offs in ecodesign tools for sustainable product development and procurement	22
53	Adopting and applying eco-design techniques: a practitioners perspective	23
53	Life-cycle based methods for sustainable product development	24
52	Integration of environmental aspects in product development: a stepwise procedure based on quantitative life cycle assessment	25
52	Sustainability in electrical and electronic equipment closed-loop chains	26
49	Mainstreaming Green Product Innovation: Why and How Companies Integrate Environmental Sustainability	27
48	The new product design process and design for environment - "Crossing the chasm	28
45	Materials selection for optimal environmental impact in mechanical design	29
43	Design for environment - do we get the focus right?	30
43	Ecodesign tool for designers: defining the requirements	31

flourish. From 1996 to 2000, several authors started to explore ways to tackle integration of environmental issues into product development from different angles. Studies started to be developed for the establishment of CAD tools with the incorporation of ecodesign features, and approaches were developed to support material selection. The beginning of the concern with end-of-life (EOL) issues could be observed with the development of approaches towards design for disassembly and design for recycling. During this period, the first studies with proposals of approaches to evaluate the environmental performance of products were published, including mainly Life Cycle Assessment. Design for production optimization and the need for a systemic approach also appeared as main topics from 1996–2000. The overall integration of environmental issues in Research and Development (R&D) and product development started to be discussed. Major results obtained in this period are related to the establishment of LCA as a robust tool to support decision-making and communication of environmental performance of products; on the increased focus on end-of-life strategies and on the understanding that the highest opportunities for increasing the environmental performance of products were in the initial stages of product development.

By the turn of the millennium, ecodesign was established as a more consolidated research area. Without losing the focus on the main topics

End-of-Life (EOL): Life cycle stage that occurs when the product does not fulfill any longer the function to which it was designed for

Table 5: Most cited references in the analyzed sample.

Cited by # papers	Title	Reference
39	C. Luttropp, J. Lagerstedt, EcoDesign and The Ten Golden Rules: Generic advice for merging environmental aspects into product development, J. Clean. Prod. 14 (2006)	13
34	J.C. Brezet, C. Van Hemel, Ecodesign: A promising approach to sustainable production and consumption, 1997	32
28	H. Baumann, F. Boons, A. Bragd, Mapping the green product development field: Engineering, policy and business perspectives, J. Clean. Prod. 10 (2002)	2
27	ISO, ISO 14040: Life Cycle Assessment—Principles and Framework, Environ. Manage. 3 (2006) 28	33
22	S. Byggeth, E. Hochschorner, Handling trade-offs in ecodesign tools for sustainable product development and procurement, J. Clean. Prod. 14 (2006)	22
20	R. Karlsson, C. Luttropp, EcoDesign: What's happening? An overview of the subject area of EcoDesign and of the papers in this special issue, J. Clean. Prod. 14 (2006)	34
19	P. Knight, J.O. Jenkins, Adopting and applying eco-design techniques: A practitioners perspective, J. Clean. Prod. 17 (2009)	23
18	ISO 14040, Environmental Management–Life Cycle Assessment–Principles and Framework (revised in 2006), ISO 14040 (1997)	35
18	J. Fiksel, K. Cook, S. Roberts, D. Tsuda, Design for environment at Apple Computer: A case study of the new PowerMacintosh 7200, Proc. 1996 IEEE Int. Symp. Electron. Environ. ISEE-1996	36
17	ISO/TR 14062—Environmental management—Integrating environmental aspects into product design and development, Tech. Rep. 2002 (2002).	37

that started to be addressed during 1996–2000, research started to be developed on new issues that showed potential to enhance ecodesign application in industry, such as information and knowledge management, strategic considerations and life cycle costing. Special attention started to be taken on how to integrate ecodesign in the conceptual design (including the selection of concepts and analyses of trade-offs), bringing customers and stakeholders' requirements into account early in the design process and starting to consider the managerial issues related to ecodesign implementation. Despite the availability of a large variety of tools, the researchers identified that companies were still not fully embracing the concept. The understanding of the need to integrate ecodesign with strategic decision-making, marketing research and economic issues to strengthen its implementation in companies can be highlighted as a major development in the field. Furthermore, the need to evaluate trade-offs between environmental criteria and the traditional product development criteria (such as costs, esthetics, quality, etc.) became evident.

Conceptual design: Phase of a product development process in which alternative concepts and solution principles are developed based on the identified requirements for the product under development

The period 2006–2010 was characterized by the consolidation of knowledge and tools for the evaluation of the environmental performance of products and technologies, on methods and tools to deal with EOL and on material selection approaches and techniques. Furthermore, there was a strong focus on the integration of ecodesign in the early stages of product development and a better understanding of the managerial and strategic issues required for a successful ecodesign implementation. At that point, several tools and methods were already available, but not necessarily applied by industry, and research started to be performed to provide guidelines on how to develop more applicable tools, to support their selection and implementation into companies. Furthermore, the recognition of the complexity related to the traditional LCA tools led to the development of simplified guidelines and checklists that would more easily support designers to take decisions, especially in the early stages of product development. At the same time, and because of the increase of product-related environmental regulations, research was focussed on supporting companies to comply with those new policies, legislation and standards by developing tailored tools and methods. Initial research started to be carried out on increasing the robustness and extending the lifetime of products, through modularization. Green marketing practices started to be explored, as a way to ensure a high demand for the ecodesigned products.

Robustness: The ability of a system to resist to change

Table 6: Main results obtained over the last three decades: An evolution of the ecodesign methods and tools knowledge area.

Main topics	1990–1995	1996–2000	2001–2005	2006–2010	2011–2015
Products and services	38		15,39,40	17,41	42–44
CAD tools		45	46,47		48,49
EOL methods		50–55	56–61	26,41,62–74	75–93
Evaluation of environmental performance		94–97	25,61,98–110	20,24,63,68, 111–130	131–175
Material selection		176	177,178	126,129,179–181	152,182–190
Design for production optimization		191	192	193–197	76,198–203
System approach		204		26	92,205
R&D and product development integration		21,28,206	107,207–209	210–214	137,215–222
Information and knowledge management			223	123,224,225	226–231
Conceptual design, selection and trade-offs			232,233,234	22,235–241	132,242–24481, 149,151,174, 230,245–250
KPIs			156,251	68,252,253	166,254–256
Strategic considerations			257	258–261	262–268
Life cycle costing			104,269	63,115,116	150,170,270
Customers and stakeholders requirements			107,110	19,127,271–275	43,136,137,226, 276–284
Managerial integration			285,286	27,260,287–292	162,228,263,293–300
Development, selection and implementation of tools				23,31,301	6,302–306
Simplified guidelines and checklists				13,68,117, 307–310	183,311
Policy and standardization				120,122,243, 312–315	143,254,298,316–319
Support for SMEs				314,320	321
Extending lifetime and modularization				322–325	326–331
Robustness				332	333,334
Green marketing				335	336–341
Supply chain involvement					82,133,205,267, 270,336,342–346
Ideation tools					137,169,347–350
Decision support systems					146,249,294,351–358
Monetization of environmental impacts					359,360
Portfolio management					361
Use-oriented design					362
Territorial resources					363

Major achievements in the period 2006–2010 are related to the understanding that existing ecodesign tools and methods were not necessarily useful for companies, and that there was a need to improve, simplify and customize existing methods and tools for effective implementation by industry. Furthermore, the understanding of the importance of identification of internal and external drivers for ecodesign implementation (such as customers' requirements and legislative compliance) became key success factors for the application of the concept.

The last 5 years (2011–2015) are characterized by increased research and consolidation of ecodesign as a multidisciplinary research area that is continuously optimizing the foundations and expanding the borders. Increasingly, research is being conducted on the intensification of supply

Upstream: Stakeholders of a value chain involved in the early-stages of the product's life cycle (raw material extraction and manufacturing)

Downstream: Stakeholders of a value chain involved in the later-stages of the product's life cycle (use & maintenance and EOL)

Life Cycle Assessment (LCA): Quantitative method for the assessment of potential environmental impacts of products and services

Life Cycle Costing (LCC): Method to evaluate the direct and indirect costs related to a product's life cycle (from raw material extraction to end-of-life)

Value chain: Network of companies/organizations directly or indirectly involved in the product's life cycle (includes suppliers, service providers, recyclers, etc.)

chain involvement in the product development process, both upstream and downstream—ecodesign is increasingly going beyond the company borders. Furthermore, tools and methods are being developed to support the generation of ideas that have the potential to originate radical improvements in the environmental performance of products and services. Decision support systems are being explored in recognition of the difficulties to take decisions that will have influences on different environmental impact categories and business areas/functions. As an attempt to involve and engage top management, there is ongoing research on the monetization of environmental impacts and on portfolio management considering ecodesign parameters for a comprehensive decision-making. Furthermore, in order to increase the perceived value by consumers, research is programs are being initiated to develop on use-oriented design. Major results of this period are related to the expansion of ecodesign from product development to the other processes in the organization that will have significant influence on the environmental performance of products, such as supply chain management. Furthermore, the understanding that radical improvements on the environmental performance of products are required can be seen an important achievement, which will be further deployed in the next developments in the knowledge area.

5 Trends for the Ecodesign Tools and Methods in the Next Decade

Over the next decade, an intensification of focus in following nine main areas related to ecodesign tools and methods is expected by the authors:

I. Development of products and services: The development of product/service-systems has been increasingly explored in ecodesign research due to its potential to significantly minimize resource consumption by dematerialization, which would lead to an extension of the products' lifetime and enable EOL strategies, such as recycling and remanufacturing. Research is currently being developed, for example, to measure the environmental improvements of PSS business models compared to traditional products;

II. Focus on sustainable design: The growing importance of the sustainability concept, which entails the balance among the environmental, economic and social dimensions, is currently being explored in ecodesign research, mainly for the integration of social sustainability principles into design and product development. Research is currently being developed to identify how design could contribute to increase sustainability in the product level (in opposition to a corporate level);

III. Development of comprehensive tools to evaluate the sustainability performance of products: There is a clear trend for development of unified tools that can measure the sustainability performance of products considering the environmental, social and economic dimensions –research focus has been, for example, on the integration of Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Social Life Cycle Assessment (S-LCA)—the creation of common units for measure has been explored;

IV. Increased focus on systems thinking for understanding relations and interactions among elements: Systems thinking is emerging as a promising approach to support the consideration of sustainability into product design and development—a systems perspective has the potential to enable a better understanding of the effects of decisions taken during product development on the sustainability performance of products, and would enable the complex consideration of user behavior;

V. Increased focus on circular economy as an overall strategy for sustainability: Circular economy is emerging as a promising approach to guide companies in the transition towards a stronger consideration of waste as resources in closed-loop economies. Ecodesign research is currently focusing on the identification of how product design and development can enable circular economy by the implementation of Design for EOL (e.g. design for recycling, design for remanufacturing, design for reuse, etc.);

VI. Enhanced link between product development and related business processes: There is a trend to expand the traditional ecodesign scope (product development) to additional organizational processes that can have significant influence on the environmental performance of products (such as marketing, purchasing, financing, services, etc.). Research is currently being conducted to enable a better understanding of the interface between internal stakeholders with an aim to enable the integration of ecodesign in companies' processes;

VII. Incorporation of planetary boundaries in evaluation of environmental and social performance of products and technologies: There is an increasing trend for the consideration of absolute sustainability in evaluation of performance of products and services. An absolute sustainability mindset enables the consideration of the Earth's carrying capacity into product development, which has the potential to spark development of more innovative products;

VIII. Stronger focus on the managerial and strategic issues towards ecodesign implementation: There is a trend to expand the focus of ecodesign considerations from a strict technical arena to more managerial and strategic considerations. New approaches are being developed and tested to allow implementation of ecodesign in the strategic, tactical and operational levels of organizations, enabling a broader uptake and more significant results;

IX. Consolidation of existing tools, approaches and methods for a streamlined application by industry: The large number of tools and methods currently seen in ecodesign literature is being understood by a set of researchers as a barrier for ecodesign implementation—companies usually do not know which tools to select based on their current needs and situation. Consequently, the decision is often not optimum, leading to frustration on ecodesign implementation. Currently, research is being carried out to consolidate existing methods, tools and approaches to support selection and application by industry.

6 Final Remarks

This research mapped the state of the art and provided a classification of the last three decades of research on ecodesign methods and tools by means of a systematic review of the literature, combined with a bibliometric analysis. The research involved the analysis, consolidation and systematization of more than 500 studies, resulting in the categorization of 30 main topics in four periods (from 1990 to 2015).

The main findings from the bibliometric analysis are:

- Growing interest in the development and application of ecodesign methods and tools. It is expected that the number of papers will continuously increase in the coming years;
- Increased number of authors in the recent years indicates an expansion of the knowledge area, while the relatively low number of articles per author indicate that ecodesign might not be their primary research topic;
- Europe, Asia and South America hosts the institutions with the highest publication track on ecodesign methods and tools, while USA as a country holds the highest number of published journal articles;
- One hundred different journals were recorded, indicating high multidisciplinary level of the knowledge area, and establishing the Journal of Cleaner Production as the main journal for the publication of ecodesign-related methods and tools research.

In addition to providing an understanding of the ecodesign methods and tools knowledge area, the authors attempted to indicate nine areas where an intensification of research is expected over the next decade:

- Development of sustainable products and services;
- Focus on sustainable design, by means of the integration of social, environmental and economic issues in product development;
- Development of comprehensive tools to evaluate the economic, environmental and social performance of products;
- Increased focus on systems thinking for the understanding of relations and interactions between elements;
- Increased focus on circular economy as an overall strategy for EOL strategies and a sustainable economy;
- Enhanced link between product development and other business processes of organizations (such as marketing, purchasing, financing, services, etc.);
- Incorporation of the planetary boundaries in the evaluation of the environmental and social performance of products and technologies;
- Stronger focus on the managerial and strategic issues towards ecodesign implementation;
- Increased industry uptake by the consolidation of existing tools, approaches and methods for a streamlined application by industry.

Received 16 June 2015.

References

1. Communities, C. of the E. *Green paper on integrated product policy*. *Environment* (Office for Official Publications of the European Communities, 2001).
2. H. Baumann, F. Boons and A. Bragd, Mapping the green product development field: engineering, policy

and business perspectives, *J. Clean. Prod.* **10,** 409–425 (2002).

3. G. Johansson, Success factors for integration of ecodesign in product development: a review of state of the art, *Environ. Manag. Heal.,* **13,** 98–107 (2002).
4. J. Van Weenen, Towards sustainable product development, *J. Clean. Prodm.,* **3,** 95–100 (1995).
5. S. Byggeth and E. Hochschorner, Handling trade-offs in ecodesign tools for sustainable product development and procurement, *J. Clean. Prod.,* **14,** 1420–1430 (2006).
6. M.D. Bovea and V. Pérez-Belis, A taxonomy of ecodesign tools for integrating environmental requirements into the product design process, *J. Clean. Prod.,* **20,** 61–71 (2012).
7. F. Vallet, et al., Using eco-design tools: an overview of experts' practices, *Des. Stud.,* **34,** 345–377 (2013).
8. D.C.A. Pigosso, T.C. McAloone and H. Rozenfeld, Systematization of best practices for ecodesign implementation, in *International Design Conference-DESIGN 2014,* 1651–1662 (2014).
9. *Researching Operations Management*, (Routledge, 2009).
10. P. Brereton, B. Kitchenham, D. Budgen, M. Turner and M. Khalil, Lessons from applying the systematic literature review process within the software engineering domain, *J. Syst. Softw.,* **80,** 571–583 (2007).
11. J. Biolchini, P.G. Mian, A.C.C. Natali and G.H. Travassos, *Systematic Review in Software Engineering*, (2005).
12. D. Maxwell and Vorst, R. Van Der, Developing sustainable products and services, *J. Clean. Prod.,* **11,** 883–895 (2003).
13. C. Luttropp and J. Lagerstedt, EcoDesign and the ten golden rules: generic advice for merging environmental aspects into product development, *J. Clean. Prod.,* **14,** 1396–1408 (2006).
14. C. Chen, Design for the environment: a quality-based model for green product development, *Manage, Sci.,* **47,** 250–263 (2001).
15. E. Manzini and C. Vezzoli, A strategic design approach to develop sustainable product service systems: examples taken from the 'environmentally friendly innovation' Italian prize, *J. Clean. Prod.,* **11,** 851–857 (2003).
16. A.J.D. Lambert, Linear programming in disassembly/clustering sequence generation, *Comput. Ind. Eng.,* **36,** 723–738 (1999).
17. T. Sakao and Y. Shimomura, Service Engineering: a novel engineering discipline for producers to increase value combining service and product, *J. Clean. Prod.,* **15,** 590–604 (2007).
18. E. Hertwich, W. Pease and C. Koshland, Evaluating the environmental impact of products and production processes: a comparison of six methods, *Sci. Total Environ.,* **196,** 13–29 (1997).
19. D. Pujari, Eco-innovation and new product development: Understanding the influences on market performance, *TECHNOVATION,* **26,** 76–85 (2006).
20. C. Alves, et al., Ecodesign of automotive components making use of natural jute fiber composites, *J. Clean. Prod.,* **18,** 313–327 (2010).
21. G. Noci and R. Verganti, Managing `green' product innovation in small firms, *R D Manag.,* **29,** 3–15 (1999).
22. S. Byggeth and E. Hochschorner, Handling trade-offs in ecodesign tools for sustainable product development and procurement, *J. Clean. Prod.,* **14,** 1420–1430 (2006).
23. P. Knight and J.O. Jenkins, Adopting and applying eco-design techniques: a practitioners perspective, *J. Clean. Prod.,* **17,** 549–558 (2009).
24. W.-P. Schmidt and F. Butt, Life cycle tools within Ford of Europe's Product Sustainability Index—Case study ford S-MAX & Ford Galaxy, *Int. J. LIFE CYCLE Assess.,* **11,** 315–322 (2006).
25. P.H. Nielsen and H. Wenzel, Integration of environmental aspects in product development: a stepwise procedure based on quantitative life cycle assessment, *J. Clean. Prod.,* **10,** 247–257 (2002).
26. P. Georgiadis and M. Besiou, Sustainability in electrical and electronic equipment closed-loop supply chains: a system dynamics approach, *J. Clean. Prod.,* **16,** 1665–1678 (2008).
27. R.M. Dangelico and D. Pujari, mainstreaming green product innovation: why and how companies integrate environmental sustainability, *J. Bus. Ethics,* **95,** 471–486 (2010).
28. R. Sroufe, S. Curkovic, F. Montabon and S.A. Melnyk, The new product design process and design for environment: "Crossing the chasm", *Int. J. Oper. Prod. Manag,* **20,** 267–291 (2000).
29. L. Holloway, Materials selection for optimal environmental impact in mechanical design, *Mater. Des.,* **19,** 133–143 (1998).
30. M. Hauschild and J. Jeswiet, design for environment—do we get the focus right? *CIRP Ann.,* 1–4 (2004).
31. V. Lofthouse, Ecodesign tools for designers: defining the requirements, *J. Clean. Prod.,* **14,** 1386–1395 (2006).
32. J.C. Brezet and C. Van Hemel, *Ecodesign: A Promising Approach to Sustainable Production and Consumption,* (1997).
33. ISO. ISO 14040: Life cycle assessment—principles and framework, *Environ. Manage,* **3,** 28 (2006).
34. R. Karlsson and C. Luttropp, EcoDesign: What's happening? an overview of the subject area of EcoDesign and of the papers in this special issue, *J. Clean. Prod.,* **14,** 1291–1298 (2006).
35. ISO 14040. Environmental management—life cycle assessment—principles and framework (revised in 2006), *ISO 14040,* (1997).
36. J. Fiksel, K. Cook, S. Roberts and D. Tsuda, Design for environment at Apple Computer:—Case study of the new PowerMacintosh 7200, *Proc. 1996 IEEE Int. Symp. Electron. Environ. ISEE-1996,* 218–223, doi:10.1109/ISEE.1996.501881.
37. ISO. ISO/TR 14062—Environmental management—Integrating environmental aspects into product design and development, *Tech. Rep.,* **2002,** (2002).

38. C.F. Eubanks and K. Ishii, AI methods for life-cycle serviceability design of mechanical systems, *Artif. Intell. Eng.,* **8,** 127–140 (1993).
39. T. Lamvik, K. Walsh and O. Myklebust, Manufacturing a green service: engaging the TRIZ model of innovation, *IEEE Trans. Electron. Packag. Manuf.,* **24,** 10–17 (2001).
40. D. Maxwell and R. van der Vorst, Developing sustainable products and services, *J. Clean. Prod.,* **11,** 883–895 (2003).
41. O. Mont, C. Dalhammar and N. Jacobsson, A new business model for baby prams based on leasing and product remanufacturing, *J. Clean. Prod.,* **14,** 1509–1518 (2006).
42. T.C. Kuo, Mass customization and personalization software development: a case study eco-design product service system, *J. Intell. Manuf.,* **24,** 1019–1031 (2013).
43. J.-C. Tu, Y.-C. Huang, C.-Y. Hsu and Y.-W. Cheng, analyzing lifestyle and consumption pattern of hire groups under product service systems in Taiwan, *Math. Probl. Eng.,* (2013), doi:10.1155/2013/710981.
44. D. Chen, et al., PSS solution evaluation considering sustainability under hybrid uncertain environments, *Expert Syst. Appl.,* **42,** 5822–5838 (2015).
45. A.C. Thornton and A.L. Johnson, CADET: a software support tool for constraint processes in embodiment design, *Res. Eng. Des. Appl. Concurr. Eng.,* **8,** 1–13 (1996).
46. H.T. Chang and J.L. Chen, The conflict-problem-solving CAD software integrating TRIZ into eco-innovation, *Adv. Eng. Softw.,* **35,** 553–566 (2004).
47. S. Leibrecht, Fundamental principles for CAD-based Ecological Assessments (9 pp), *Int. J. Life Cycle Assess.,* **10,** 436–444 (2005).
48. J. Heintz, J.-P. Belaud, N. Pandya, M.T. Dos Santos and V. Gerbaud, Computer aided product design tool for sustainable product development, *Comput. Chem. Eng.,* **71,** 362–376 (2014).
49. R. Gaha, B. Yannou and A. Benamara, A new eco-design approach on CAD systems, *Int. J. Precis. Eng. Manuf.,* **15,** 1443–1451 (2014).
50. A framework for virtual disassembly analysis, *J. Intell. Manuf.,* (1997).
51. A.J.D. Lambert, Linear programming in disassembly/clustering sequence generation, *Comput. Ind. Eng.,* **36,** 723–738 (1999).
52. K. Feldmann, O. Meedt, S. Trautner, H. Scheller and W. Hoffman, The "Green Design Advisor": A tool for design for environment, *J. Electron. Manuf.,* **9,** 17–28 (1999).
53. C.M. Rose and K. Ishii, Product end-of-life strategy categorization design tool, *J. Electron. Manuf.,* **9,** 41–51 (1999).
54. M.C. Zhou, R.J. Caudill and D. Sebastian, Multi-lifecycle product recovery for electronic products, *J. Electron. Manuf.,* **9,** 1–15 (1999).
55. L.H. Shu and W.C. Flowers, Application of a design-for-remanufacture framework to the selection of product life-cycle fastening and joining methods, *Robot. Comput. Integr. Manuf.,* **15,** 179–190 (1999).
56. T. Eichner and R. Pethig, Product design and efficient management of recycling and waste treatment, *J. Environ. Econ. Manage.,* **41,** 109–134 (2001).
57. C.M. Rose, A.B. Stevels and K. Ishii, Method for formulating product end-of-life strategies for electronics industry, *J. Electron. Manuf.,* **11,** 185–196 (2002).
58. C.M. Rose, K. Ishii and A. Stevels, Influencing design to improve product end-of-life stage, *Res. Eng. Des. Appl. Concurr. Eng.,* **13,** 83–93 (2002).
59. F. Ardente, G. Beccali and M. Cellura, Eco-sustainable energy and environmental strategies in design for recycling: the software "ENDLESS", *Ecol. Modell.,* **163,** 101–118 (2003).
60. X.M. Xu, et al., Modelling and solving of product disassembly activity logic network, *Int. J. Adv. Manuf. Technol.,* **23,** 220–226 (2004).
61. Y. Kondo and S. Nakamura, Evaluating alternative life-cycle strategies for electrical appliances by the waste input-output model, *Int. J. LIFE CYCLE Assess.,* **9,** 236–246 (2004).
62. L.H. Shih, Y.S. Chang and Y.T. Lin, Intelligent evaluation approach for electronic product recycling via case-based reasoning, *Adv. Eng. INFORMATICS,* **20,** 137–145 (2006).
63. S. Nakamura and Y. Kondo, A waste input-output life-cycle cost analysis of the recycling of end-of-life electrical home appliances, *Ecol. Econ.,* **57,** 494–506 (2006).
64. P. Zwolinski, M.-A. Lopez-Ontiveros and D. Brissaud, Integrated design of remanufacturable products based on product profiles, *J. Clean. Prod.,* **14,** 1333–1345 (2006).
65. P. Ferrao and J. Amaral, Design for recycling in the automobile industry: new approaches and new tools, *J. Eng. Des.,* **17,** 447–462 (2006).
66. P.-J. Park, K. Tahara, I.-T. Jeong and K.-M. Lee, Comparison of four methods for integrating environmental and economic aspects in the end-of-life stage of a washing machine, *Resour. Conserv. Recycl.,* **48,** 71–85 (2006).
67. T.C. Kuo, Enhancing disassembly and recycling planning using life-cycle analysis, *Robot. Comput. Integr. Manuf.,* **22,** 420–428 (2006).
68. C. Mascle and H.P. Zhao, Integrating environmental consciousness in product/process development based on life-cycle thinking, *Int. J. Prod. Econ.,* **112,** 5–17 (2008).
69. F. Mathieux, D. Froelich and P. Moszkowicz, ReSICLED: A new recovery-conscious design method for complex products based on a multicriteria assessment of the recoverability, *J. Clean. Prod.,* **16,** 277–298 (2008).
70. J. Um, J. Yoon and S. Suh, An architecture design with data model for product recovery management systems, *Resour. Conserv. Recycl.,* **52,** 1175–1184 (2008).
71. C.-J. Chung and H.-M. Wee, Green-product-design value and information-technology investment on replenishment model with remanufacturing, *Int. J. Comput. Integr. Manuf.,* **23,** 466–485 (2010).

72. D.C.A. Pigosso, E.T. Zanette, A.G. Filho, A.R. Ometto and H. Rozenfeld, Ecodesign methods focused on remanufacturing, *J. Clean. Prod.,* **18,** 21–31 (2010).
73. G. Gaustad, E. Olivetti and R. Kirchain, Design for recycling, *J. Ind. Ecol.,* **14,** 286–308 (2010).
74. A. Santini, et al., Assessment of Ecodesign potential in reaching new recycling targets, *Resour. Conserv. Recycl.,* **54,** 1128–1134 (2010).
75. S.S. Smith and W. Chen, Advanced engineering informatics rule-based recursive selective disassembly sequence planning for green design, *Adv. Eng. Informatics,* **25,** 77–87 (2011).
76. Y.-J. Tseng, F.-Y. Yu and F.-Y. Huang, A green assembly sequence planning model with a closed-loop assembly and disassembly sequence planning using a particle swarm optimization method, *Int. J. Adv. Manuf. Technol.,* **57,** 1183–1197 (2011).
77. Q. Yang, S. Yu and A. Sekhari, A modular eco-design method for life cycle engineering based on redesign risk control, *Int. J. Adv. Manuf. Technol.,* **56,** 1215–1233 (2011).
78. C.-J. Chung and H.-M. Wee, Short life-cycle deteriorating product remanufacturing in a green supply chain inventory control system, *Int. J. Prod. Econ.,* **129,** 195–203 (2011).
79. L. Candido, et al., The recycling cycle of materials as a design project tool, *J. Clean. Prod.,* **19,** 1438–1445 (2011).
80. S. Bernard, Remanufacturing, *J. Environ. Econ. Manage.,* **62,** 337–351 (2011).
81. M. Remery, C. Mascle and B. Agard, A new method for evaluating the best product end-of-life strategy during the early design phase, *J. Eng. Des.,* **23,** 419–441 (2012).
82. F. Rizzi, I. Bartolozzi, A. Borghini and M. Frey, Environmental management of end-of-life products: nine factors of sustainability in collaborative networks, *Bus. Strateg. Environ.,* **22,** 561–572 (2013).
83. E. Dostatni, J. Diakun, A. Hamrol and W. Mazur, Application of agent technology for recycling-oriented product assessment, *Ind. Manag. DATA Syst.,* **113,** 817–839 (2013).
84. S. Ibbotson, T. Dettmer, S. Kara and C. Herrmann, Eco-efficiency of disposable and reusable surgical instruments-a scissors case, *Int. J. LIFE CYCLE Assess.,* **18,** 1137–1148 (2013).
85. S. Mangla, J. Madaan and F.T.S. Chan, Analysis of flexible decision strategies for sustainability-focused green product recovery system, *Int. J. Prod. Res.,* **51,** 3428–3442 (2013).
86. N. Tchertchian, D. Millet and O. Pialot, Modifying module boundaries to design remanufacturable products: the modular grouping explorer tool, *J. Eng. Des.,* **24,** 546–574 (2013).
87. S.V. Nagalingam, S.S. Kuik and Y. Amer, Performance measurement of product returns with recovery for sustainable manufacturing, *Robot. Comput. Integr. Manuf.,* **29,** 473–483 (2013).
88. C. Achillas, et al., Depth of manual dismantling analysis: A cost-benefit approach, *WASTE Manag.,* **33,** 948–956 (2013).
89. P. Kiddee, R. Naidu and M.H. Wong, Electronic waste management approaches: an overview, *WASTE Manag.,* **33,** 1237–1250 (2013).
90. H.M. Lee, W.F. Lu and B. Song, A framework for assessing product end-of-life performance: reviewing the state of the art and proposing an innovative approach using an end-of-life index, *J. Clean. Prod.,* **66,** 355–371 (2014).
91. Q. Yang, S. Yu and D. Jiang, A modular method of developing an eco-product family considering the reusability and recyclability of customer products, *J. Clean. Prod.,* **64,** 254–265 (2014).
92. E. Dace, G. Bazbauers, A. Berzina and P.I. Davidsen, System dynamics model for analyzing effects of eco-design policy on packaging waste management system, *Resour. Conserv. Recycl.,* **87,** 175–190 (2014).
93. M. Kwak and H. Kim, Design for life-cycle profit with simultaneous consideration of initial manufacturing and end-of-life remanufacturing, *Eng. Optim.,* **47,** 18–35 (2015).
94. G.A. Keoleian and G.M. Lewis, Application of life-cycle energy analysis to photovoltaic module design, *Prog. Photovoltaics Res. Appl.,* **5,** 287–300 (1997).
95. Environment, T. Evaluating the environmental impact of products and production processes: A comparison of six methods, 96–97, (1997).
96. J.A. Fava, Life cycle perspectives to achieve business benefits: From concept to technique. *Hum. Ecol. RISK Assess.* **4,** 1003–1017 (1998).
97. K.G. Mueller, A.W. Court and C.B. Besant, Energy life cycle design: a method, *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf,* **213,** 415–419 (1999).
98. C. Vezzoli, F. Ceschin, J.C. Diehl and C. Kohtala, Why have 'Sustainable Product-Service Systems' not been widely implemented?, *J. Clean. Prod.,* **35,** 288–290 (2012).
99. B.C. Lippiatt and A.S. Boyles, Using BEES to select cost-effective green products, *Int. J. LIFE CYCLE Assess.,* **6,** 76–80 (2001).
100. D.Q. Xiao, H.T. Wang, J.G. Zhu and S.Q. Peng, Sequent and accumulative life cycle assessment of materials and products, *Mater. Des.,* **22,** 147–149 (2001).
101. G. Fleischer, K. Gerner, H. Kunst, K. Lichtenvort and G. Rebitzer, A semi-quantitative method for the impact assessment of emissions within a simplified life cycle assessment, *Int. J. Life Cycle Assess.,* **6,** 149–156 (2001).
102. S.W. Lye, S.G. Lee and M.K. Khoo, ECoDE—an environmental component design evaluation tool, *Eng. Comput,* **18,** 14–23 (2002).
103. G.S. Bhander, M. Hauschild and T. McAloone, Implementing life cycle assessment in product development, *Environ. Prog.,* **22,** 255–267 (2003).
104. W. Klopffer, Life-cycle based methods for sustainable product development, *Int. J. LIFE CYCLE Assess.,* **8,** 157–159 (2003).

105. J. Lagerstedt, C. Luttropp and L.-G. Lindfors, Functional Priorities in LCA and Design for Environment, *Int. J. Life Cycle Assess.,* **8,** 160–166 (2003).

106. N. Krishnan, S. Raoux and D. Dornfeld, Quantifying the environmental footprint of semiconductor equipment using the environmental value systems analysis (EnV-S), *IEEE Trans. Semicond. Manuf,* **17,** 554–561 (2004).

107. M.D. Bovea and R. Vidal, Increasing product value by integrating environmental impact, costs and customer valuation, *Resour. Conserv. Recycl,* **41,** 133–145 (2004).

108. L. Stromberg, Integrated life-cycle design of coatings on exterior wood Part 2: Life-cycle assessment, *Surf. COATINGS Int. PART B-COATINGS Trans,* **87,** 211–220 (2004).

109. T. Hur, J. Lee, H. Ryu and E. Kwon, Simplified LCA and matrix methods in identifying the environmental aspects of a product system, *J. Environ. Manage,* **75,** 229–237 (2005).

110. Y. Kobayashi, H. Kobayashi, A. Hongu and K. Sanehira, A Practical Method for Quantifying Eco-efficiency Using Eco-design Support Tools, *J. Ind. Ecol.,* **9,** 131–144 (2005).

111. M. Finkbeiner, R. Hoffmann, K. Ruhland, D. Liebhart and B. Stark, Application of life cycle assessment for the environmental certificate of the Mercedes-Benz S-Class, *Int. J. LIFE CYCLE Assess.,* **11,** 240–246 (2006).

112. I. Munoz, J. Rieradevall, X. Domenech and C. Gazulla, Using LCA to assess eco-design in the automotive sector—Case study of a polyolefinic door panel, *Int. J. LIFE CYCLE Assess.,* **11,** 323–334 (2006).

113. P.-J. Park, K.-M. Lee and W. Wimmer, Development of an environmental assessment method for consumer electronics by combining top-down and bottom-up approaches, *Int. J. LIFE CYCLE Assess.,* **11,** 254–264 (2006).

114. M. Rossi, S. Charon, G. Wing and J. Ewell, Design for the next generation incorporating cradle-to-cradle design into Herman Miller products, *J. Ind. Ecol.,* **10,** 193–210 (2006).

115. Q. Yu, H. Zhixian and Y. Zhiguo, Integrated assessment of environmental and economic performance of chemical products using analytic hierarchy process approach, *CHINESE J. Chem. Eng.,* **15,** 81–87 (2007).

116. J.C. Alonso, et al., Electrical and electronic components in the automotive sector: Economic and environmental assessment, *Int. J. LIFE CYCLE Assess.,* **12,** 328–335 (2007).

117. K. Verghese and D. Hes, Qualitative and quantitative tool development to support environmentally responsible decisions, *J. Clean. Prod.,* **15,** 814–818 (2007).

118. Y. Jianjun, J. Baiyang, G. Yifeng, D. Jinxiang and L. Chenggang, Research on evaluation methodologies of product life cycle engineering design (LCED) and development of its tools, *Int. J. Comput. Integr. Manuf,* **21,** 923–942 (2008).

119. C. Koffler, S. Krinke, L. Schebek and J. Buchgeister, Volkswagen slimLCl: A procedure for streamlined inventory modelling within life cycle assessment of vehicles, *Int. J. Veh. Des.,* **46,** 172–188 (2008).

120. W.K.C. Yung, H.K. Chan, A.C.K. Choi, T.M. Yue and M.I. Mazhar, An environmental assessment framework with respect to the Requirements of Energy-using Products Directive, *Proc. Inst. Mech. Eng. PART B-JOURNAL Eng. Manuf,* **222,** 643–651 (2008).

121. E. Benetto, M. Becker and J. Welfring, life cycle assessment of Oriented Strand Boards (OSB): from process innovation to ecodesign, *Environ. Sci. Technol,* **43,** 6003–6009 (2009).

122. W.K.C. Yung, et al., Life cycle assessment of two personal electronic products-a note with respect to the energy-using product directive, *Int. J. Adv. Manuf. Technol,* **42,** 415–419 (2009).

123. J.-H. Eun, J.-H. Son, J.-M. Moon and J.-S. Chung, Integration of life cycle assessment in the environmental information system, *Int. J. LIFE CYCLE Assess.,* **14,** 364–373 (2009).

124. I. Munoz, C. Gazulla, A. Bala, R. Puig and P. Fullana, LCA and ecodesign in the toy industry: Case study of a teddy bear incorporating electric and electronic components, *Int. J. LIFE CYCLE Assess.,* **14,** 64–72 (2009).

125. C. Koffler and K. Rohde-Brandenburger, On the calculation of fuel savings through lightweight design in automotive life cycle assessments, *Int. J. LIFE CYCLE Assess.,* **15,** 128–135 (2010).

126. C.M.V.B. Almeida, A.J.M. Rodrigues, S.H. Bonilla and B.F. Giannetti, Emergy as a tool for Ecodesign: Evaluating materials selection for beverage packages in Brazil, *J. Clean. Prod.,* **18,** 32–43 (2010).

127. S. Vinodh and G. Rathod, Integration of ECQFD and LCA for sustainable product design, *J. Clean. Prod.,* **18,** 833–842 (2010).

128. S. Kota and A. Chakrabarti, A method for estimating the degree of uncertainty with respect to life cycle assessment during design, *J. Mech. Des.,* **132,** (2010).

129. B. De Benedetti, D. Toso, G.L. Baldo and S. Rollino, EcoAudit: A renewed simplified procedure to facilitate the environmentally informed material choice orienting the further life cycle analysis for ecodesigners, *Mater. Trans.,* **51,** 832–837 (2010).

130. M. Princaud, A. Cornier and D. Froelich, Developing a tool for environmental impact assessment and eco-design for ships, *Proc. Inst. Mech. Eng. PART M-JOURNAL Eng. Marit. Environ,* **224,** 207–224 (2010).

131. H. Ostad-Ahmad-Ghorabi and D. Collado-Ruiz, Tool for the environmental assessment of cranes based on parameterization, *Int. J. LIFE CYCLE Assess.,* **16,** 392–400 (2011).

132. E. Gasafi and M. Weil, Approach and application of life cycle screening in early phases of process design: case study of supercritical water gasification, *J. Clean. Prod.,* **19,** 1590–1600 (2011).

133. K. Nakano and M. Hirao, Collaborative activity with business partners for improvement of product

environmental performance using LCA, *J. Clean. Prod.*, **19,** 1189–1197 (2011).

134. W.K.C. Yung, et al., A life-cycle assessment for eco-redesign of a consumer electronic product, *J. Eng. Des.*, **22,** 69–85 (2011).
135. M. Herva, A. Alvarez and E. Roca, Sustainable and safe design of footwear integrating ecological footprint and risk criteria, *J. Hazard. Mater.,* **192,** 1876–1881 (2011).
136. K.S. Whitefoot, et al., Consequential life cycle assessment with market-driven design development and demonstration, *J. Ind. Ecol.,* **15,** 726–742 (2011).
137. A.J.C. Trappey, J.J.R. Ou, G.Y.P. Lin and M.Y. Chen, An eco- and inno-product design system applying integrated and intelligent qfde and triz methodology, *J. Syst. Sci. Syst. Eng.,* **20,** 443–459 (2011).
138. A.T. Mayyas, A. Qattawi, A.R. Mayyas and M.A. Omar, Life cycle assessment-based selection for a sustainable lightweight body-in-white design, *ENERGY,* **39,** 412–425 (2012).
139. C. Chen, J. Zhu, J.Y. Yu and H. Noori, A new methodology for evaluating sustainable product design performance with two-stage network data envelopment analysis, *Eur. J. Oper. Res.,* **221,** 348–359 (2012).
140. M. Herva, A. Franco-Uria, E.F. Carrasco and E. Roc, Application of fuzzy logic for the integration of environmental criteria in ecodesign, *Expert Syst. Appl.,* **39,** 4427–4431 (2012).
141. C.J. Yang and J.L. Chen, Forecasting the design of eco-products by integrating TRIZ evolution patterns with CBR and Simple LCA methods, *Expert Syst. Appl.,* **39,** 2884–2892 (2012).
142. M. Torrent, E. Martinez and P. Andrada, Assessing the environmental impact of induction motors using manufacturer's data and life cycle analysis, *IET Electr. POWER Appl.,* **6,** 473–483 (2012).
143. C. Askham, et al., Strategy tool trial for office furniture, *Int. J. LIFE CYCLE Assess.,* **17,** 666–677 (2012).
144. M. Torrent, E. Martinez and P. Andrada, Life cycle analysis on the design of induction motors, *Int. J. LIFE CYCLE Assess.,* **17,** 1–8 (2012).
145. J. Bonvoisin, A. Lelah, F. Mathieux and D. Brissaud, An environmental assessment method for wireless sensor networks, *J. Clean. Prod.,* **33,** 145–154 (2012).
146. V. Poudelet, J.A. Chayer, M. Margni, R. Pellerin and R. Samson, A process-based approach to operationalize life cycle assessment through the development of an eco-design decision-support system, *J. Clean. Prod.,* **33,** 192–201 (2012).
147. X.F. Zhang, et al., Identification of connection units with high GHG emissions for low-carbon product structure design, *J. Clean. Prod.,* **27,** 118–125 (2012).
148. D. Millet, P.A. Yvars and P. Tonnelier, A method for identifying the worst recycling case: Application on a range of vehicles in the automotive sector, *Resour. Conserv. Recycl,* **68,** 1–13 (2012).
149. N.M.P. Bocken, J.M. Allwood, A.R. Willey and J.M.H. King, Development of a tool for rapidly assessing the implementation difficulty and emissions benefits of innovations, *Technovation,* **32,** 19–31 (2012).
150. M. Ristimaki, A. Saynajoki, J. Heinonen and S. Junnila, Combining life cycle costing and life cycle assessment for an analysis of a new residential district energy system design, *ENERGY,* **63,** 168–179 (2013).
151. H.K. Chan, X. Wang, G.R.T. White and N. Yip, An extended fuzzy-ahp approach for the evaluation of green product designs, *IEEE Trans. Eng. Manag,* **60,** 327–339 (2013).
152. C.W. Lam, et al., Integrating toxicity reduction strategies for materials and components into product design: A case study on utility meters, *Integr. Environ. Assess. Manag,* **9,** 319–328 (2013).
153. D. Maga, M. Hiebel and C. Knermann, Comparison of two ICT solutions: Desktop PC versus thin client computing, *Int. J. LIFE CYCLE Assess.,* **18,** 861–871 (2013).
154. Y. Mery, L. Tiruta-Barna, E. Benetto and I. Baudin, An integrated "process modelling-life cycle assessment" tool for the assessment and design of water treatment processes, *Int. J. LIFE CYCLE Assess.,* **18,** 1062–1070 (2013).
155. N. Mirabella, V. Castellani and S. Sala, Life cycle assessment of bio-based products: A disposable diaper case study, *Int. J. LIFE CYCLE Assess.,* **18,** 1036–1047 (2013).
156. T. Zimmermann, Parameterized tool for site specific LCAs of wind energy converters, *Int. J. LIFE CYCLE Assess.,* **18,** 49–60 (2013).
157. A. Mestre and J. Vogtlander, Eco-efficient value creation of cork products: an LCA-based method for design intervention, *J. Clean. Prod.,* **57,** 101–114 (2013).
158. N. Tchertchian, P.-A. Yvars and D. Millet, Benefits and limits of a Constraint Satisfaction Problem/Life Cycle Assessment approach for the ecodesign of complex systems: a case applied to a hybrid passenger ferry, *J. Clean. Prod.,* **42,** 1–18 (2013).
159. H. Andriankaja, G. Bertoluci and D. Millet, Development and integration of a simplified environmental assessment tool based on an environmental categorisation per range of products, *J. Eng. Des.,* **24,** 1–24 (2013).
160. D. Collado-Ruiz and H. Ostad-Ahmad-Ghorabi, Estimating environmental behavior without performing a life cycle assessment, *J. Ind. Ecol.* **17,** 31–42 (2013).
161. X.L. Zhao, W. Li and J. Stanbrook, A framework for the integration of performance based design and life cycle assessment to design sustainable structures, *Adv. Struct. Eng.,* **17,** 461–470 (2014).
162. H.K. Chan, X. Wang and A. Raffoni, An integrated approach for green design: Life-cycle, fuzzy AHP and environmental management accounting, *Br. Account. Rev.,* **46,** 344–360 (2014).
163. S.-J. Kim and S. Kara, Predicting the total environmental impact of product technologies, *CIRP Ann. Technol,* **63,** 25–28 (2014).
164. F. Toyasaki, P. Daniele and T. Wakolbinger, A variational inequality formulation of equilibrium models for end-of-

life products with nonlinear constraints, *Eur. J. Oper. Res.*, **236,** 340–350 (2014).
165. X. Wang, H.K. Chan and D. Li, A case study of an integrated fuzzy methodology for green product development, *Eur. J. Oper. Res.*, **241,** 212–223 (2014).
166. F. Ardente and F. Mathieux, Identification and assessment of product's measures to improve resource efficiency: the case-study of an Energy using Product, *J. Clean. Prod.*, **83,** 126–141 (2014).
167. F. Ardente and F. Mathieux, Environmental assessment of the durability of energy-using products: Method and application, *J. Clean. Prod.*, **74,** 62–73 (2014).
168. J. Bonvoisin, A. Lelah, F. Mathieux and D. Brissaud, An integrated method for environmental assessment and ecodesign of ICT-based optimization services, *J. Clean. Prod.*, **68,** 144–154 (2014).
169. S.J. Clune and S. Lockrey, Developing environmental sustainability strategies, the Double Diamond method of LCA and design thinking: A case study from aged care, *J. Clean. Prod.* **85,** 67–82 (2014).
170. S.J. Kim, S. Kara and B. Kayis, Economic and environmental assessment of product life cycle design: volume and technology perspective, *J. Clean. Prod.*, **75,** 75–85 (2014).
171. A. Le Duigou and C. Baley, Coupled micromechanical analysis and life cycle assessment as an integrated tool for natural fibre composites development, *J. Clean. Prod.*, **83,** 61–69 (2014).
172. J.R. Perez-Gallardo, C. Azzaro-Pantel, S. Astier, S. Domenech and A. Aguilar-Lasserre, Ecodesign of photovoltaic grid-connected systems, *Renew. ENERGY,* **64,** 82–97 (2014).
173. A. Jullien, M. Dauvergne and C. Proust, Road LCA: The dedicated ECORCE tool and database, *Int. J. LIFE CYCLE Assess.*, **20,** 655–670 (2015).
174. Q. Meng, et al., A rapid life cycle assessment method based on green features in supporting conceptual design, *Int. J. Precis. Eng. Manuf. Technol,* **2,** 189–196 (2015).
175. D.R. Iritani, D.A.L. Silva, Y.M.B. Saavedra, P.F.F. Grael and A.R. Ometto, Sustainable strategies analysis through Life Cycle Assessment: A case study in a furniture industry, *J. Clean. Prod.*, **96,** 308–318 (2015).
176. L.H.U. Materials selection for optimal environmental impact in mechanical design, (1998).
177. M.D. Bovea and R. Vidal, Materials selection for sustainable product design: A case study of wood based furniture eco-design, *Mater. Des.*, **25,** 111–116 (2004).
178. F. Giudice, G. La Rosa and A. Risitano, Materials selection in the Life-Cycle Design process: A method to integrate mechanical and environmental performances in optimal choice, *Mater. Des.*, **26,** 9–20 (2005).
179. H. Huang, Z. Liu, L. Zhang and J.W. Sutherland, Materials selection for environmentally conscious design via a proposed life cycle environmental performance index, *Int. J. Adv. Manuf. Technol,* **44,** 1073–1082 (2009).
180. J. Kim, Y. Hwang and K. Park, An assessment of the recycling potential of materials based on environmental and economic factors: Case study in South Korea, *J. Clean. Prod.*, **17,** 1264–1271 (2009).
181. L. Perez-Redondas, J. Asensio-Lozano and M. Angeles Garcia, An environmentally-friendly materials selection method: a proposal aimed at first- and second-cycle engineering students, *J. Mater. Educ.*, **32,** 139–152 (2010).
182. H. Huang, L. Zhang, Z. Liu and J.W. Sutherland, Multi-criteria decision making and uncertainty analysis for materials selection in environmentally conscious design, *Int. J. Adv. Manuf. Technol,* **52,** 421–432 (2011).
183. C. Allione, C. De Giorgi, B. Lerma and L. Petruccelli, From ecodesign products guidelines to materials guidelines for a sustainable product. Qualitative and quantitative multicriteria environmental profile of a material, *Energy,* **39,** 90–99 (2012).
184. J. Asensio-Lozano, L. Perez-Redondas, M. Angeles Garcia-Garcia and J.F. Alvarez-Antolin, A materials selection and design procedure for selection of automobile vehicles that are environmentally friendly in terms of available energy resources, *J. Mater. Educ.*, **34,** 1–19 (2012).
185. L. Qiu, L. Sun, X. Liu and S. Zhang, Material selection combined with optimal structural design for mechanical parts, *J. Zhejiang Univ. A,* **14,** 383–392 (2013).
186. M.R. Mansor, S.M. Sapuan, E.S. Zainudin, A.A. Nuraini and A. Hambali, Hybrid natural and glass fibers reinforced polymer composites material selection using Analytical Hierarchy Process for automotive brake lever design, *Mater. Des.*, **51,** 484–492 (2013).
187. P. Pecas, I. Ribeiro, A. Silva and E. Henriques, Comprehensive approach for informed life cycle-based materials selection, *Mater. Des.*, **43,** 220–232 (2013).
188. I. Ribeiro, P. Pecas and E. Henriques, A life cycle framework to support materials selection for Ecodesign: A case study on biodegradable polymers, *Mater. Des.*, **51,** 300–308 (2013).
189. S. Prendeville, F. O'Connor and L. Palmer, Material selection for eco-innovation: SPICE model, *J. Clean. Prod.*, **85,** 31–40 (2014).
190. H.-T. Chang and C.-H. Lu, Simultaneous evaluations of material toxicity and ease of disassembly during electronics design integrating environmental assessments with commercial computer-aided design software, *J. Ind. Ecol.*, **18,** 478–490 (2014).
191. S. Siddhaye and P. Sheng, Integration of environmental factors in pre-layout design optimization for printed circuit boards, *J. Electron. Manuf,* **8,** 1–14 (1998).
192. G.C.C. Yang, CMP wastewater management using the concepts of design for environment, *Environ. Prog.*, **21,** 57–62 (2002).
193. H.-Z. Huang, Y.-K. Gu and Z.-G. Tian, Integrated product and process development model supporting life cycle, *Int. J. Ind. Eng. Appl. Pract.*, **13,** 270–279 (2006).

194. N. Hopkinson, Y. Gao and D.J. McAfee, Design for environment analyses applied to rapid manufacturing, *Proc. Inst. Mech. Eng. PART D-JOURNAL Automob. Eng.,* **220,** 1363–1372 (2006).
195. A. Helland, Dealing with uncertainty and pursuing superior technology options in risk management—The inherency risk analysis, *J. Hazard. Mater.,* **164,** 995–1003 (2009).
196. S. Vinodh, Improvement of agility and sustainability: A case study in an Indian rotary switches manufacturing organisation, *J. Clean. Prod.,* **18,** 1015–1020 (2010).
197. M.D.K.L. Wood, F. Mathieux, D. Brissaud and D. Evrard, Results of the first adapted design for sustainability project in a South Pacific small Island developing state: Fiji, *J. Clean. Prod.,* **18,** 1775–1786 (2010).
198. T. Short, A. Lee-Mortimer, C. Luttropp and G. Johansson, Manufacturing, sustainability, ecodesign and risk: Lessons learned from a study of Swedish and English companies, *J. Clean. Prod.,* **37,** 342–352 (2012).
199. J. Bonvoisin, S. Thiede, D. Brissaud and C. Herrmann, An implemented framework to estimate manufacturing-related energy consumption in product design, *Int. J. Comput. Integr. Manuf,* **26,** 866–880 (2013).
200. M. Mani, B. Johansson, K.W. Lyons, R.D. Sriram and G. Ameta, Simulation and analysis for sustainable product development, *Int. J. LIFE CYCLE Assess.,* **18,** 1129–1136 (2013).
201. H.S. Park and T.T. Nguyen, Optimization of roll forming process with evolutionary algorithm for green product, *Int. J. Precis. Eng. Manuf,* **14,** 2127–2135 (2013).
202. M. Strano, M. Monno and A. Rossi, Optimized design of press frames with respect to energy efficiency, *J. Clean. Prod.,* **41,** 140–149 (2013).
203. F. Pacelli, F. Ostuzzi and M. Levi, Reducing and reusing industrial scraps: A proposed method for industrial designers, *J. Clean. Prod.,* **86,** 78–87 (2015).
204. M.A. Hersh, A systems approach to green design, with illustrations from the computer industry, *Syst. Res. Behav. Sci.,* **15,** 497–510 (1998).
205. A.J.C. Trappey, C.V. Trappey, C.-T. Hsiao, J.J.R. Ou and C.-T. Chang, System dynamics modelling of product carbon footprint life cycles for collaborative green supply chains, *Int. J. Comput. Integr. Manuf.,* **25,** 934–945 (2012).
206. P. Yan, M. Zhou and D. Sebastian, An integrated product and process development methodology: Concept formulation, *Robot. Comput. Integr. Manuf,* **15,** 201–210 (1999).
207. L. Cedola and G. Di Stasio, Development and application to a real scenario of a design for environment methodology for power plants, *J. ENERGY Resour. Technol, ASME* **123,** 297–303 (2001).
208. M.Z. Hauschild, J. Jeswiet and L. Alting, Design for environment—Do we get the focus right? *CIRP Ann. Technol,* **53,** 1–4 (2004).
209. H. Kobayashi, Strategic evolution of eco-products: A product life cycle planning methodology, *Res. Eng. Des.,* **16,** 1–16 (2005).
210. H. Kobayashi, A systematic approach to eco-innovative product design based on life cycle planning, *Adv. Eng. Informatics,* **20,** 113–125 (2006).
211. G. Howarth and M.A. Hadfield, Sustainable product design model, *Mater. Des.,* **27,** 1128–1133 (2006).
212. Q.L. Xu, S.K. Ong and A.Y.C. Nee, Evaluation of product performance in product family design re-use, *Int. J. Prod. Res.,* **45,** 4119–4141 (2007).
213. K. Kernstine, B. Boling, L. Bortner, E. Hendricks and D. Mavris, Designing for a green future: a unified aircraft design methodology, *J. Aircr.,* **47,** 1789–1797 (2010).
214. J.H. Spangenberg, A. Fuad-Luke and K. Blincoe, Design for Sustainability (DfS): the interface of sustainable production and consumption, *J. Clean. Prod.,* **18,** 1485–1493 (2010).
215. B. Lu, J. Zhang, D. Xue and P. Gu, Systematic lifecycle design for sustainable product development, *Concurr. Eng. Appl.,* **19,** 307–323 (2011).
216. D. Abbes, A. Martinez and G. Champenois, Eco-design optimisation of an autonomous hybrid wind-photovoltaic system with battery storage, *IET Renew. POWER Gener,* **6,** 358–371 (2012).
217. P.H. Driessen, B. Hillebrand, R.A.W. Kok and T.M.M. Verhallen, Green new product development: the pivotal role of product greenness, *IEEE Trans. Eng. Manag,* **60,** 315–326 (2013).
218. P. Deutz, M. McGuire and G. Neighbour, Eco-design practice in the context of a structured design process: An interdisciplinary empirical study of UK manufacturers, *J. Clean. Prod.,* **39,** 117–128 (2013).
219. C. Achillas, D. Aidonis, C. Vlachokostas, D. Folinas and N. Moussiopoulos, Re-designing industrial products on a multi-objective basis: A case study, *J. Oper. Res. Soc.,* **64,** 1336–1346 (2013).
220. S.J. Kim, S. Kara and B. Kayis, Analysis of the impact of technology changes on the economic and environmental influence of product life-cycle design, *Int. J. Comput. Integr. Manuf,* **27,** 422–433 (2014).
221. C. Gauthier and C. Genet, Nanotechnologies and green knowledge creation: paradox or enhancer of sustainable solutions? *J. Bus. ETHICS,* **124,** 571–583 (2014).
222. J.-R. Chou, An ARIZ-based life cycle engineering model for eco-design, *J. Clean. Prod.,* **66,** 210–223 (2014).
223. R. Carlson, M. Erixon, P. Forsberg and A.C. Palsson, System for integrated business environmental information management, *Adv. Environ. Res.,* **5,** 369–375 (2001).
224. R. Houe and B. Grabot, Knowledge modeling for eco-design, *Concurr. Eng. Appl.,* **15,** 7–20 (2007).
225. X. Yang, P.R. Moore, C.-B. Wong, J.-S. Pu and S.K. Chong, Product lifecycle information acquisition and management for consumer products, *Ind. Manag. DATA Syst.,* **107,** 936–953 (2007).

226. S.K.S. Wong, Environmental requirements, knowledge sharing and green innovation: empirical evidence from the electronics industry in China, *Bus. Strateg. Environ,* **22,** 321–338 (2013).
227. V. Goepp, E. Caillaud and B. Rose, A framework for the design of knowledge management systems in eco-design, *Int. J. Prod. Res.,* **51,** 5803–5823 (2013).
228. F. Zhang, et al., Toward an systemic navigation framework to integrate sustainable development into the company, *J. Clean. Prod.,* **54,** 199–214 (2013).
229. M. Rio, T. Reyes and L. Roucoules, FESTivE: An information system method to improve product designers and environmental experts information exchanges, *J. Clean. Prod.,* **83,** 329–340 (2014).
230. D. Eddy, et al., An integrated approach to information modeling for the sustainable design of products, *J. Comput. Inf. Sci. Eng.,* **14,** (2014).
231. H. Andriankaja, F. Vallet, J. Le Duigou and B. Eynard, A method to ecodesign structural parts in the transport sector based on product life cycle management, *J. Clean. Prod.,* **94,** 165–176 (2015).
232. M.K. Low and D.J. Williams, A framework to encourage step-change reduction in environmental impact in the creation of electronics products, *IEEE Trans. Electron. Packag. Manuf,* **24,** 136–143 (2001).
233. J.Y. Zhu and A. Deshmukh, Application of Bayesian decision networks to life cycle engineering in Green design and manufacturing, *Eng. Appl. Artif. Intell,* **16,** 91–103 (2003).
234. G.A. Keoleian and K. Kar, Elucidating complex design and management tradeoffs through life cycle design: Air intake manifold demonstration project, *J. Clean. Prod.,* **11,** 61–77 (2003).
235. R. Gheorghe and P. Xirouchakis, Decision-based methods for early phase sustainable product design, *Int. J. Eng. Educ.,* **23,** 1065–1080 (2007).
236. K. Verghese and D. Hes, Qualitative and quantitative tool development to support environmentally responsible decisions, *J. Clean. Prod.,* **15,** 814–818 (2007).
237. K. Sakita and T. Mori, Environmental simulation system for environmentally conscious product design, *STROJARSTVO,* **49,** 85–89 (2007).
238. P. Boonkanit and A. Aphikajornsin, An energetic ecodesign at conceptual design phase, *Int. J. Ind. Eng. Appl. Pract.,* **17,** 190–199 (2010).
239. A. Anand and M.F. Wani, Product life-cycle modeling and evaluation at the conceptual design stage: A digraph and matrix approach, *J. Mech. Des.,* **132,** (2010).
240. S. Devanathan, D. Ramanujan, W.Z. Bernstein, F. Zhao and K. Ramani, Integration of sustainability into early design through the function impact matrix, *J. Mech. Des.,* **132,** 081004 (2010).
241. D.P. Fitzgerald, J.W. Herrmann and L.C. Schmidt, A conceptual design tool for resolving conflicts between product functionality and environmental impact, *J. Mech. Des.,* **132,** 091006 (2010).
242. D.-C. Gong and Y.-T. Wang, UML presentation of a conceptual green design control system to react to environmental requirements, *Int. J. Adv. Manuf. Technol,* **52,** 463–476 (2011).
243. A. Kengpol and P. Boonkanit, The decision support framework for developing Ecodesign at conceptual phase based upon ISO/TR 14062, *Int. J. Prod. Econ.,* **131,** 4–14 (2011).
244. T.-A. Chiang, Z.H. Che and T.-T. Wang, A design for environment methodology for evaluation and improvement of derivative consumer electronic product development, *J. Syst. Sci. Syst. Eng.,* **20,** 260–274 (2011).
245. M. Inoue, et al., Decision-making support for sustainable product creation, *Adv. Eng. INFORMATICS,* **26,** 782–792 (2012).
246. C.-C. Tsai, A research on selecting criteria for new green product development project: Taking Taiwan consumer electronics products as an example, *J. Clean. Prod.,* **25,** 106–115 (2012).
247. C. Chen and J. Zhang, Green product design with engineering tradeoffs under technology efficient frontiers: analytical results and empirical tests, *IEEE Trans. Eng. Manag,* **60,** 340–352 (2013).
248. C.Y. Ng and K.B. Chuah, Evaluation of design alternatives' environmental Performance using AHP and ER approaches, *IEEE Syst. J.,* **8,** 1182–1189 (2014).
249. X. Wang, H.K. Chan and L. White, A comprehensive decision support model for the evaluation of eco-designs, *J. Oper. Res. Soc.,* **65,** 917–934 (2014).
250. X. Wang, H.K. Chan, C.K.M. Lee and D. Li, A hierarchical model for eco-design of consumer electronic products, *Technol. Econ. Dev. Econ.,* **21,** 48–64 (2015).
251. T.A. Lenau and N. Bey, Design of environmentally friendly products using indicators, *Int. J. Manuf. Eng.,* **215,** 637–645 (2001).
252. I.-T. Jeong and K.-M. Lee, Assessment of the ecodesign improvement options using the global warming and economic performance indicators, *J. Clean. Prod.,* **17,** 1206–1213 (2009).
253. M.D. Tabone, J.J. Cregg, E.J. Beckman and A.E. Landis, Sustainability Metrics: Life Cycle Assessment and Green Design in Polymers, *Environ. Sci. Technol.,* **44,** 8264–8269 (2010).
254. C. Askham, A.L. Gade and O.J. Hanssen, Combining REACH, environmental and economic performance indicators for strategic sustainable product development, *J. Clean. Prod.,* **35,** 71–78 (2012).
255. L.D. Ingeneer, F. Mathieux and D. Brissaud, A new 'in-use energy consumption' indicator for the design of energy-efficient electr(on)ics, *J. Eng. Des.,* **23,** 217–235 (2012).
256. C.A. Dean, B.D. Fath and B. Chen, Indicators for an expanded business operations model to evaluate eco-smart corporate communities, *Ecol. Indic.,* **47,** 137–148 (2014).

257. C.L. Chen, Design for the environment: A quality-based model for green product development, *Manage. Sci.,* **47,** 250–263 (2001).
258. J.L. De Vries and H.R.M. te Riele, Playing with hyenas—Renovating environmental product policy strategy, *J. Ind. Ecol.,* **10,** 111–127 (2006).
259. F. Schiavone, M. Pierini and V. Eckert, Strategy-based approach to eco-design: Application to an automotive component, *Int. J. Veh. Des.,* **46,** 156–171 (2008).
260. J.K. Choi, L.F. Nies and K. Ramani, A framework for the integration of environmental and business aspects toward sustainable product development, *J. Eng. Des.,* **19,** 431–446 (2008).
261. S. Kondoh and N. Mishima, Strategic decision-making method for eco-business planning, *CIRP Ann.—Manuf. Technol,* **59,** 41–44 (2010).
262. S.H.M. Zailani, T.K. Eltayeb, C.-C. Hsu and K.C. Tan, The impact of external institutional drivers and internal strategy on environmental performance, *Int. J. Oper. Prod. Manag,* **32,** 721–745 (2012).
263. Y.-S Chen and C.-H. Chang, The determinants of green product development performance: green dynamic capabilities, green transformational leadership and green creativity, *J. Bus. ETHICS,* **116,** 107–119 (2013).
264. S.I. Hallstedt, A.W. Thompson and P. Lindahl, Key elements for implementing a strategic sustainability perspective in the product innovation process, *J. Clean. Prod.,* **51,** 277–288 (2013).
265. J.-C. Tu, P.-L. Chiu, Y.-C. Huang and C.-Y. Hsu, Influential factors and strategy of sustainable product development under corporate social responsibility in taiwan, *Math. Probl. Eng.,* (2013), doi:10.1155/2013/303850.
266. V. Panapanaan, T. Uotila and A. Jalkala, creation and alignment of the eco-innovation strategy model to regional innovation strategy: A case from lahti (Paijat-Hame Region), Finland, *Eur. Plan. Stud.,* **22,** 1212–1234 (2014).
267. H. Kim, S.H. Lee and K. Yang, The heuristic-systemic model of sustainability stewardship: Facilitating sustainability values, beliefs and practices with corporate social responsibility drives and eco-labels/indices, *Int. J. Consum. Stud,* **39,** 249–260 (2015).
268. C.-H. Chang, Proactive and reactive corporate social responsibility: Antecedent and consequence, *Manag. Decis.,* **53,** 451–468 (2015).
269. W.P. Schmidt, Life cycle costing as part of design for environment - Environmental business cases, *Int. J. LIFE CYCLE Assess.,* **8,** 167–174 (2003).
270. H.-M. Wee, M.-C. Lee, J.C.P. Yu and C.E. Wang, Optimal replenishment policy for a deteriorating green product: Life cycle costing analysis, *Int. J. Prod. Econ.,* **133,** 603–611 (2011).
271. T. Sakao, A QFD-centred design methodology for environmentally conscious product design, *Int. J. Prod. Res.,* **45,** 4143–4162 (2007).
272. C.P. Ge and B. Wang, An activity-based modelling approach for assessing the key stakeholders' corporation in the eco-conscious design of electronic products, *J. Eng. Des.,* **18,** 55–71 (2007).
273. P. Park and K. Tahara, Quantifying producer and consumer-based eco-efficiencies for the identification of key ecodesign issues, *J. Clean. Prod.,* **16,** 95–104 (2008).
274. E.F. MacDonald, R. Gonzalez and P.Y. Papalambros, Preference Inconsistency in Multidisciplinary Design Decision Making, *J. Mech. Des.,* **131,** (2009).
275. T. Ramayah, J.W.C. Lee and O. Mohamad, Green product purchase intention: Some insights from a developing country, *Resour. Conserv. Recycl,* **54,** 1419–1427 (2010).
276. L. Zhang, Y. Zhan, Z.F. Liu, H.C. Zhang and B.B. Li, Development and analysis of design for environment oriented design parameters, *J. Clean. Prod.,* **19,** 1723–1733 (2011).
277. S. Vinodh and G. Rathod, Application of fuzzy logic-based environmental conscious QFD to rotary switch: A case study, *CLEAN Technol. Environ. POLICY,* **14,** 319–332 (2012).
278. C.-S. Liao, K.-R. Lou and C.-T. Gao, Sustainable Development of Electrical and Electronic Equipment: User-driven Green Design for Cell Phones, *Bus. Strateg. Environ,* **22,** 36–48 (2013).
279. W.-M. Hur, Y. Kim and K. Park, Assessing the effects of perceived value and satisfaction on customer loyalty: A 'Green' perspective, *Corp. Soc. Responsib. Environ. Manag,* **20,** 146–156 (2013).
280. I. Bereketli and M.E. Genevois, An integrated QFDE approach for identifying improvement strategies in sustainable product development, *J. Clean. Prod.,* **54,** 188–198 (2013).
281. S.-C. Tseng and S.-W. Hung, A framework identifying the gaps between customers' expectations and their perceptions in green products, *J. Clean. Prod.* **59,** 174–184 (2013).
282. S. Vinodh, V. Kamala and K. Jayakrishna, Integration of ECQFD, TRIZ and AHP for innovative and sustainable product development, *Appl. Math. Model,* **38,** 2758–2770 (2014).
283. E. Cor, L. Domingo, D. Brissaud and P. Zwolinski, A protocol to perform usage oriented ecodesign, *CIRP Ann. Technol,* **63,** 169–172 (2014).
284. F. Lemke and J.P.P. Luzio, Exploring green consumers' mind-set toward green product design and life cycle assessment the case of skeptical brazilian and portuguese green consumers, *J. Ind. Ecol.,* **18,** 619–630 (2014).
285. J. Ammenberg and E. Sundin, Products in environmental management systems: The role of auditors, *J. Clean. Prod.,* **13,** 417–431 (2005).
286. P. Erol and J. Thoming, ECO-design of reuse and recycling networks by multi-objective optimization, *J. Clean. Prod.,* **13,** 1492–1503 (2005).

287. J. Tingstrom, L. Swanstrom and R. Karlsson, Sustainability management in product development projects—The ABB experience, *J. Clean. Prod.,* **14,** 1377–1385 (2006).

288. H. Ny, J.P. MacDonald, G. Broman, R. Yamamoto and K.H. Robert, Sustainability constraints as system boundaries—An approach to making life-cycle management strategic, *J. Ind. Ecol.,* **10,** 61–77 (2006).

289. N.-J. Chang, C.-M. Fong, Green product quality, green corporate image, green customer satisfaction and green customer loyalty, *AFRICAN J. Bus. Manag,* **4,** 2836–2844 (2010).

290. R. Pamfilie, R. Procopie and M. Bobe, Managing eco-design of industrial goods and consumers' protection nexus, *AMFITEATRU Econ.,* **12,** 454–465 (2010).

291. P. Kurczewski and A. Lewandowska, ISO 14062 in theory and practice—ecodesign procedure. Part 2: Practical application, *Int. J. Life Cycle Assess.,* 777–784 (2010), doi:10.1007/s11367–010–0231–0.

292. A. Lewandowska and P. Kurczewski, ISO 14062 in theory and practice—ecodesign procedure, Part 1: Structure and theory, *Int. J.* 769–776 (2010), doi:10.1007/s11367–010–0228–8.

293. S. Vinodh, M. Prasanna and S. Manoj, Application of analytical network process for the evaluation of sustainable business practices in an Indian relays manufacturing organization, *CLEAN Technol. Environ. POLICY,* **14,** 309–317 (2012).

294. W.-H. Tsai, et al., Applying a mathematical programming approach for a green product mix decision, *Int. J. Prod. Res.,* **50,** 1171–1184 (2012).

295. D.C. Pigosso, H.a. Rozenfeld and T.C. McAloone, Ecodesign maturity model: A management framework to support ecodesign implementation into manufacturing companies, *J. Clean. Prod.,* 1–14 (2013), doi:10.1016/j.jclepro.2013.06.040.

296. A.A. Alblas, K. (Alex), Peters, J.C. (Kristian) and Wortmann, (Hans). Fuzzy sustainability incentives in new product development An empirical exploration of sustainability challenges in manufacturing companies, *Int. J. Oper. Prod. Manag,* **34,** 513–545 (2014).

297. M. Fargnoli, M. De Minicis and M. Tronci, Design Management for Sustainability: An integrated approach for the development of sustainable products, *J. Eng. Technol. Manag,* **34,** 29–45 (2014).

298. G. Radonjic, A. Pisnik and D. Krajnc, Product ecodesign in companies with iso 14001 certified environmental management system, *Environ. Eng. Manag. J.,* **14,** 167–181 (2015).

299. F. Brones and M.M. de Carvalho, From 50 to 1: Integrating literature toward a systemic ecodesign model, *J. Clean. Prod.,* **96,** 44–57 (2015).

300. C.J. Chiappetta Jabbour, D. Jugend, A.B. de Sousa Jabbour, A. Gunasekaran and H. Latan, Green product development and performance of Brazilian firms: Measuring the role of human and technical aspects, *J. Clean. Prod.,* **87,** 442–451 (2015).

301. M. Lindahl, Engineering designers' experience of design for environment methods and tools—requirement definitions from an interview study, *J. Clean. Prod.,* **14,** 487–496 (2006).

302. N.V. Hernandez, G.O. Kremer, L.C. Schmidt and P.R.A. Herrera, Development of an expert system to aid engineers in the selection of design for environment methods and tools, *Expert Syst. Appl.,* **39,** 9543–9553 (2012).

303. M.-C. Chiu and C.-H. Chu, Review of sustainable product design from life cycle perspectives, *Int. J. Precis. Eng. Manuf,* **13,** 1259–1272 (2012).

304. A. Birch, K.K.B. Hon and T. Short, Structure and output mechanisms in Design for Environment (DfE) tools, *J. Clean. Prod.,* **35,** 50–58 (2012).

305. J.L. Casamayor and D. Su, Integration of eco-design tools into the development of eco-lighting products, *J. Clean. Prod.,* **47,** 32–42 (2013).

306. V. Goepp, B. Rose and E. Caillaud, Coupling reference modelling and performance evaluation for the effective integration of eco-design tools into the design process, *Int. J. Comput. Integr. Manuf,* **27,** 242–265 (2014).

307. C. Vezzoli and D. Sciama, 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, *J. Clean. Prod.,* **14,** 1319–1325 (2006).

308. S. Byggeth, G. Broman and K.-H. Robert, A method for sustainable product development based on a modular system of guiding questions, *J. Clean. Prod.,* **15,** 1–11 (2007).

309. C. Alves, et al., Sustainable design procedure: The role of composite materials to combine mechanical and environmental features for agricultural machines, *Mater. Des.,* **30,** 4060–4068 (2009).

310. Y. Kishita, et al., Checklist-Based Assessment Methodology for Sustainable Design, *J. Mech. Des.,* **132,** (2010).

311. J.P. Santos, M. Oliveira, F.G. Almeida, J.P. Pereira and A. Reis, Improving the environmental performance of machine-tools: Influence of technology and throughput on the electrical energy consumption of a press-brake. *J. Clean. Prod.* **19,** 356–364 (2011).

312. C.A. Grote, R.M. Jones, G.N. Blount, J. Goodyer and M. Shayler, An approach to the EuP Directive and the application of the economic eco-design for complex products, *Int. J. Prod. Res.,* **45,** 4099–4117 (2007).

313. K. Parikka-Alhola, Promoting environmentally sound furniture by green public procurement, *Ecol. Econ.,* **68,** 472–485 (2008).

314. M. Zackrisson, C. Rocha, K. Christiansen and A. Jarnehammar, Stepwise environmental product declarations: Ten SME case studies, *J. Clean. Prod.,* **16,** 1872–1886 (2008).

315. F. Taghaboni-Dutta, A.J.C. Trappey and C.V. Trappey, An XML based supply chain integration hub for green product lifecycle management, *Expert Syst. Appl.,* **37,** 7319–7328 (2010).

316. E. Brouillat and V. Oltra, Extended producer responsibility instruments and innovation in eco-design: An exploration through a simulation model, *Ecol. Econ.,* **83,** 236–245 (2012).
317. W.K.C. Yung, et al., Eco-redesign of a personal electronic product subject to the energy-using product directive, *Int. J. Prod. Res.,* **50,** 1411–1423 (2012).
318. M. Dubois, Extended producer responsibility for consumer waste: The gap between economic theory and implementation, *WASTE Manag. Res.,* **30,** 36–42 (2012).
319. K. Schischke, N.F. Nissen and K.-D. Lang, Welding Equipment under the Energy-related Products Directive The Process of Developing Eco-design Criteria, *J. Ind. Ecol.,* **18,** 517–528 (2014).
320. S. Le Pochat, G. Bertoluci and D. Froelich, Integrating ecodesign by conducting changes in SMEs, *J. Clean. Prod.,* **15,** 671–680 (2007).
321. S. Gonzalez-Garcia, et al., Application of ecodesign methodology in smes run according to lean management: the case of a furniture publishing company, *Environ. Eng. Manag. J.,* **13,** 2977–2988 (2014).
322. Y. Umeda, S. Fukushige, K. Tonoike and S. Kondoh, Product modularity for life cycle design, *CIRP Ann.—Manuf. Technol,* **57,** 13–16 (2008).
323. S. Hickey, C. Fitzpatrick, M. O'Connell and M. Johnson, Use phase signals to promote lifetime extension for windows PCs, *Environ. Sci. Technol,* **43,** 2544–2549 (2009).
324. X. Qian and H.C. Zhang, Design for Environment: An Environmentally Conscious Analysis Model for Modular Design, *IEEE Trans. Electron. Packag. Manuf,* **32,** 164–175 (2009).
325. S. Smith and C.-C. Yen, Green product design through product modularization using atomic theory, *Robot. Comput. Integr. Manuf,* **26,** 790–798 (2010).
326. O. Pialot, D. Millet and N. Tchertchian, How to explore scenarios of multiple upgrade cycles for sustainable product innovation: the "Upgrade Cycle Explorer" tool, *J. Clean. Prod.,* **22,** 19–31 (2012).
327. J. Yan, C. Feng and K. Cheng, Sustainability-oriented product modular design using kernel-based fuzzy c-means clustering and genetic algorithm, *Proc. Inst. Mech. Eng. PART B-JOURNAL Eng. Manuf,* **226,** 1635–1647 (2012).
328. V.N. Ajukumar and O.P. Gandhi, Evaluation of green maintenance initiatives in design and development of mechanical systems using an integrated approach, *J. Clean. Prod.,* **51,** 34–46 (2013).
329. Y. Ji, R.J. Jiao, L. Chen and C. Wu, Green modular design for material efficiency: A leader follower joint optimization model, *J. Clean. Prod.,* **41,** 187–201 (2013).
330. C. Bakker, F. Wang, J. Huisman and M. den Hollander, Products that go round: exploring product life extension through design, *J. Clean. Prod.,* **69,** 10–16 (2014).
331. S. Yu, Q. Yang, J. Tao and X. Xu, Incorporating Quality Function Deployment with modularity for the end-of-life of a product family, *J. Clean. Prod.,* **87,** 423–430 (2015).
332. I. Ben-Gal, R. Katz and Y. Bukchin, Robust eco-design: A new application for air quality engineering, *IIE Trans,* **40,** 907–918 (2008).
333. I. Gremyr, V. Siva, H. Raharjo and T.N. Goh, Adapting the Robust Design Methodology to support sustainable product development, *J. Clean. Prod.,* **79,** 231–238 (2014).
334. S. Hoffenson, A. Dagman and R. Soderberg, Tolerance optimisation considering economic and environmental sustainability, *J. Eng. Des.,* **25,** 367–390 (2014).
335. R.M. Dangelico and P. Pontrandolfo, From green product definitions and classifications to the green option matrix, *J. Clean. Prod.,* **18,** 1608–1628 (2010).
336. A. Sharma and G.R. Iyer, Resource-constrained product development: Implications for green marketing and green supply chains, *Ind. Mark. Manag,* **41,** 599–608 (2012).
337. B.C.Y. Lee, Critical decisions in new product launch: Pricing and advertising strategies on consumer adoption of green product innovation, *ASIAN J. Technol. Innov.,* **22,** 16–32 (2014).
338. J. Ma, M. Kwak and H.M. Kim, Demand trend mining for predictive life cycle design, *J. Clean. Prod.,* **68,** 189–199 (2014).
339. E. Sanye-Mengual, et al., Eco-Designing the use phase of products in sustainable manufacturing the importance of maintenance and communication-to-user strategies, *J. Ind. Ecol.,* **18,** 545–557 (2014).
340. N. Kaufman, Overcoming the barriers to the market performance of green consumer goods, *Resour. ENERGY Econ.,* **36,** 487–507 (2014).
341. J. Kim, H. Wang, J. Kim and S. Lee, The analysis and design of rf sub-sampling frontend for SDR, *Aperture,* **5,** 5–9
342. K.-H. Lee and J.-W. Kim, Integrating suppliers into green product innovation development: an empirical case study in the semiconductor industry, *Bus. Strateg. Environ,* **20,** 527–538 (2011).
343. T. Arslan, V. Yilmaz and H.K. Aksoy, Structural equation model for environmentally conscious purchasing behavior, *Int. J. Environ. Res.,* **6,** 323–334 (2012).
344. M.-C. Chiu and L.-W. Teng, sustainable product and supply chain design decisions under uncertainties, *Int. J. Precis. Eng. Manuf,* **14,** 1953–1960 (2013).
345. V.-H. Lee, K.-B. Ooi, A.Y.-L. Chong and C. Seow, Creating technological innovation via green supply chain management: An empirical analysis, *Expert Syst. Appl.,* **41,** 6983–6994 (2014).
346. R. Rostamzadeh, K. Govindan, A. Esmaeili and M. Sabaghi, Application of fuzzy VIKOR for evaluation of green supply chain management practices, *Ecol. Indic.,* **49,** 188–203 (2015).
347. N.M.P. Bocken, J.M. Allwood, A.R. Willey and J.M.H. King, Development of an eco-ideation tool to identify stepwise greenhouse gas emissions reduction options for consumer goods, *J. Clean. Prod.,* **19,** 1279–1287 (2011).
348. C.J. Yang and J.L. Chen, Accelerating preliminary eco-innovation design for products that integrates case-based

reasoning and TRIZ method, *J. Clean. Prod.,* **19,** 998–1006 (2011).

349. D. Russo, C. Rizzi and G. Montelisciani, Inventive guidelines for a TRIZ-based eco-design matrix, *J. Clean. Prod.,* **76,** 95–105 (2014).
350. B. Tyl, J. Legardeur, D. Millet and F. Vallet, A comparative study of ideation mechanisms used in eco-innovation tools, *J. Eng. Des.,* **25,** 325–345 (2014).
351. M. Borchardt, M.A. Sellitto, G.M. Pereira and L.P. Gomes, ecodesign case studies for furniture companies using the analytic hierarchy process, *Int. J. Ind. Eng. Appl. Pract.,* **19,** 330–340 (2012).
352. J.C.P. Su, C.-H. Chu and Y.-T. Wang, A decision support system to estimate the carbon emission and cost of product designs, *Int. J. Precis. Eng. Manuf,* **13,** 1037–1045 (2012).
353. D.C. Eddy, S. Krishnamurty, I.R. Grosse, J.C. Wileden and K.E. Lewis, A normative decision analysis method for the sustainability-based design of products, *J. Eng. Des.,* **24,** 342–362 (2013).
354. Z. Lounis and L. Daigle, Multi-objective and probabilistic decision-making approaches to sustainable design and management of highway bridge decks, *Struct. Infrastruct. Eng.,* **9,** 364–383 (2013).
355. R.A.R. Ghazilla, Z. Taha, S. Yusoff, S.H. Abdul-Rashid and N. Sakundarini, Development of decision support system for fastener selection in product recovery oriented design, *Int. J. Adv. Manuf. Technol,* **70,** 1403–1413 (2014).
356. L.G. Beng and B. Omar, Integrating axiomatic design principles into sustainable product development, *Int. J. Precis. Eng. Manuf. Technol,* **1,** 107–117 (2014).
357. D. Ramanujan, et al., Prioritizing Design for Environment Strategies using a stochastic analytic hierarchy process, *J. Mech. Des.,* **136,** (2014).
358. A. Romli, P. Prickett, R. Setchi and S. Soe, Integrated eco-design decision-making for sustainable product development, *Int. J. Prod. Res.,* **53,** 549–571 (2015).
359. S.-R. Lim, Y.R. Kim, S.H. Woo, D. Park and J.M. Park, System optimization for eco-design by using monetization of environmental impacts: a strategy to convert bi-objective to single-objective problems, *J. Clean. Prod.,* **39,** 303–311 (2013).
360. R.-C. Tsaur, Green product pricing decision analysis with application to personal computers, *Int. J. Prod. Res.,* **53,** 307–320 (2015).
361. T.P. Gloria, et al., A statistical approach to interpret relative environmental performance within product categories, *Int. J. LIFE CYCLE Assess.,* **19,** 491–499 (2014).
362. L. Serna-Mansoux, A. Popoff and D.A Millet, Simplified model to include dynamic product-user interaction in the eco-design process the paper towel dispenser case Study, *J. Ind. Ecol.,* **18,** 529–544 (2014).
363. R. Allais, T. Reyes and L. Roucoules, Inclusion of territorial resources in the product development process, *J. Clean. Prod.,* **94,** 187–197 (2015).

Daniela C.A. Pigosso is a senior researcher at the Technical University of Denmark (DTU). She received her PhD from the University of São Paulo (USP) in 2012, where she developed a maturity model to support companies on ecodesign implementation and management. Her first degree is in Environmental Engineering from the University of São Paulo in 2008.

Tim C. McAloone is a professor of Product/Service-Systems at the Technical University of Denmark (DTU). He received his PhD from Cranfield University in 1998, where he studied the integration of ecodesign strategies into industry. His first degree is in Mechanical Engineering from Manchester Metropolitan University in 1993.

Henrique Rozenfeld is a professor of Integrated Manufacturing at the University of São Paulo (USP). He received his PhD from WZL RWTH Aachen in 1988, with a research focused on computer-based process planning. His first degree is in Mechanical Engineering from the University of São Paulo in 1980.