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A Survey on Sustainable Product Development

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Abstract

The emergent field of sustainable product development has been rapidly evolving in several academic publications. Furthermore, sustainable product development is the basis for innovative products (and services). The analysis begins by identifying published studies within the last five years. A systematic mapping of the field evolution overtime is performed by identifying areas of current research interests and potential directions for future research. The findings will provide a roadmap for further investigations in this field.

Keywords: Product development; Sustainability; Manufacturing

1. Introduction

Lately, environmental issues have involved considerations due to pollution, resource reduction, global warming, etc. Life cycle assessment (LCA), was a tool developed during the 60s and 70s, to answer those problems and to measure environmental impacts. According to the International Standards Organization (ISO 14040, 14044) it consists of four stages: goal and scope, life cycle inventory, life cycle impact assessment, and interpretation. It comprises the whole product (goods and services) life [1]. In addition, LCA research concerns environmental

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aspects, social, and economical ones – the triple bottom line (TBL) approach. Companies are designing, manufacturing, and delivering products with new value to the customer, being sustainable in the market. In fact, social and ecological impacts of a product occur during its life cycle and by decisions in the early or fuzzy front phase of product development (PD) processes. Hence, sustainable product development (SPD) is an important subject for industries and a goal for engineers and designers in achieving more sustainable products [2]. To some extent, in the early phases of PD, one should be mindful of an "environmentally-conscious design process paradox" or eco-design [3].

A few literature reviews on the subject and research papers have been completed in the past five years. Studies had provided an understanding of the field, but an additional analysis can provide further insights and research directions. The paper starts with an outline of the subject, reviewing main definitions of SPD over the last half-decade. Then, a proposed methodology is used to classify and further refine the literature assessed so far, where general observations are made. An evaluation of the results is discussed which summarize the main findings and trends with conclusions.

2. Sustainable product development definition

The perspective of sustainability in PD is a need to efficiently create product innovation and innovative processes. This can be achieved with some basics, such as: ensuring organizational support from senior management, introducing a sustainability perspective in the early phase of PD, including social and ecological aspects across product life-cycle management (PLM), using tools for guiding decisions as a complement, and assigning sustainability implementation in the PD process, etc. In sum, in the early phases of PD, is critical to reduce costs and enhance the sustainability performance of a product. Footings like eco-design, design for the environment (DFE), life cycle design or green design are found in the literature with reference to SPD [1,4].

Design for X (DFX) and 3Rs (reduce, reuse and recycle) are best practices to add additional value to products. DFX covers, e.g. design for assembly (DFA) or DFE. Some guidelines for manufacture include life-cycle thinking in product development, metrics for product life-cycle performance, systematic design strategies, performance design and trade-offs, and nature inspired design of products. Also LCA for PD concerns with concept design, such as eco-concepts, eco-design and design environment. It deals with material selection, packaging design and alternatives during the part design phase. Likewise, process design relates with pollutant and toxic material, waste minimization and production efficiency. Some tools for SPD might also include social-LCA, design for longevity, total cost for ownership or safety management [1,3].

The traditional quality function deployment (QFD) can be improved with environmental factors, including a sustainable end of life strategy considering design for reuse, recycling and disposal issues [4]. Companies are forced to implement concepts like PLM in the reduction of managerial complexity in PD. This fact expresses the designer attitude of the product life cycle which integrates people, processes, and data. PLM is also expected to improve cross functional collaboration, reducing product data discrepancies and improving coordination of development teams in order to progress PD. In fact, the main objective of PLM is to maximize product's value, reducing costs and increasing revenues. Besides, the intersection of PLM with (new) PD success is based on four important pillars, i.e., cross-functional work, top-management involvement, market planning, and formalized processes. The life cycle approach towards SPD reflects the sustainable development to the PBL paradigm, which sometimes is represented as "green" PD [5,6,7,8].

In order to achieve SPD, a sustainable product aims environmental and social quality improvement. In other words, SPD is the process for developing a sustainable good or service to the market [6,7]. Till date, some methods and tools [8] have already been developed regarding the environmental performance.

3. Research methodology

An important literature review objective is to map and evaluate the state-of-the-art of a field by identifying potential research gaps, thus highlighting its boundaries of knowledge. Main stages include searching keywords, literatures and performing the analysis [9]. This iterative cycle is a structured methodology for scanning data, structure a mind map, and reporting the study. As proposed by Fahimnia et al. [10], a five-step (see 3.1 to 3.3) method is used for data collection and evaluation of the field by identifying significant studies and main areas of investigation followed by current research interests and future directions.

3.1. Defining terms

Combinations of the keyword's 'sustainability' AND 'product development' retrieved 567 articles in Scopus database, as other similar such as "green" AND "product development" (257 articles found). Hence, the keyword used was 'sustainable product development' for the initial search (142 papers found). The keyword 'sustainable product design' was ignored so far avoiding possible replications (110 papers found).

3.2. First results and refinement

Scopus database, the largest peer-review database for abstract and citation [11], was used for initial screening in the field of science, technology, and social sciences. The field 'title/abstract/keywords' was used for searching the defined term. Due to the rapid evolution of the field of SPD and the scope of this survey, only the last five years (2014-2018) were considered in this paper. As mentioned, a first search produced 142 documents. Further screening was devoted to "article or review" type documents [10] (conference papers, books, and chapters of books are excluded) for obtaining a result of 80 papers. From this, the final search was limited to the *exact keyword* 'sustainable product development'[†], excluding others such: product development, sustainable development, product design, life cycle, sustainability, eco-design, environmental impact, design, and sustainable products. Finally, 56 documents were considered for this survey.

3.3. Data statistics and analyses

Once it is interesting to analyze some characteristic of the selected articles, the following search results are presented below. Fig. 1 represents the number of documents by year. Fig. 2 shows documents per year by the source, which displays main journals where the subject was published: Journal of Cleaner Production (20), Sustainability Switzerland (5), International Journal of Advanced Manufacturing Technology (2), International Journal of Supply Chain Management (2), Academic Journal of Manufacturing Engineering (1), CIRP Annals Manufacturing Technology (1). Fig. 3 displays sources by affiliation, namely Chalmers University of Technology (4), Technical University of Berlin (4), Blekinge Tekniska Hogskola (3), Fraunhofer Institute (2). Fig. 4 demonstrates the countries (mainly Germany, Malaysia, Sweden, Brazil, India and USA) involved in the production of documents. Finally, Fig. 5 depicts that the subject of research is included in Engineering (24.8%), followed by Environmental Studies (19%) and Business and Management (19%), while Fig. 6 shows the number of documents produced by the same author. The top ten of cited papers are presented in Table 1, where half of them are from the Journal of Cleaner Production. All data were obtained using Scopus 'analyze search results' and collected December 29, 2018.

[†] Final search syntax: TITLE-ABS-KEY ("sustainable product development") AND DOCTYPE (ar OR re) AND PUBYEAR > 2013 AND (LIMIT-TO (EXACTKEYWORD , "Sustainable Product Development"))

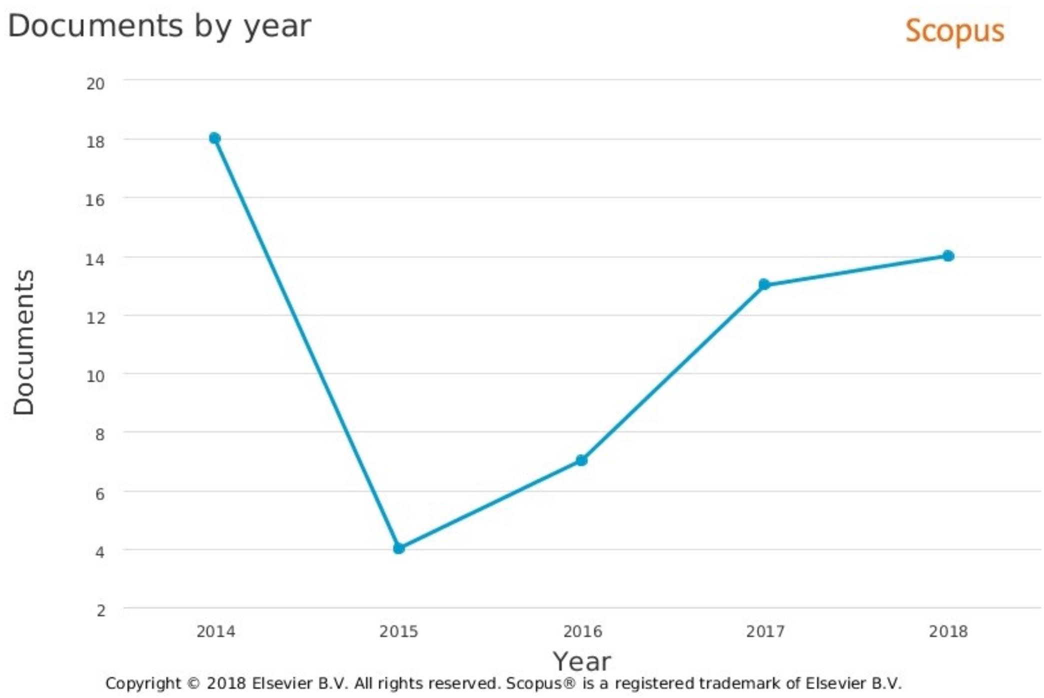

Fig. 1. Number of documents produced by year.

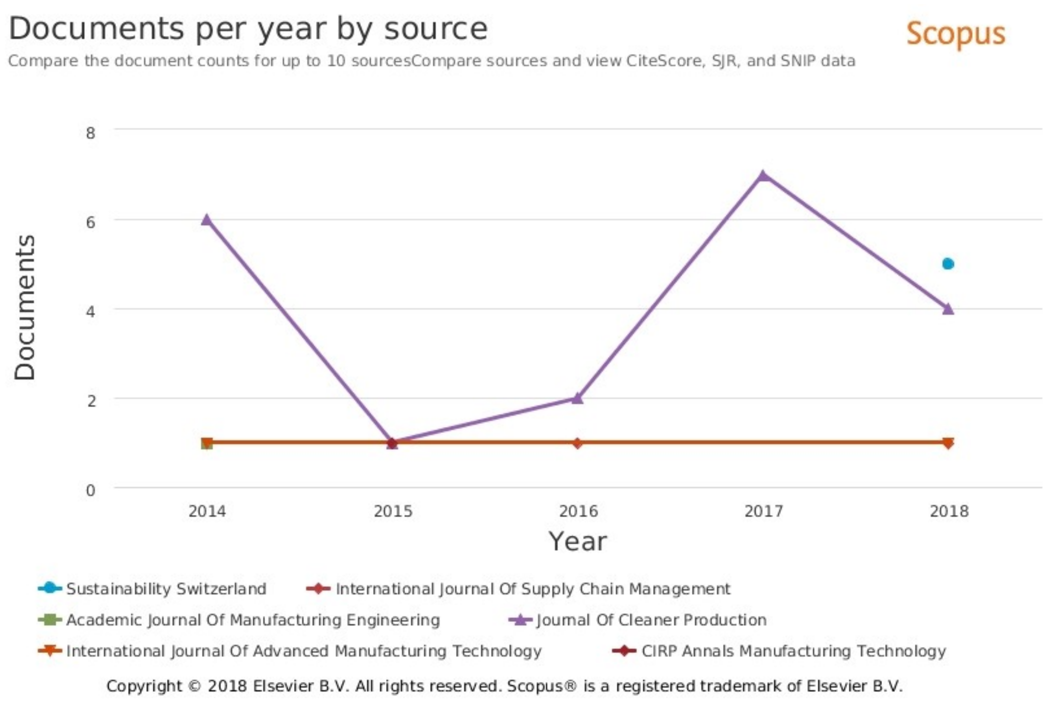

Fig. 2. Documents per year by source.

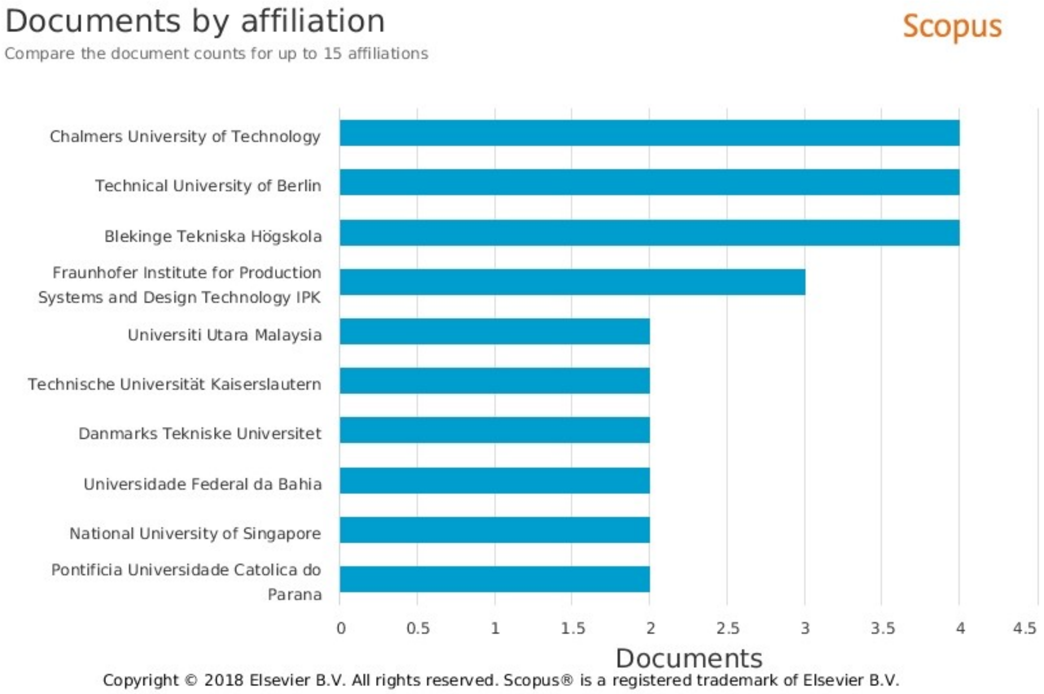

Fig 3. Number of documents by affiliation.

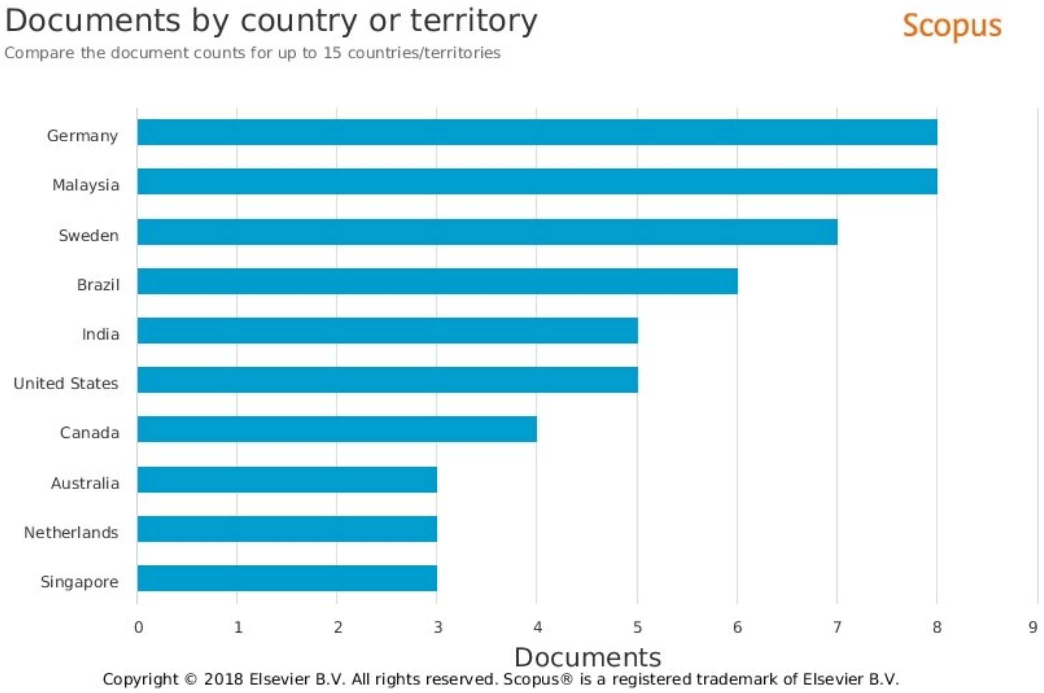

Fig 4. Number of documents by country.

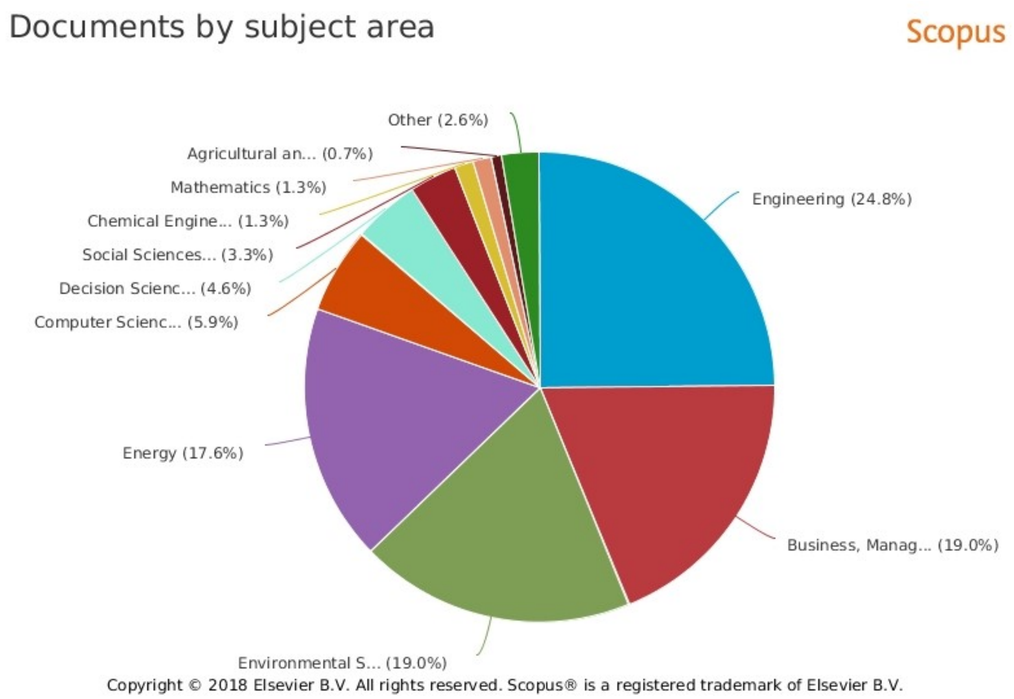

Fig. 5. Number of documents by subject.

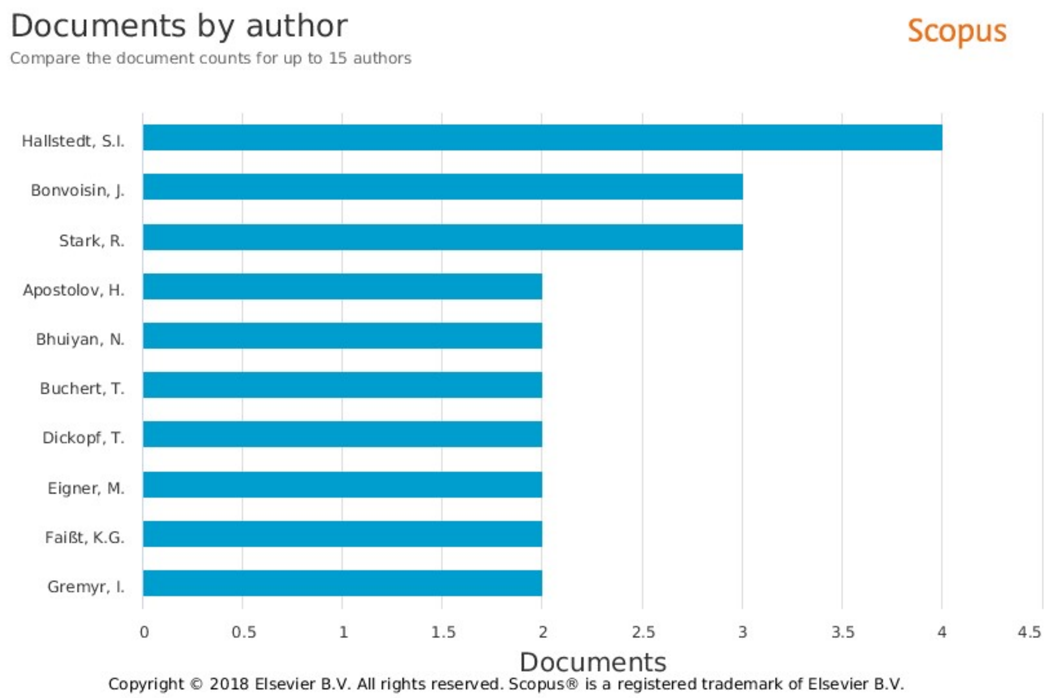

Fig. 6. Number of documents by author

Table 1. Top 10 papers by number of citations.

Document title	Authors	Year	Source	Cited by
Review of life cycle assessment towards sustainable product development	Chang, D. Lee, C.K.M. Chen, C.-H.	2014	Journal of Cleaner Production 88, 48-60	54
Green product development and performance of Brazilian firms: Measuring the role of human and technical aspects	Jabbour, C.J.C. Jugend, D. De Sousa Jabbour, A.B.L.	2015	Journal of Cleaner Production 87, 442-451	50
Life cycle environmental impact of high capacity lithium ion battery with silicon nanowires anode for electric vehicles	Li, B. Gao, X. Li, J. Yuan, C.	2014	Environmental Science and Technology 48, 3047-3055	41
Sustainability criteria and sustainability compliance index for decision support in product development	Hallstedt, S.I.	2017	Journal of Cleaner Production 140, 251-266	40
Fuzzy sustainability incentives in new product development: An empirical exploration of sustainability challenges in manufacturing companies	Alblas, A.A. Peters, K. Wortmann, J.C.	2014	International Journal of Operations and Production Management 34, 513-545	34
Integrated eco-design decision-making for sustainable product development	Romli, A. Prickett, P. Setchi, R. Soe, S.	2015	International Journal of Production Research 53, 549-571	30
Improving sustainability performance in early phases of product design: A checklist for sustainable product development tested in the automotive industry	Schöggl, J.-P. Baumgartner, R.J. Hofer, D.	2017	Journal of Cleaner Production 140, 1062-1617	29
Achieving sustainable new product development by integrating product lifecycle management capabilities	Gmelin, H. Seuring, S.	2014	International Journal of Production Economics 154, 166-177	29
Integration of ECQFD, TRIZ, and AHP for innovative and sustainable product development	Vinodh, S. Kamala, V. Jayakrishna, K.	2014	Applied Mathematical Modelling 38, 2758-2770	25
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	Lee, H.M. Lu, W.F. Song, B.	2014	Journal of Cleaner Production 66, 355-371	23

3.4. Clustering

Bibliographic network investigation is an important tool for understanding data analysis while performing a review [10]. Applying a software tool, such as VOS Clustering algorithm (Van Eck and Waltman 2010) is possible to identify clusters. Using exported data from Scopus (refine results values) in the form of .CSV file it is relatively easy to do so. For example, a *co-occurrence* and *author keywords* analysis through the *full counting method* was performed as displayed in Fig. 7 and a summary in Table 2. This is illustrative of a mind map of the subject studied.

The clusters analyze retrieved 4 major clusters regarding keywords. *Cluster 1* is composed by: life cycle assessment, product design, product development and sustainability. *Cluster 2* is originated by: case study, new product development, sustainable manufacturing and sustainable product development. *Cluster 3* is summarized by: Malaysian automotive industry and organizational performance, and *cluster 4* is composed by: eco-design and sustainable product design.

This analysis shows that any framework will be considered to have the 4 expected keywords. Cluster 1 deal regarding two dimensions: product design/development and LAC/sustainability. Cluster 2 shows the importance of case studies and sustainable manufacturing for the subject. Cluster 3 points out the automotive industry in an expected country but also gives attention to organizational performance - an important issue to any successful SPD. Finally, cluster 4 says that eco-design and SP design are other words for SPD.

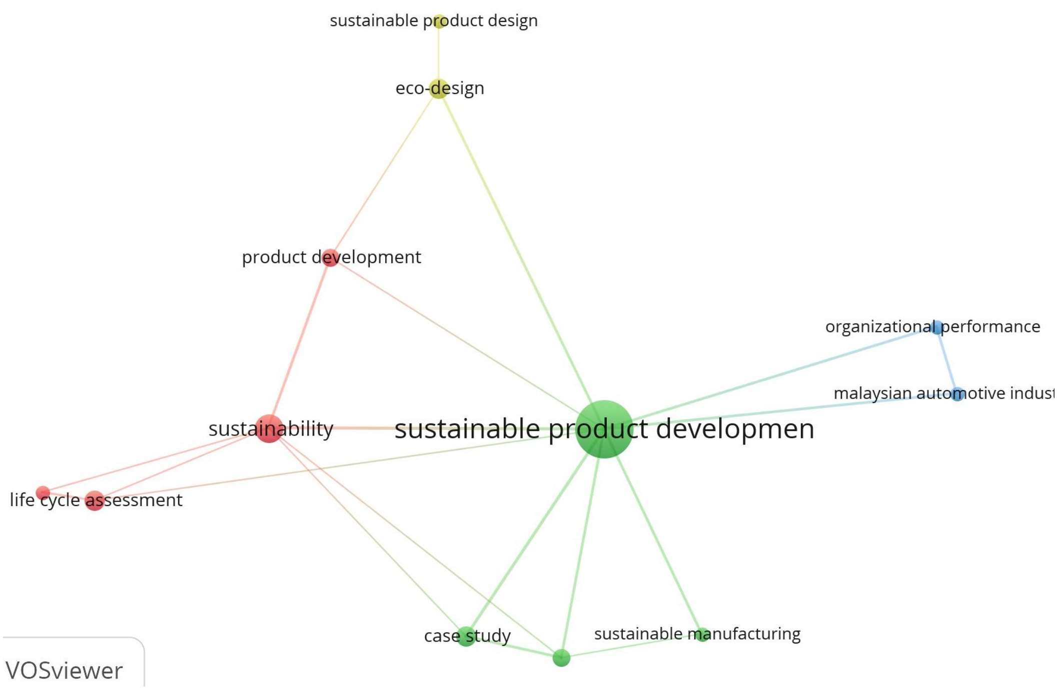

Fig. 7. Co-occurrence network of author keywords.

Table 2. Clusters identified using VOS Clustering algorithm.

Cluster 1	Cluster 2	Cluster 3	Cluster 4
Life cycle assessment	Case study	Malaysian automotive industry	Eco-design
Product design	New product development	Organizational performance	Sustainable product development
Product development	Sustainable manufacturing		
Sustainability	Sustainable product development		

4. Discussion

From this survey some models, methods and tools were identified. They propose guidance and recommendations on features to consider during PD, in order to mitigate environmental problems. This interrelated strands for LCA in PD are taken into consideration for recovering (e.g. reuse, recycle, remanufacturing), servicing (e.g. maintenance, quality control, carbon-footprint), and production control (e.g. non-toxic raw material, green technology, waste). The principles found may also include for instance: embed life cycle thinking, resource efficiency and effectiveness, appropriate metrics, or seeking inspiration from nature. Some of them are qualitative, quantitative, analytical, or decision-making techniques for DFX [1,2,3,8,].

For example, Gmelin & Seuring [5] refer the influence that PLM pillars have on the application of SPD for different companies in the automotive industry. In fact, PLM still lacks a holistic view of product data management.

For the authors, PLM is dependent on cost awareness, quality, flexibility and environmental aspects where case studies are essential for applying possible frameworks developed so far.

Hallstedt [2] refers that one main part to efficiently introduce a sustainability point of view in PD is the "sustainability criteria" used for decision-making in PD. The criteria were presented in a set of matrices, untying the criteria into PLM phases and "socio-ecological sustainability" values. A qualitative scale - index was introduced, representing to what step a product performs relative to a sustainable result. Being tested so far, as a case study in an aerospace company, it showed indications and guidance in bringing sustainability to the early phases of PD.

Schoggl et al. [3] refer that a checklist for SPD (CSPD) can be used for facilitating decision making in early phases of PD. They stress that the iterative nature of PD could be integrated into different levels/stages of the PD process (e.g. feedback loops) and can be combined with quantifiable assessment methods such as LCA. The need of a customized tool for SPD is a current gap, as the focus on SPD is centered on market opportunities and tradeoffs.

An integrated eco-design decision-making (IEDM) methodology was proposed by Romli et al. [4] to serve as a tool for SPD, showing how information about environmental considerations can be created and merged into IEDM, and further used as parameters for an Eco-Process model and enhanced Eco-QFD.

Similarly, an ontology-based identification of sustainable option (OBISO) method was proposed by Stark and Pfortner [7]. The ontology's knowledge base is combined with sustainable engineering tools/knowledge (e.g. FEM, CAD and PLM database) for material's decision.

Also, Jabbour et al. [12] tested a conceptual framework concerning technical, human and organizational aspects of "green product development" (GPD) practices when compared to businesses' environmental, operational and market performance, suggesting that the relationship among human features and green products justifies further investigation.

Well known authors – Ulrich and Eppinger (2012) – cited by [8], defined seven steps regarding environmental aspects to be considered during PD phases: setting DFE agenda, identifying potential environmental impact, selecting DFE guidelines, applying DFE guidelines to initial design, assessing environmental impact, refining design, and reflecting on DFE process and results.

Another topic of research concerns additive manufacturing (AM) and sustainable production and consumption. The emergence of AM, regarding trends like servitization and personalization, is leading companies to rethink their manufacturing activities. AM enables complex and optimum products and is linked with shorter value chains and significant sustainable benefits. AM creates products layer-by-layer, which are more economical than subtractive manufacturing, decoupling social and economic value creation. Benefits from this technology may include prolonged product life, reconfigurable value chains, and the redesign of life cycle recycle, repair, or reuse. Other paybacks include input recycled materials (resin or powder), energy efficiency, and improved performance for environmental impact. Despite this, AM is still insufficient for sustainability uncertainties and eco-efficient production. Being 95-98% recycled, it is a great contribution for new product and service business models [13], where creativity and innovation [14] can play an important role.

5. Conclusion

This paper presented a structure survey of SPD over the last five years. The amount of papers found is considerable for this time period and the number of citations gives a good perspective on the importance and actuality of the field. It was found that there is a worldwide dispersion of contributions from European, American, and Asian industrialized countries, and from India and Australia. Germany and Malaysia, lead institutions where the theme is more studied, and these are followed by Sweden and Brazil. German automotive industry is a global leader [16], where industry sector technological trends incorporate sustainable mobility as vehicle lifestyle choice for a more sustainable future. An example is production technologies for ecologically sustainable production of hybrid lightweight components using metals, plastic and textiles. The Malaysian automotive industry hosts several domestic-foreign joint venture companies, which assemble a large variety of vehicles. The government has established 'sustainable development goals' recently [17]. The topic is studied mostly in the engineering field where the Journal of Cleaner Production plays an important role. The topic is also studied by key institutions in the country. Case studies (see cluster 2) shows that some of the key concepts are already implemented in practice.

This survey is limitative in the number of years; the selected number of papers and of course the selected *keyword(s)* and further refinement. In fact, the former is the most sensible factor to be taken into consideration. Likewise, only some of the 57 papers were subjected to a more in-depth assessment as presented in Table 1. Clustering the papers [10] used so far and others are to be considered and the outcome can be summarized in a future extensive literature review. By now, one can say that any future SPD conceptual framework will contain, at least, two dimensions - sustainability and PD - and most probably will serve to a specific kind of manufacturing system or industry. Another interesting challenge is to understand new features of SPD during Industry 4.0 context.

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References

[1] D. Chang et al., Review of life cycle assessment towards sustainable product development, Journal of Cleaner Production 83 (2014) 48-60
[2] S.I. Hallstedt., Sustainability criteria and sustainability compliance index for decision support in product development, Journal of Cleaner Production 140 (2017) 251-266
[3] J.-P. Schoggl et al., Improving sustainability performance in early phases of product design: A checklist for sustainable product development tested in the automotive industry, Journal of Cleaner Production 140 (2017) 1602-617
[4] A. Romli et al., Integrated eco-design decision-making for sustainable product development, International Journal of Production Research 53 (2015) 549–571
[5] H. Gmelin, S. Seuring, Achieving sustainable new product development by integrating product life-cycle management capabilities, International Journal of Production Economics 154 (2014)166–177
[6] H. Gmelin, S. Seuring, Determinants of a sustainable new product development, Journal of Cleaner Production 69 (2014) 1-9
[7] R. Stark, A. Pfortner, Integrating ontology into PLM-tools to improve sustainable product development, CIRP Annals - Manufacturing Technology 64 (2015) 157–160
[8] M. Salari and N. Bhuiyan, A proposed approach to improve current sustainable product development, Journal of Industrial and Production Engineering 33 (2016) 297-307
[9] S. Seuring, M. Muller, From a literature review to a conceptual framework for sustainable supply chain management, Journal of Cleaner Production 16 (2008) 1699–1710
[10] B. Fahimnia et al., Green supply chain management: A review and bibliometric analysis, International. Journal of Production Economics 162 (2015) 101–114
[11] A. Tukker, Product services for a resource-efficient and circular economy - a review, Journal of Cleaner Production 97 (2015) 76-91
[12] C.J.C. Jabbour et al. Green product development and performance of Brazilian firms: measuring the role of human and technical aspects Journal of Cleaner Production 87 (2015) 442-451
[13] S. Ford, M. Despeisse, Additive manufacturing and sustainability: an exploratory study of the advantages and challenges, Journal of Cleaner Production 137 (2016) 1573-1587
[14] P. Marques, A. Silva, E. Henriques, C. Magee, A descriptive model of the design process from a dual cognitive-engineering perspective, International Journal of Design Creativity and Innovation 3 (2014) 142-164
[15] Germany Trade & Invest, The Automotive Industry in Germany, Industry Overview 2018/19
[16] Economic Planning Unit, Government of Malaysia, Sustainable Development Goals, 2017