26th CIRP Life Cycle Engineering (LCE) Conference

Implications of developing a tool for sustainability screening of circular economy initiatives

Mariia Kravchenko[a]*, Tim C. McAloone[a], Daniela C. A. Pigosso[a]

[a]Technical University of Denmark (DTU), Department of Mechanical Engineering, Produktionstorvet, Building 404 / Room 226, DK- 2800 Kgs. Lyngby
* Corresponding author. Tel.: +45 25 55 65; fax: +45 45 25 19 61. E-*mail address*: makrav@dtu.dk

Abstract

Circular economy seems to offer abounding opportunities for companies that are seeking to optimize their business practices while reducing the environmental burden. Circular economy therefore is often seen as a stepping-stone towards sustainability. However, to ensure the transition from linear to circular economy in a sustainable way, a shift requires implementation of not only financially beneficial circular strategies, but also environmentally and socially valuable ones. The challenge for companies is to understand how a particular circular initiative in their business context contributes to sustainability and what elements of sustainability have to be assessed prior to the initiative implementation. This paper illustrates how an indicator-based sustainability screening tool for circular economy initiatives can guide companies in their decision making towards a more sustainable circular initiative choice. In addition, the paper highlights challenges of measuring sustainability in a circular economy context.

Keywords: sustainability screening; circular economy; indicators for sustainability; micro-level; business processes; life cycle thinking

1. Introduction

Sustainable development has never been as high on the global agenda as nowadays. Since the development and adoption of the Sustainable Development Goals (SDGs) by the United Nations Development Programme, an enhanced awareness of the need to combat global challenges and work on improving environmental and social well-being and sustaining economic resilience can be observed across continents, countries, corporations and citizens [1]. It is also more evident that businesses are now embracing other ways of addressing sustainability, going from "internal" sustainability considerations, i.e. focusing mostly on internal benefits by creating value for shareholders, to the "external" sustainability considerations, by creating value for customers, societies and other stakeholders [2]. Circular economy (CE) is a new economic and industrial paradigm that offers a myriad of strategies that focus on rethinking businesses, products and systems with main goal of generating economic and social

benefits by optimizing and retaining value of resources [3,4]. CE initiatives can be adopted at a product level (by designing products to allow for their longer use or by facilitating reuse, repair, remanufacture or recycling of products, parts and materials at the end of life) [5]; at production level (by focusing on material and energy efficiency of processes and by using renewable and non-toxic materials) [3,4,6], and at strategic level (by fostering innovative circular business models and circular supply chain configurations [7,8]). Therefore, many authors see CE as a tool for sustainable development that is expected to lead to new employment opportunities, maximized resource efficiency and development of new innovative markets for business growth [4,9–12].

Despite numerous benefits that CE potentially could bring, it is, however, important to note, that not all CE approaches are intrinsically sustainable and not necessarily better than "non-circular" solutions [13–16]. For example, product leasing is not automatically 'greener'[17], as it might inspire more frequent product replacement, therefore leading to an increased

production. Also, there is a risk of "burden shift" as a reduced impact in one stage of a product's life cycle can induce increased impact in another (e.g. due to excessive use of energy and transport) [14]. For instance, using a mixture of recycled and virgin feedstock in product manufacture can contribute to lower virgin resource consumption in the beginning of product's life; however, it could make recycling at the end of life complicated or impossible, possibly leading to higher energy use and larger fraction of waste generated in the recycling process. It becomes evident that due to the abundance of conceptualizations of CE, the dominant focus on recycling and lack of focus on consumers, supply chain and novel business models as enablers of CE [6,20,56], industrial practitioners are struggling to understand CE and are not aware that CE should be approached from a systems perspective, often requiring fundamental changes [20,23]. Furthermore, many academics try to contrast CE and sustainability, highlighting that CE stays unclear on its contribution to sustainability, particularly to social well-being [3,57]. Authors as Sauve et al., [58] explain that CE can be defined as a "bottom-up" approach, while sustainability is a "top-down" approach, reckoning that they ever overlap.

Therefore, in order to ensure a more sustainable transition from linear to CE, micro-level actors (industrial practitioners) need to be supported in the assessment of how particular CE initiatives they are considering will contribute to sustainability.

This paper presents the implications of conceptualizing and developing a tool to assess the potential sustainability impact of CE initiatives implementation across a number of business processes in manufacturing companies. The ultimate goal of the sustainability screening tool is to support decision-making process and allow for comparison of different CE initiatives and other improvement initiatives across business processes in their potential contribution to economic resilience, environmental integrity and social well-being prior to actual implementation. The sustainability screening tool employs an indicator-based approach, allowing for the assessment from all the three main angles of sustainability and providing early warning information for decision makers [18,19]. The sustainability screening tool comprises of the database of sustainability-related key performance indicators (KPIs) charted according to the selected criteria, such as business processes and circular economy strategies, and the corresponding guidelines for KPIs selection. This paper is designated to the development of the KPIs database as one of the main components of the sustainability screening tool for the assessment of circular economy initiative implementation.

This paper is structured in the following way. Firstly, it provides the theoretical background that has influenced the development of the sustainability screening tool and its contextual application (section 2), secondly, it explains the research methodology used to extract indicators to be used as a foundation for the tool (section 3), thirdly, it elaborates on the foreground of the sustainability screening tool, namely identification and classification of key performance indicators (KPIs) (section 4), followed by a discussion on main gaps and particularities of making sustainability assessment in a CE context. Lastly, suggestions for further development and improvements are discussed in the conclusion (section 5).

2. Theoretical background

2.1. Circular Economy initiatives and Business processes

There are more than 100 definitions of CE [20], that are being suggested and widely used by both academia and governmental and industrial actors around the world. Many authors call CE as a business or economic model [3,9,20], others refer to CE as an industrial system [21], however most agree that CE aims at fostering economic prosperity and boosting growth by preserving and regenerating environmental quality. CE relies on principles of regenerative and restorative design [21], industrial ecology [6], cradle to cradle approach, eco-efficiency and eco-effectiveness, performance economy and the extended producers responsibility [9,22], and involves systemic thinking [21,23], thus can be understood as a paradigm that creates a relation between pre-existing independent concepts (an umbrella concept) [24].

The authors of this paper have adopted one of the CE definitions, provided by Ellen MacArthur Foundation, where CE is defined as "… is an economy that provides multiple value creation mechanisms, which are decoupled from the consumption of finite resources" [19].

CE principles are viewed by majority of authors as "how to" for CE and are sometimes referred to as "initiatives", "strategies" [25], "resource efficiency strategies" [26] or RE-strategies (e.g. reuse, recycle, recover, remanufacture, etc) [27–29]. In this research, the model for CE strategies proposed by Potting et al., 2017 has been adopted and slightly restructured. The modified model gives a good overview of major existing CE initiatives, gives definitions of each initiative and examples of implementation.

Business processes (BP) are structured activities or tasks that need to be managed to produce a specific valuable outcome (e.g. service or product) [30]. BPs can be seen as a "playground" for delivering the CE initiatives, meaning that CE initiatives can be embedded into different BP to bring desired improvements and potentially contribute to sustainability.

2.2. Sustainability assessment

Sustainability assessment (SA) is a process that directs the planning and decision-making towards sustainability [31]. There are different types of sustainability assessment, for example, ex-ante, which helps assessing sustainability impact of current or future actions or initiatives, and post-evaluation, which evaluates the consequences of actions taken [32]. This research presents a SA of an ex-ante type, aiming at "predicting" potential contribution of particular actions to sustainability. Moreover, its purpose is to assess actions' contribution to social well-being, economic prosperity and environmental integrity rather than simply "direction to target", thus enabling decision-makers to determine which actions should or should not be taken [33]. SA of CE initiatives contributes to better understanding of sustainability within CE context, as CE can be seen as a means towards achieving desired sustainability, however, whether CE brings desired effects has to be carefully predicted, monitored and evaluated. The tool to SA in this research is called sustainability screening

and is built on an indicator-based approach. The indicator-based approach for sustainability screening provides a solid, traceable and measurable ground for identifying future consequences of proposed or current CE actions in relation to the economic, environmental and social benefits. Sustainability screening allows companies to apply their data to calculate suitable indicators, thus making a screening of proposed CE actions on their potential sustainability impacts. According to Waas et al., [33] "an indicator is the operational representation of an attribute (quality, characteristic, property) of a given system, by a quantitative or qualitative variable (parameter, measure)…". Indicators enable detection, monitoring, quantification, assessment and interpretation of the systems' status in terms of sustainable progress. In addition, indicators allow comparison of alternatives and highlight potentials for optimization; then can help internal and external benchmarking and be used as a tool to communicate and promote sustainability [33–35].

3. Research methodology

In order to develop an indicator-based sustainability screening tool, a systematic literature review was executed. The main goal of the systematic literature was to identify leading key performance indicators that will form a base for the sustainability screening of CE strategies across different BP. The systematic literature review followed the procedure proposed by [36] consisting of: (1) review planning; (2) review execution and (3) results analysis. The review focused on identification, selection and systematization of leading sustainability related KPIs.

A literature search was performed in the databases Scopus and ISI Web of Knowledge, due to availability of advanced web search mechanisms, high volume of indexed papers and proven relevance in the fields of research [37–39]. Search strings (title, abstract and keywords) were composed of the main keywords and their synonyms, as follows ("key performance indicator*" OR "metric" OR "index" OR "indices" OR "measure*" OR "indicator*" OR "evaluation") AND ("sustainab*" OR "triple bottom line") AND ("social" OR "environment*" OR "econom*") AND ("business model" OR "product dev*" OR "end of life" OR "supply chain"). The initial set of found literature consisted of 892 documents. The results were further refined by choosing relevant scientific area (engineering, environmental science, economics and social science), so the second set consisted of 665 documents.

The next step was to gradually select relevant literature by screening the title, abstract and keywords, and when reading the introduction and conclusion applying the inclusion criteria. Inclusion criteria the studies must meet are following: a) contain proposition, application or review of a leading indicator for sustainability assessment; b) focus on manufacturing companies or at micro-level (product, process, industry). The final set consisted of 52 publications that also included articles used from the "snowballing technique", i.e. using references' references to develop the search out to all relevant studies. This allowed retrieving around 400 leading sustainability related KPIs. The KPIs were then charted according to such criteria as business processes, circular economy initiatives, and

sustainability dimensions and were all registered in an excel database. The characterization was done based on the literature the KPIs were extracted from. For example, product related KPIs were assigned to BP of pre-manufacturing, manufacturing and end of life stages, i.e. following the usual life cycle approach. Supply chain related KPIs were assigned to supply chain BP, business model KPIs were assigned to business model BP. Furthermore, the retrieved KPIs were classified according to CE initiatives and sustainability dimensions. Additional information about each KPI was collected and registered, including name of the KPI, symbol, detailed description of the KPI, how to measure it and unit of measure.

4. Conceptualizing and developing an indicator-based sustainability screening tool

The KPIs retrieved from the literature are quantitative and leading, or proactive, indicators. The advantage of using leading indicators is that they provide warning in advance and give a good estimation of the potential sustainability impact of the proposed actions [40–42]. At the same time, lagging, or reactive, indicators help measuring the effect of actions approved and undertaken by the company. Many authors [40,41] advice using leading indicators for corporate performance measurements, as they provide insight into the organization's potential impact and indicate about future performance, thus assist decision makers with information to introduce improvements in the early stages of decision making. One of the challenges of working with leading KPIs, however, is the level of uncertainty of data needed to calculate the KPIs. Since the decision needs to be taken early in the process, data may not always be accurate or available. Nevertheless, leading KPIs can be used throughout the implementation of the initiative to monitor its performance and to indicate future improvements.

In terms of representation of KPIs according to the three dimensions of sustainability, the largest fraction (about 65 %) of all KPIs retrieved from literature belongs to the environmental dimension, which is also confirmed by other authors working with sustainability indicators [43,44]. At the same time, the social dimension is "underrepresented" by KPIs, also confirmed by literature [45,46]. In terms of KPIs distribution according to BP, most of the KPIs are related to the pre-manufacturing stage, which includes inbound logistics and product design and development. The "end of life" BP has also a very good KPIs coverage. This can be explained by the fact that aspects related to the life cycle of a product are very well researched and KPIs are developed, again, with a large focus on environmental part. In terms of business model, many KPIs belong to the economic dimension and only few relate to social and environmental, which several authors had expressed their concern about [2,47]. Regarding the supply chain BP, many KPIs are available and are very aligned with indicators related to product development, manufacturing, and end of life, however with a gap in social indicators [48]. Despite many KPIs being available for supply chain measurements, literature reports difficulties when it comes to KPI application. Many companies do not have bilateral agreements with all the

suppliers in different tiers, thus have no accessibility to their data [48,49].

To develop the indicator-based sustainability screening tool, the identified KPIs were classified according to different categories. The classification categories were: the BP, the CE initiatives, and sustainability dimensions.

CE initiatives included in the sustainability screening tool are: reinvent; rethink; reduce impact in raw material, sourcing and product design; reduce impact in manufacturing and logistics; reduce impact in product use and operation; recirculate products and parts by providing: upgrade, repair and maintenance, reuse, refurbish, remanufacture, repurpose options; recirculate materials by providing: recycle, cascade and recover options. BP, included in the sustainability screening tool, are encompassing primary activities, mainly related to life cycle of a product and related services, i.e. product development, manufacturing, closing the loop (end of life), but also business model and supply chain.

An example of a BP that can encompass specific CE is given in figure 1. Important to emphasize, that CE often requires several configurations of CE initiatives to be introduced in business in sequence or parallel (for example, a business model for leasing or renting a product to give access to more customers, may involve redesign of a product to make it more durable and easier to reassemble in case repair is needed). Some authors [24] stress that implementation and assessment of CE initiatives should shift from singular towards different CE configurations.
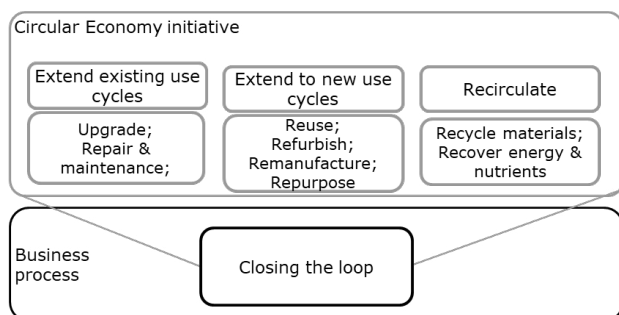

Fig. 1. A business process and corresponding circular economy initiatives.

Sustainability dimensions, the KPIs are also classified according to, are defined as economic resilience, environmental integrity and social well-being, each comprising several categories, which align with international standards and frameworks as shown in the table 1.

These sustainability categories were then unfolded to aspects, allowing to be analyzed by the KPIs, assigned to them. An aspect is defined as an element of an organization's activities, products or services that interacts with the environment, society and other stakeholders (partners, suppliers, employees) [53]. An aspect may trigger a change (impact) in the economy, society or environment, therefore has to be managed responsibly. For instance, "supply chain category" under social well-being dimension has one of the aspects "relationships", which can be assessed with help of several KPIs assigned to it, one is them being "suppliers that affirmed business code of conduct and ethical policy" [54]. Similarly, category "product composure" under environmental

integrity dimension has one of the aspects "product circulation", which can be assessed by calculating assigned to it KPI, "product degree of utilization" [55].

Table 1. Sustainability dimensions with corresponding categories and occurrence in international standards and frameworks.

Sustainability dimension	Categories	Alignment with
Social well-being	supply chain, employees, customers, local community	S-LCA [50] IChemE [51] GRI [52]
Economic resilience	value creation, value distribution investment, product information	GRI IChemE
Environmental integrity	material, energy, transport, product composure, packaging, waste, water, land, air	ISO 14031[53] GRI IChemE

Such hierarchical model (i.e. sustainability dimension – category – aspect – KPIs) allows decision makers detect and understand what a specific value of a calculated KPI can signal about in relation to the management of a specific organizational sustainability aspect.

In addition to the classification categories, more information was added to help understanding and interpreting each KPI. Additional information indicates name of the KPI, symbol, detailed description of the KPI, how to measure it and unit of measure. Furthermore, each KPIs is supplemented with an elaborated explanation of the purpose of measuring it and what its measured value can potentially signal about. Also, more information is provided about what benefits a company can potentially achieve by managing a certain aspect, hence improving the value of a certain KPI.

In order to select KPIs, it is important to define the scope for the sustainability screening. The scope can be defined by prioritizing the business process and /or CE initiative that the company wants to introduce and make screening for. Such prioritization allows filtering suitable KPIs for the chosen scope. The filtered set of proposed KPIs can then be reviewed and customized depending on the particularities of the organizational business processes. Despite all the indicators in the tool being referred to as key performance indicators, only the final set of indicators chosen will consist of KPIs that are key for the screening of a particular CE initiative by a particular company. At the same time, other indicators in the tool will not be taken into account, although can still become key indicators if the company decides to change the scope of the screening and select different combination of CE and BP.

An example of the set of KPIs that can be obtained from the screening tool is given in the table 2. In order to arrive at the given set of KPIs, a specific combination of BP and CE strategies was selected. In the example from the table 2 it was assumed that the company wants to introduce remanufacturing of its used products as a part of its business model. Therefore, the business processes "business model" and "end of life management" as well as the CE strategy "remanufacturing" were selected as the scope for the screening that allowed

filtering the suitable set of KPIs. Notably, the set of KPIs aims at screening the CE initiative on its potential sustainability impact, but not at assessing the internal business suitability to undertake CE.

Table. 2. Example of the set of KPIs that were obtained from the tool by limiting the screening scope to "business model", "end of life management" and "remanufacturing". The KPIs are also charted according to sustainability dimensions.

Business Processes*		Circular Economy Strategies*	Sustainability dimension			KPI
Business Model	End of life Management	Remanuf	Env	Soc	Econ	
x	x	x			x	Revenues from remanufactured products
x	x	x			x	Take back cost
x	x	x		x		Number of customers with take-back contract
x	x	x			x	Cost of remanufacturing
x	x	x	x			Useful Life of a product
x	x	x	x			Distance traveled in reverse supply chain

Greyed BP and CE in the table are taken as an example, as there are more BP and CE strategies available in the screening tool.

5. Conclusion and future work

This research is a first attempt to conceptualize and develop a sustainability screening tool to enable assessment of potential sustainability impact of future or current CE initiatives across a number of business processes in manufacturing companies. It is evident that due to the abundance of conceptualizations of CE and various implementation strategies, it becomes challenging for decision makers from industry to identify which initiative would bring more benefits to them and their stakeholders. Moreover, the main goal of many industries is to contribute to sustainable development by introducing improvements into their business processes, including CE initiatives. Therefore, the sustainability screening tool is intended to support industrial practitioners to assess CE strategies before implementation and possibly guide them towards choosing and improving the initiatives that are to benefit to environmental integrity, social well-being and economic resilience.

The main objective of the screening tool is to support decision makers from industry in: selecting suitable KPIs according to the CE initiative or the improvement in a BP that they consider introducing; providing guidelines how to calculate suitable KPIs and then how to interpret their values for sustainability assessment and comparison of different initiatives. Since the sustainability screening tool is under development, there are several considerations to be made in order to improve it. First, most of the retrieved KPIs cover environmental dimension of sustainability, whereas social dimension is underrepresented by KPIs in most CE initiatives and BP. The screening tool can be enhanced by making suggestions of new social KPIs. Second, despite the environmental dimension being most covered, a variety of KPIs need to be redefined with the purpose of addressing the particularities of circular systems and products (for example, the product's lifetime can be lower than industrial average, however the intensity of its use is higher, allowing it to deliver its function many more times than an industrial average). Also,

system models for each CE strategy have to be understood and explained to support companies in the selection of suitable KPIs for their CE strategy or BP (for example, system model of remanufacturing process clearly showing when does the process of remanufacturing start and finish and what operations it involves). Third, the KPIs have to be critically analyzed and clarified to allow for transparent and effective interpretation of KPIs and their calculated values (for instance, having a KPI addressing number of locally purchased goods can bias companies to make more focus on local supplies, which are not necessarily "better" than non-local). Fourth, the tool has to be validated by testing it in manufacturing companies. Application of the sustainability screening tool in industry will serve to assess the usefulness of both, the KPIs the screening database comprises of (relevancy and applicability of KPIs) and the screening tool itself (accuracy of delimitation from the database of KPIs).

Acknowledgements

References

[1] UN. UN SDG. Https://WwwUnOrg/Sustainabledevelopment/Sustainable-Development-Goals/ 2015. https://www.un.org/sustainabledevelopment/sustainable-development-goals/.

[2] Evans S, Vladimirova D, Holgado M, Van Fossen K, Yang M, Silva EA, et al. Business Model Innovation for Sustainability: Towards a Unified Perspective for Creation of Sustainable Business Models. Bus Strateg Environ 2017;26:597–608. doi:10.1002/bse.1939.

[3] Murray A, Skene K, Haynes K. The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. J Bus Ethics 2017;140:369–80. doi:10.1007/s10551-015-2693-2.

[4] Ellen MacArthur Foundation. Growth within: a circular economy vision for a competitive europe. Ellen MacArthur Found 2015:100. doi:Article.

[5] den Hollander MC, Bakker CA, Hultink EJ. Product Design in a Circular Economy: Development of a Typology of Key Concepts and Terms. J Ind Ecol 2017;21:517–25. doi:10.1111/jiec.12610.

[6] Ghisellini P, Cialani C, Ulgiati S. A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. J Clean Prod 2016;114:11–32. doi:10.1016/j.jclepro.2015.09.007.

[7] Masi D, Day S, Godsell J. Supply Chain Configurations in the Circular Economy: A Systematic Literature Review. Sustainability 2017;9:1602. doi:10.3390/su9091602.

[8] Geissdoerfer M, Morioka SN, de Carvalho MM, Evans S. Business models and supply chains for the circular economy. J Clean Prod 2018;190:712–21. doi:10.1016/j.jclepro.2018.04.159.

[9] Korhonen J, Honkasalo A, Seppälä J. Circular Economy: The Concept and its Limitations. Ecol Econ 2018;143:37–46. doi:10.1016/j.ecolecon.2017.06.041.

[10] European Commission. Closing the loop - An EU action plan for the Circular Economy 2015.

[11] EASAC. Indicators for a circular economy. 2016.

[12] WBCSD. Vision 2050: The new agenda for business. Wbcsd 2010:80. doi:10.1111/j.1530-9290.2009.00117.x.

[13] Agrawal V V, Ferguson M, Toktay LB, Thomas VM, Thomas VM. Is Leasing Greener Than Selling ? Is Leasing Greener Than Selling ? 2012.

[14] van Buren N, Demmers M, van der Heijden R, Witlox F. Towards a circular economy: The role of Dutch logistics industries and governments. Sustain 2016;8:1–17. doi:10.3390/su8070647.

[15] Andersen MS. An introductory note on the environmental economics of the circular economy. Sustain Sci 2007;2:133–40. doi:10.1007/s11625-006-0013-6.

[16] Allwood JM. Squaring the Circular Economy: The Role of Recycling within a Hierarchy of Material Management Strategies. 2014. doi:10.1016/B978-0-12-396459-5.00030-1.

[17] Agrawal V V., Ferguson M, Toktay LB, Thomas VM. Is Leasing Greener Than Selling? Manage Sci 2012;58:523–33. doi:10.1287/mnsc.1110.1428.

[18] Rotmans J. Tools for Integrated Sustainability Assessment: A two-track approach. Integr Assess J 2006;6:35–57.

[19] Joung CB, Carrell J, Sarkar P, Feng SC. Categorization of indicators for sustainable manufacturing. Ecol Indic 2013. doi:10.1016/j.ecolind.2012.05.030.

[20] Kirchherr J, Reike D, Hekkert M. Conceptualizing the circular economy: An analysis of 114 definitions. Resour Conserv Recycl 2017. doi:10.1016/j.resconrec.2017.09.005.

[21] EMF - Ellen MacArthur Foundation. TOWARDS THE CIRCULAR ECONOMY. 2013. doi:10.1162/108819806775545321.

[22] Geissdoerfer M, Savaget P, Bocken NMP, Hultink EJ. The Circular Economy – A new sustainability paradigm? J Clean Prod 2017;143:757–68. doi:10.1016/j.jclepro.2016.12.048.

[23] Cayzer S, Griffiths P, Beghetto V. Design of indicators for measuring product performance in the circular economy. Int J Sustain Eng 2017;10:289–98. doi:10.1080/19397038.2017.1333543.

[24] Blomsma F, Brennan G. The emergence of circular economy - a new framing around prolonging resource productivity. J Ind Ecol 2017.

[25] Nußholz JLK. Circular business models: Defining a concept and framing an emerging research field. Sustain 2017;9:14–7. doi:10.3390/su9101810.

[26] Bocken NMP, de Pauw I, Bakker C, van der Grinten B. Product design and business model strategies for a circular economy. J Ind Prod Eng 2016;33:308–20. doi:10.1080/21681015.2016.1172124.

[27] Winans K, Kendall A, Deng H. The history and current applications of the circular economy concept. Renew Sustain Energy Rev 2017;68:825–33. doi:10.1016/j.rser.2016.09.123.

[28] Parkinson HJ, Thompson G. Analysis and taxonomy of remanufacturing industry practice. Proc Inst Mech Eng Part E-Journal Process Mech Eng 2003;217:243–56. doi:10.1243/095440803322328890.

[29] Potting J, Hekkert M, Worrell E, Hanemaaijer A. Circular Economy: Measuring innovation in the product chain - Policy report. PBL Netherlands Environ Assess Agency 2017:42.

[30] Persson A, Stirna J. The Practice of Enterprise Modeling. Second IFIPWG 8.1Working Conf. PoEM 2009 Stock. Sweden, Novemb. 18-19, 2009, 2009, p. 29–46. doi:10.1007/978-3-642-32273-0.

[31] Sala S, Ciuffo B, Nijkamp P. A meta-framework for sustainability assessment Research Memorandum 2013-16 Serenella Sala Biagio Ciuffo Peter Nijkamp A Meta - Framework for Sustainability Assessment 2013:38.

[32] Pope J, Bond A, Hugé J, Morrison-Saunders A. Reconceptualising sustainability assessment. Environ Impact Assess Rev 2017. doi:10.1016/j.eiar.2016.11.002.

[33] Waas T, Hugé J, Block T, Wright T, Benitez-Capistros F, Verbruggen A. Sustainability assessment and indicators: Tools in a decision-making strategy for sustainable development. Sustain 2014;6:5512–34. doi:10.3390/su6095512.

[34] Krajnc D, Glavic P. Indicators of sustainable production. Clean Technol Environ Policy 2003;5:279–88. doi:10.1007/s10098-003-0221-z.

[35] Azapagic A, Perdan S. An integrated sustainability decision-support framework Part I: Problem structuring. Int J Sustain Dev World Ecol 2005;12:98–111. doi:10.1080/13504500509469622.

[36] Biolchini J, Mian PG, Candida A, Natali C. Systematic Review in Software Engineering. Engineering 2005;679:1–31. doi:10.1007/978-3-540-70621-2.

[37] Adriaanse LS, Rensleigh C. Web of Science, Scopus and Google Scholar: A content comprehensiveness comparison. Electron Libr 2013;31:727–44. doi:10.1108/EL-12-2011-0174.

[38] Gavel Y, Iselid L. Web of Science and Scopus: a journal title overlap study. Online Inf Rev 2008;32:8–21. doi:10.1108/14684520810865958.

[39] Falagas ME, Pitsouni EI, Malietzis GA, Pappas G. Comparison of PubMed, Scopus, Web of Science, and Google Scholar: strengths and weaknesses. FASEB J 2007;22:338–42. doi:10.1096/fj.07-9492LSF.

[40] Morioka SN, Carvalho MM. Measuring sustainability in practice: exploring the inclusion of sustainability into corporate performance systems in Brazilian case studies. J Clean Prod 2016;136:123–33. doi:10.1016/j.jclepro.2016.01.103.

[41] Epstein MJ, Roy MJ. Sustainability in Action:Identifying and Measuring the Key Performance Drivers. Long Range Plann 2001;34:585–604. doi:10.1016/S0024-6301(01)00084-X.

[42] Ness B, Urbel-Piirsalu E, Anderberg S, Olsson L. Categorising tools for sustainability assessment. Ecol Econ 2007. doi:10.1016/j.ecolecon.2006.07.023.

[43] Ahi P, Searcy C. An analysis of metrics used to measure performance in green and sustainable supply chains. J Clean Prod 2015;86:360–77. doi:10.1016/j.jclepro.2014.08.005.

[44] Valenzuela-Venegas G, Salgado JC, Díaz-Alvarado FA. Sustainability indicators for the assessment of eco-industrial parks: classification and criteria for selection. J Clean Prod 2016;133:99–116. doi:10.1016/j.jclepro.2016.05.113.

[45] von Geibler J, Liedtke C, Wallbaum H, Schaller S. Accounting for the social dimension of sustainability: Experiences from the biotechnology industry. Bus Strateg Environ 2006;15:334–46. doi:10.1002/bse.540.

[46] Kaenzig J, Friot D, Saadé M, Margni M, Jolliet O. Using life cycle approaches to enhance the value of corporate environmental disclosures. Bus Strateg Environ 2011;20:38–54. doi:10.1002/bse.667.

[47] Manninen K, Koskela S, Antikainen R, Dahlbo H. Do circular economy business models capture the environmental value propositions? - Framework for evaluating of the environmental value propositions circular economy business models n.d.

[48] Ashby A, Leat M, Hudson-Smith M. Making connections: A review of supply chain management and sustainability literature. Supply Chain Manag 2012;17:497–516. doi:10.1108/13598541211258573.

[49] United Nations Environmental Program (UNEP). Towards a Life Cycle Sustainability A ssessment: Making informed choices on products. 2011. doi:DTI/1412/PA.

[50] João Fontes SC at PrS. Handbook for Product Social Impact Assessment. 2016:153.

[51] IChemE. The Sustainability Metrics 2002:1–28.

[52] Guidelines SR. Sustainability Reporting Guidelines © 2000-2011 2011.

[53] ISO (International Organization for Standardization). INTERNATIONAL STANDARD Environmental management — Environmental performance evaluation — Guidelines. 2014.

[54] Rezaee Z. Supply chain management and business sustainability synergy: A theoretical and integrated perspective. Sustain 2018;10:1–17. doi:10.3390/su10010275.

[55] Ellen MacArthur Foundation. Circularity Indicators: An Approach to Measuring Circularity. Ellen MacArthur Found 2015:12. doi:10.1016/j.giq.2006.04.004.

[56] Lieder M, Rashid A. Towards circular economy implementation: A comprehensive review in context of manufacturing industry. J Clean Prod 2016;115:36–51. doi:10.1016/j.jclepro.2015.12.042.

[57] Moreau V, Sahakian M, van Griethuysen P, Vuille F. Coming Full Circle: Why Social and Institutional Dimensions Matter for the Circular Economy. J Ind Ecol 2017;21:497–506. doi:10.1111/jiec.12598.

[58] Sauvé S, Bernard S, Sloan P. Environmental sciences, sustainable development and circular economy: Alternative concepts for trans-disciplinary research. Environ Dev 2016;17:48–56. doi:10.1016/j.envdev.2015.09.002.