4th PLATE 2021 Virtual Conference
Limerick, Ireland - 26-28 May 2021

Interplay of Digital Technologies and Sustainable Product Development – What Can Product Life Cycle Data Tell Us?

Magdalena Rusch, Josef Peter Schöggl, Lukas Stumpf, Rupert J. Baumgartner
Christian Doppler Laboratory for Sustainable Product Management enabling a Circular Economy, Institute of Systems Sciences, Innovation and Sustainability Research, University of Graz, Austria

Keywords: circular economy; data management; eco-design; design for circularity; sustainability assessment.

Abstract: Today's linear economic paradigm leads to a situation where products are not designed and used to maximize their sustainability and circularity performance. The circular economy concept proposes a modern framing of value retention strategies by increasing the awareness of their ability to prolong the use of resources and minimize waste. The utilization of product life cycle data, partly facilitated by digital technologies, is not only an enabler for such value retention strategies but also an essential input for sustainable product development processes aimed at minimizing a products' environmental and social impact. However, what strategies are being pursued in practice, what sustainability-related data are available, and how digital technologies can facilitate these processes requires further investigation. In this regard, the contributions of this study are twofold. First, it provides a collection of key aspects for sustainable product development based on a literature review. Second, it reveals the degree of implementation of sustainable product development and value retention strategies and the availability of related data. The latter contribution is derived from a survey with 59 sustainability executives from Austrian companies. The results show that the degree of implementation varies considerably between the different strategies. So far, a focus is set on avoiding toxic substances and closing internal material loops. Digital systems to support a circular economy business model, product, or service are available in less than half of the cases. The implementation of digital technologies is rather a single-case phenomenon than an established business strategy.

Introduction

Sustainable product development (SPD) is not a "nice-to-have" activity anymore but becomes imperative for today's businesses (Buchert, Halstenberg, Bonvoisin, Lindow, & Stark, 2017). One reason for that is the increasing number of regulations (ibid.), especially in the European Union (EU), where, for example, the "European Green Deal" aims to "*[…] transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use."* (European Commission, 2019, p.2). EU's commitments to tackle urgent environmental-related challenges come with the need for prompt actions in various areas. One among several strategies on how to transform the economy is delineated in the circular economy (CE) action plan (European Commission, 2020b). This plan includes a 'sustainable products' policy to support the circular design of products based on a common methodology and principles. Additionally, international standards for incorporating material circularity in the design phase of products and their constitute parts exist already (ISO, 2020). And not only on a policy level but also in business and research the CE concept has gained attention (EMF, 2015; European Commission, 2020b; Schöggl, Stumpf, & Baumgartner, 2020) and has become one of the most recent ways to engage with environmental sustainability (Barreiro-Gen & Lozano, 2020). Regarding Bocken, de Pauw, Bakker, & van der Grinten (2016) one strategy to operationalize the CE concept on the micro level is to extend the life time of a product. For this, maintenance and repair strategies are crucial to address for organizations to provide circular services and products (Emilia Ingemarsdotter, Kambanou, Jamsin, & Sakao, 2021). Digital technologies (DTs), such as the internet of things (IoT) and big data analytics, can be used as enablers for such product lifetime extension (e.g. predictive maintenance) activities (ibid.). In general, several authors pointed out that for the transition from the current linear economy (take-make-waste approach) towards a CE, DTs play an essential role (Kristoffersen, Blomsma, Mikalef, & Li, 2020; Lieder & Rashid, 2016; Pagoropoulos, Pigosso, & McAloone, 2017).

However, practical insights are largely missing so far. Therefore, the following research questions are addressed in this study. First, to which degree SPD is adopted in practice and which environmental and social product life cycle data (PLCD) are available for it? Second, what is the use of DTs for SPD in practice (e.g., as a data source or for exchanging and analyzing data)?

This study aims to provide an explorative overview of PLCD in general and the availability of PLCD for SPD in a CE context. More specifically, this research will make the following contributions to answer the research questions. First, key issues for SPD from the literature were identified. Second, the degree of implementation of SPD in a CE context and the availability of environmental and social PLCD in practice were assessed by conducting a telephone survey with manufacturing companies. Additionally, examples from the literature were collected that focused on the use of DTs for SPD in practice.

Methods and materials

First, a literature review (Fink, 2005) was conducted on the intersection of SPD, CE, and DTs to identify current approaches that can be used to collect, manage, and exchange PLCD and define data needs for SPD in a CE. A particular emphasis was on journal articles that studied the use of DTs to enable product life extension, e.g., with predictive maintenance activities.

Second, a fully structured survey (Bryman & Bell, 2011) including closed and open questions was conducted via telephone. The aim was to examine the status of the Austrian companies' degree of implementation regarding SPD in a CE context, the availability of sustainability-related data, and their maturity level in applying DTs for sustainability management and CE. The sample includes 59 answers from company representatives (sustainability executives) from all sizes and different industry sectors such as chemical and electronics, automotive supply, machinery and metalware, food, paper, and textile. More specifically, 32 % of the companies have a turnover below 10 Million (Mio.) Euros, 50 % between 10-100 Mio. and 18% above 100 Million. 73 % of the companies have between 1-250 employees, 20% 251-1000 and 7% between 1001-10000.

The statistical program R version 3.6.1 (R Core Team, 2019) was used for the (descriptive) analysis of the answers.

Results

SPD in a CE context

A clear strategy and the planning of circularity strategies for products and materials should precede their design and development (ISO, 2020). Therefore, we asked firms about the general importance of (I) implementing circular products or services and (II) eco-design guidelines for product development. For 61% of the firms in the sample, the implementation of circular products or services is very important or important. For almost 56%, the use of eco-design guidelines for product development is very important or important.

In this study, we used SPD as an umbrella term to subsume different synonymous and/or complementary approaches from the beginning-of-life phase of a product, such as eco-design, circular design or sustainable design. In literature, SPD is described as product development where *"[…] a strategic sustainability perspective is integrated and implemented into the early phases of the product innovation process, including life cycle thinking."* (Jaghbeer, Hallstedt, Larsson, & Wall, 2017, p.271). To assess the current state of implementation of SPD in practice, a range of 16 SPD aspects was used (see Figure 1). The range covers relevant CE issues (i.e. from the 10-R hierarchy (Reike, Vermeulen, & Witjes, 2018) and the ReSOLVE framework (EMF, 2015)) as well as issues required to consider a more comprehensive sustainability perspective (e.g. related to social and environmental impacts along the supply chain). As can be seen in Figure 1, the avoidance of toxic substances in products is the aspect that is already most often implemented company-wide. Other frequently implemented aspects are an increased material and/or energy efficiency in production, design for the environment, the closing of internal material loops in production, green and social supply chain management, and the use of renewable resources for products. However, these aspects are more often only implemented in pilot projects yet, or the company-wide implementation is underway.

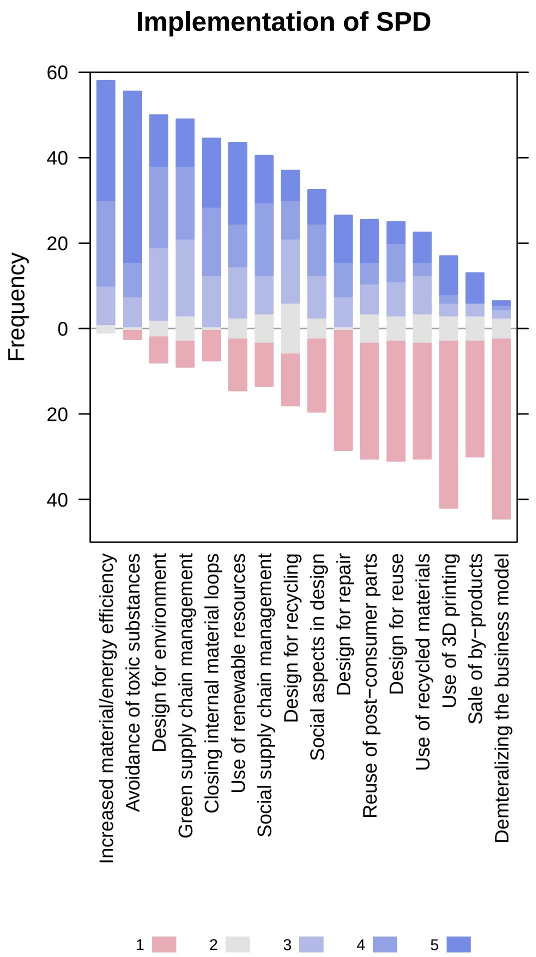

Figure 1: Degree of implementation of SPD aspects (n=59). Note: 1=not considered, 2=considering it, 3=implementation in pilot or individual project, 4=company-wide implementation underway, 5=already implemented company-wide. Missing=no response.

More than half of the firms in the sample did not consider design for repair or reuse, reuse post-consumer products, or use recycled materials and the degree of implementation of these aspects varies a lot. The implementation of the sale of by-products, the use of 3D printing, or the dematerialization of business models was not considered by most of the firms. For the latter aspects, also the degree of missing answers was the highest (e.g., 16 for sales of by-products). However, it was found in another survey question (not illustrated in Figure 1) that almost 53% of the firms already provide (*implemented* or *implementation underway)* after-sale services, e.g., inexpensive repairs, free take-back or spare part services for their products. Subsequently, these activities contribute to a product lifetime extension, although the accompanying SPD aspects like the design for repair or reuse were not implemented.

Availability of environmental and social PLCD

Furthermore, the firms in the sample were asked about the availability of environmental and social PLCD required for SPD. The data sources were categorized into three areas: company-internal data, data from the supply chain, and data from the use or end-of-life (EOL) phase.

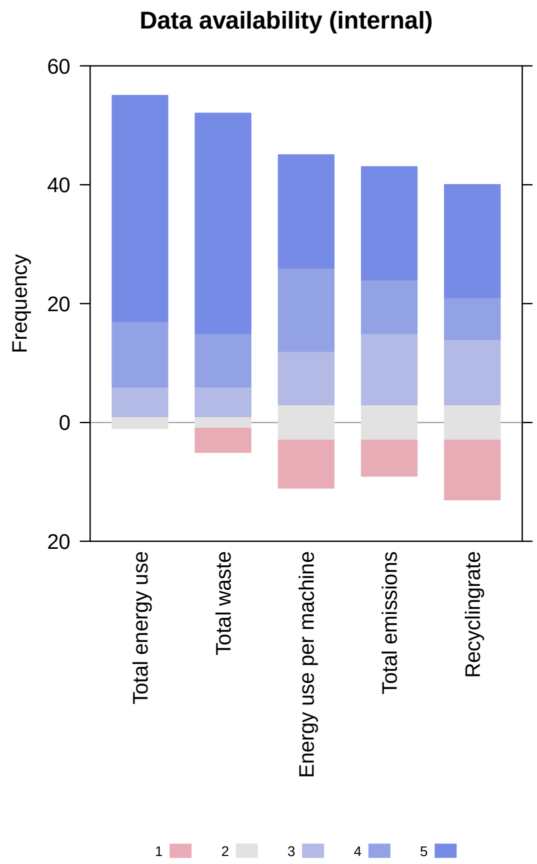

Figure 2: Company internal sustainability data availability (n=59). Note: 1=not available, 2=hardly/barely available, 3=partly available, 4=mostly available, 5=fully available. Missing=no response.

The survey results regarding company-internal data (Figure 2) show that the availability of data on the firm's total energy use and waste generation is very high (fully available) or high (mostly available) for most of the firms. Regarding the firm's total emissions, the specific energy use per production machine and their waste recycling rates, most firms reported a high data availability (data is fully or mostly available), but there is a bigger difference between them. For all five aspects, the median is at least three, which generally shows a good availability of company-internal data.

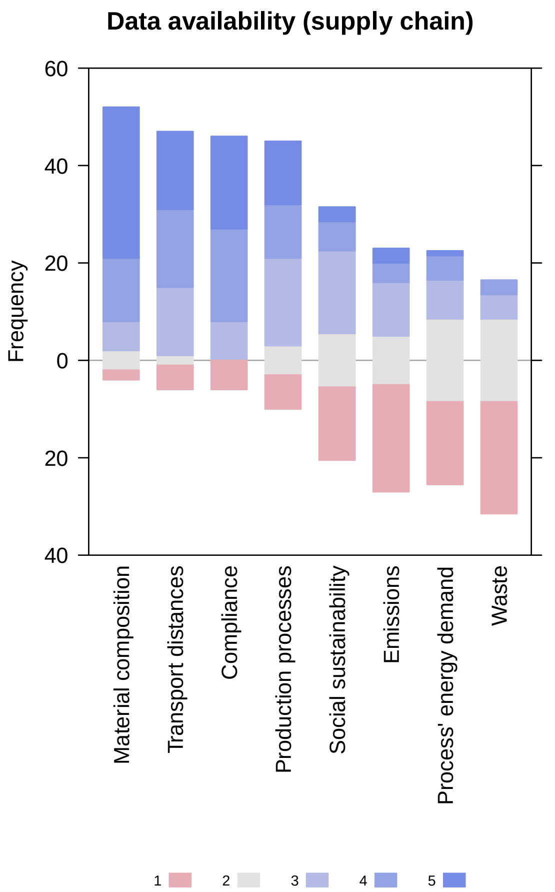

Figure 3: Supply chain sustainability data availability (n=59). Note: 1=not available, 2=hardly/barely available, 3=partly available, 4=mostly available, 5=fully available. Missing=no response.

Regarding the data availability from the supply chain (Figure 3), the results show that the material composition of the components and products, transport distances, information required by law (compliance), and the used production processes are well known. Data about the social sustainability in the supply chain are most often at least partly available. In contrast, the data of the emission in the supply chain, the energy demand of suppliers' production processes, and the waste generation in the supply chain are not or barely available in most firms.

Especially for the use or EOL phase (Figure 4), the data availability is relatively low for all three aspects (median two or three) with minor variations between the firms. Most data are available about the energy demand during the product use but in most cases only partly. No firm reported that data is fully available for the product's EOL routes and also data about the recycling rates are most often not available.

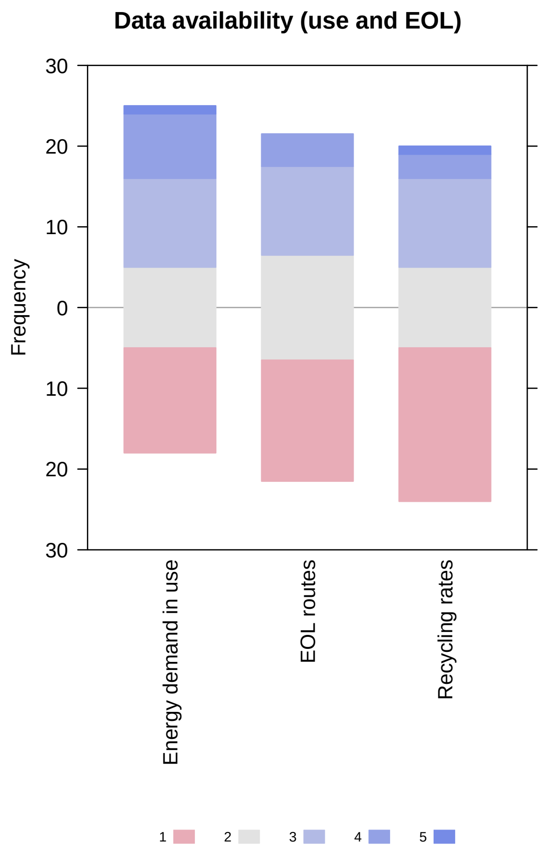

Figure 4: Use and EOL phase sustainability data availability (n=59). Note: 1=not available, 2=hardly/barely available, 3=partly available, 4=mostly available, 5=fully available. Missing=no response.

Use of DTs and related strategies

Mobilizing the potential of digitalization and DTs for enhancing the collection, management, and exchange of product information, including solutions such as digital product passports (DPPs), is described as a critical enabler for a

CE (European Commission, 2020b). Such DPPs should include information on a product's origin, durability, composition, reuse, repair and dismantling possibilities, and EOL handling (European Commission, 2020a) to provide relevant technical and sustainability-related information about a product along a value chain and promote circular value retention options (Lemos, 2020). In our sample, almost 41% of the survey respondents reported that appropriate IT and other digital systems to support a circular economy business model, product, or service are available.

Around a third of the firms (37%) have a digitalization strategy for product development tasks, around 40% for product management and 22% for sustainability management.

Furthermore, twelve out of 59 firms in the sample use IoT applications for production data collection. Big data analytics for process- and equipment maintenance issues is used in ten firms only. Blockchain technology and artificial intelligence applications are so far not applied in most firms.

Application examples of DTs from literature

During the design phase, in order to implement IoT enabled circular strategies, companies have to consider the integration of, e.g. sensors, to derive reliable insights about a product's condition (Ingemarsdotter et al., 2021). Afterwards, activities such as condition-based monitoring and (predictive) maintenance can be used, as part of the firm's value proposition, to facilitate the lifetime extension of products, as one among other CE strategies (ibid.). In the scientific literature, already implemented application examples of DTs for SPD and maintenance activities were found. The following examples not only focus on the design phase but also show how the integration of DTs during the product's design and development can influence the use phase and enable the extension of the product's lifetime.

Most examples come from big corporations like **Rolls-Royce** that execute preventive and predictive maintenance by monitoring the engine data received via satellites in real-time and automatically elaborating the collected data through appropriate analytics to extend the useful life of engines (Bressanelli, Adrodegari, Perona, & Saccani, 2018). Or from **Toyota,** where cars are equipped with smart sensors and continuously collecting data about their locks, location, ignitions, and tires which can be later used by the manufacturer assembly line (Fahmideh & Beydoun, 2019). **HP** monitors their printers and collects data from products-in-use to support design for durability (E Ingemarsdotter, Jamsin, Kortuem, & Balkenende, 2019). **Whirlpool's** washing machines give the user notifications about upcoming maintenance needs (ibid). Cars from **Tesla** can schedule their own repairs based on fault monitoring. Tesla also performs remote services and upgrades on their cars (ibid).

Discussion

The examples from the literature show that DTs are already in place to support SPD and sustainable product management in general. The application of DTs serves as an enabler for improved product design (e.g., design-for-durability) and is important to collect and analyze PLCD. Moreover, DTs can not only be used as the data source for PLCD, but also, based on the newly gained insights, products can be designed to directly interact with customers and give notifications about upcoming maintenance needs. These after-sale services can prolong the lifetime of a product, and SPD insights can be derived. Most examples come from large international corporations. They could be described as forerunners regarding the implementation of DTs. However, some Austrian firms also confirmed using DTs for various activities such as data collection from production, product development, or maintenance tasks.

Regarding the research questions, key aspects for SPD in a CE context were derived from literature. A set of 16 SPD aspects was used to evaluate the current state of implementation of SPD in practice. An additional set of 16 aspects, categorized in three areas, was used to assess the availability of environmental and social PLCD in Austrian firms. It was found that the degree of implementation is very high for the two aspects (I) avoidance of toxic substances in products and (II) increased material and/or energy efficiency in production. Data about the product's material composition was at least partly available in almost all firms which is crucial for SPD.

Additionally, the results from the empirical study show for which aspects of the three areas the availability of data is already high i.e., data of the firm's total energy use and waste generation (company-internal) and the material composition (supply chain). For all the other aspects, the data availability should be enhanced i.e., all three aspects from the use or EOL phase, most aspects from the area regarding the data availability of the supply chain and some from the company internal area. While the sample described in this study is not representative for all Austrian firms, it shows the tendencies that the availability of company internal data (Figure 2) is higher for most of the aspects than from supply chain (Figure 3) or use and EOL phase (Figure 4).

Conclusions

This study contributes to the field by investigating firms' status quo regarding their degree of implementation of SPD aspects in a CE context, and the availability of environmental and social PLCD in practice has been shown. Furthermore, concrete application examples of DTs for SPD from the literature were given. It shows that the application of DTs already in the design and development phase enables product lifetime extension activities such as (predictive) maintenance and data from products-in-use can support design decisions. Firms can intentionally design their products to facilitate the collection and management of PLCD using DTs. With the increased use of DTs, it is very likely that also the availability of data will increase for most SPD aspects.

Acknowledgements

The financial support by the Austrian Federal Ministry for Digital and Economic Affairs, the National Foundation for Research, Technology and Development and the Christian Doppler Research Association is gratefully acknowledged.

References

Barreiro-Gen, M., & Lozano, R. (2020). How circular is the circular economy? Analysing the implementation of circular economy in organisations. *Business Strategy and the Environment*, *29*(8), 3484–3494. https://doi.org/10.1002/bse.2590

Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, *33*(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Bressanelli, G., Adrodegari, F., Perona, M., & Saccani, N. (2018). Exploring how usage-focused business models enable circular economy through digital technologies. *Sustainability (Switzerland)*, *10*(3). https://doi.org/10.3390/su10030639

Bryman, A., & Bell, E. (2011). *Business Research Methods*. New York: Oxford University Press Inc.

Buchert, T., Halstenberg, F. A., Bonvoisin, J., Lindow, K., & Stark, R. (2017). Target-driven selection and scheduling of methods for sustainable product development. *Journal of Cleaner Production*, *161*, 403–421. https://doi.org/10.1016/j.jclepro.2017.05.067

EMF. (2015). Growth within: a circular economy vision for a competitive europe. In *Ellen MacArthur Foundation, SUN, McKinsey Center for Business and Environment*.

European Commission. *The European Green Deal*. , Pub. L. No. COM(2019) 640 final (2019).

European Commission. *A European strategy for data*. , Pub. L. No. COM(2020) 66 final (2020).

European Commission. *A new Circular Economy Action Plan - For a cleaner and more competitive Europe*. , Pub. L. No. COM(2020) 98 final (2020).

Fahmideh, M., & Beydoun, G. (2019). Big data analytics architecture design—An application in manufacturing systems. *Computers and Industrial Engineering*, *128*, 948–963. https://doi.org/10.1016/j.cie.2018.08.004

Fink, A. (2005). *Conducting Research Literature Reviews: From the Internet to Paper* (2.). https://doi.org/10.1111/j.1365-2648.2006.04033.x

Ingemarsdotter, E, Jamsin, E., Kortuem, G., & Balkenende, R. (2019). Circular strategies enabled by the internet of things-a framework and analysis of current practice. *Sustainability (Switzerland)*, *11*(20). https://doi.org/10.3390/su11205689

Ingemarsdotter, Emilia, Kambanou, M. L., Jamsin, E., & Sakao, T. (2021). Challenges and solutions in condition-based maintenance implementation - a multiple case study. *Journal of Cleaner Production*, *296*. https://doi.org/10.1016/j.jclepro.2021.126420

ISO. (2020). *ISO 14009:2020 Environmental management systems — Guidelines for incorporating material circulation in design and development*.

Jaghbeer, Y., Hallstedt, S. I., Larsson, T., & Wall, J. (2017). Exploration of Simulation-Driven Support Tools for Sustainable Product Development. *Procedia CIRP*, *64*, 271–276. https://doi.org/10.1016/j.procir.2017.03.069

Kristoffersen, E., Blomsma, F., Mikalef, P., & Li, J. (2020). The smart circular economy: A digital-enabled circular strategies framework for manufacturing companies. *Journal of Business Research*, *120*, 241–261. https://doi.org/10.1016/j.jbusres.2020.07.044

Lemos, P. (2020). *Towards a Circular Economy - Presentation on Product Passport. European Commission*. Conference presentation Hamburg Sustainability Session #2.

Lieder, M., & Rashid, A. (2016). Towards circular economy implementation: A comprehensive review in context of manufacturing industry. *Journal of Cleaner Production*, *115*, 36–51. https://doi.org/10.1016/j.jclepro.2015.12.042

Pagoropoulos, A., Pigosso, D. C. A., & McAloone, T. C. (2017). The Emergent Role of Digital Technologies in the Circular Economy: A Review. *Procedia CIRP*, *64*, 19–24. https://doi.org/10.1016/j.procir.2017.02.047

R Core Team. (2019). A Language and Environment for Statistical Computing. Retrieved August 11, 2020, from R Foundation for Statistical Computing website: http://www.r-project.org

Reike, D., Vermeulen, W. J. V., & Witjes, S. (2018). The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. *Resources, Conservation and Recycling*, *135*, 246–264. https://doi.org/10.1016/j.resconrec.2017.08.027

Schöggl, J.-P., Stumpf, L., & Baumgartner, R. J. (2020). The narrative of sustainability and circular economy - a longitudinal analysis of two decades of research. *Resources, Conservation & Recycling*, *163*. https://doi.org/10.1016/j.resconrec.2020.105073