World Journal of Information Systems 1(2) 61-73
DOI: https://doi.org/10.17013/wjis.v1i2.14

*Article*

# A Dynamic Circularity Information Management Roadmap for Small and Medium Enterprises

**Mário Miguel de Sousa Martins[1], Cristóvão Dinis Polido Sousa[1,2], Carla Sofia Gonçalves Pereira[2] and Bruno Silva[2,*]**

[1] ESTG, Polytechnic of Porto

[2] INESC TEC

[3] Muvu Technologies

***** Correspondence: mmsm@estg.ipp.pt

(Article history: Received March 25, 2024; Received in revised form April 19, 2024; Accepted June 07, 2024; Available online June 15, 2024)

**Abstract:** Globally, sustainability concerns have been driving several green strategies towards new business models for industry circularity. While industrial greenality is broadly discussed in literature, still missing a clear roadmap tailored for small and medium enterprises (SMEs) to translate circularity practices into tangible, value-driven datasets. This research work addresses this existing gap by proposing a circularity information management roadmap designed for SMEs. The framework aims to guide small enterprises throughout their journey on the implementation of circular business practices. The discussed framework intends to be used as a governance model to assess and increase an organization's circular level. By providing a clear and common view on circular practices and its underlying artefacts, SMEs might design their circular projects more efficiently based on a clear understanding on the needs and means to increase their circularity business performance.

**Keywords:** Circular Economy; Information Management; Circularity Governance Model; Circularity Roadmap

## 1. Introduction

Globally, there has been a great concern around industrial circularity and greenality and this paradigmatic shift takes digitization to a new demanding level of challenges. Literature is discussing around green strategies, circular business models and frameworks for circularity and sustainability measurement, yet there is a lack of a clear roadmap for small and medium enterprises (SMEs) circularity practices, and convert those in concrete data sets, from which it's possible to extract a real added value.



© 2024 ITMA. All rights reserved.

Besides the lack of a roadmap for circular practices, SMEs also face economic, social, and organizational challenges in their journey towards circularity that impair this shift in many of this companies. Alongside this, there is a plethora of definitions for this concept, some of them unclear, that make it harder for them to grasp this concept.

There is the need to move from a static approach to circularity towards a more dynamic perspective, wherein companies understand, in real time, how green and circular are their products, right from its conception and across the whole product life cycle, since this kind of data is becoming an important indicator in the decision-making process and not only at a strategic level.

This work intends to provide a circularity information management roadmap, aiming to guide SMEs to success in their shift towards a Circular Economy Business Model. The governance model presented by this study makes use of circular practices to assess and improve the organizations circularity level, while providing detail on what these practices are.

## 2. The Circularity Quagmire

During the last 5-10 years, the concept of 'circular economy' (CE) has received particular attention both politically and socially, motivating many governments around the world to design concrete policies for the adoption of CE initiatives [1].

Circular economy is a multidisciplinary concept that embraces and affects the economic, environmental, and social fields [2]. As CE encapsulates various concepts, including economic value, the reduction of energetic consumption and social wellbeing in general, "it means different things to different people" [3], which means is still underdeveloped, lacking in a common scientific definition framework, since the concept initially emerged from the practitioner's perspective [4]. This is further supported by a study by Kirchherr et all. 2017, identifying 95 different definitions for circular economy in a sample of 114 definitions [5]. A broad definition accepted for this concept is the one proposed by the Ellen MacArthur Foundation, which states that that circular economy is based on the extension of the product and materials life cycle, stating that the materials used never become waste, through the application of the R framework, re-utilizing the material in whatever way possible, through recycling, refurbishment, re-manufacture or reuse, keeping the resource in the loop, allowing for nature to regenerate, while reducing pollution, being like this "by intention and design" [6].

The main focus of circular economy is sustainability and the environment, through the maintenance of resources in the loop, avoiding the extraction of new ones from nature at the expense of natural resources and the exhaustion of the environment, but, as mentioned earlier, the social and economic factors are also taken into account, aiming to improve the quality of life of the community, through the lowering of pollutants produced and the widening of job opportunities [7], and preventing the loss of economic value, through the maintenance of the



© 2024 ITMA. All rights reserved.

products in the loop, eliminating waste while re-using it to serve as a source of material to the same or other industries [2].

This concept is introduced as an alternative to "the current socioeconomic system" that "is based on a linear economy, in which firms make products and the consumers use and dispose" [8]. The current linear model leads to unnecessary waste of resources in all stages of the product life cycle, making it so that there is an excessive use of energy and resources leading to the exhaustion of the ecosystems.

It is important that enterprises understand this concept at its various levels, so they can focus their efforts in improving circularity, and not only in one of the fields mentioned earlier, and not get lost in the circular economy quagmire.

### *2.1. Challenges of the adoption of Circular Economy*

At first sight, CE presents itself as a novelty with lots of benefits at an environmental or even at an enterprise level, but upon closer inspection of what it takes for a fully linear economy-based company to adopt circular strategies, we learn it is not that simple, especially for SMEs. SMEs face a lot of challenges while adopting these strategies across all fields and areas of business.

Beyond the ambiguity of the CE concept and the lack of guidelines for the implementation of circular economy practices [9], other challenges derail companies plans towards a circularity. Those barriers go from supply chain constrains, to financial, organizational, and administrative constraints.

As in any type of change, especially to a well-established system or work policy, people are always skeptical to the new, especially when it is unknown. Companies show concerns about the financial aspect of adopting circular practices, questioning why they should spend money innovating and what to innovate. They also fear that changing their product to be in accordance with the principles of CE will affect business, as many customers do not show many concerns about sustainability as of now. This all stems from being afraid that the return on investment (ROI) will not be enough to cover the initial expenses in the transition [10].

In some industries, circularity is almost impossible to achieve given the end of life of the product, that is handled by the consumer, that simply throws the product away, not thinking about reusing or recycling it, i.e., in the textile industry only "20% of clothing waste is collected globally for reuse or recycling" [11] (p. 341). The lack of support provided along the whole supply chain affects the ability of the firms to implement a Circular Economy Business Model (CEBM), not only because of the price of the materials and the bad end of life handling of the products, but also because of the competition and the lack of cooperation between businesses, impairing the stream of resources and knowledge. There is also the fact that there are not many suppliers providing green inputs, and the ones that exist are much more expensive than virgin materials, which are essential to manufacturing circular goods and, at the end of the supply chain, emphasizing the benefits of circular products to existing



© 2024 ITMA. All rights reserved.

and potential customers, is also a difficulty faced by companies [12, 13, 14]. The financial challenges found along the way, being it the lack of available capital or the hardships when trying to raise funds, from private or public sources, needed to implement these strategies, finance research and development (R&D) and to hire human resources, pose one of the biggest challenges in making the switch to a CEBM [13, 14, 15].

As CE is still an under-explored concept in what comes to SMEs, the lack of guidelines for implementation of this business model, legislation and incentives are also barriers that act in detriment of this business model [13, 14, 15].

These barriers also arise inside the organization. On the macro level, the lack of innovative culture, along with being slow and reluctant to adapt to change and fearful of taking risks, especially when the ROI and profitability are at stake, and on the micro level, the absence of qualified personnel, with skills and know how to push change onto the company, are a major barrier to the firm's development [13, 16].

To summarize these challenges, a table was designed to categorize them (table 1).

**Table 1.** Barriers to the implementation of CEBMs in SMEs

| Category | Barrier | Reference |
|---|---|---|
| Supply Chain | Lack of Green Product Suppliers | [10] |
| | Fear of Low Customer Interest | [13, 17] |
| | High Presence of Linear Business Models | [17] |
| | High Prices of Circular Materials | [18] |
| | Quality of the Discarded Products is Unknown | [19] |
| Financial | Lack of Funds | [17, 18] |
| | Difficulties Raising Funds with Private or Public Entities | [17] |
| | Fear of Low ROI | [16, 18] |
| | Lack of Ways to Measure the Benefits of CBM | [20] |
| | Perception of CE as a Cost without Return | [16, 18] |
| Organizational | Slow Adaptation to Change | [17] |
| | Absence of Qualified Personnel | [16, 17] |
| | Clashing Priorities | [12] |
| | Lack of Innovative Culture | [17] |
| | Fear of Risk Taking by Stakeholders | [11] |
| | Lack of Experience and Skills/Know-how | [16, 17] |
| Administrative | Lack of Legislation | [17] |
| | Ambiguity of the Concept | [5] |
| | Lack of Government Support and Incentives | [15, 17] |
| | Inexistent or Minimal Guidelines on How to Implement CE Practices | [17] |

*2.2. Benefits of the implementation of Circular Economy*

As stated before, there are many barriers in SME path of circularity and, as such, there are yet not many success stories documented in what comes to the adoption of CEBMs in



© 2024 ITMA. All rights reserved.

SMEs. Because of this, to define the benefits these business models bring forth to companies, we must look at potential benefits to provide an overview of how these enterprises may profit from its implementation.

The early adoption of CEBMs could bring about a lot of benefits for companies, as with the increase in taxes for the usage of natural resources, the companies using secondary materials will save money, having the material inputs for manufacturing their products at a lower price will inevitably generate higher profit margins. Along with the increase in taxes on the use of natural resources, the final products that contain mostly virgin materials as their input for manufacturing will also be hit with an increase in prices, turning the more and more eco-conscious population further towards the consumption of circular and sustainable goods, creating a competitive advantage [21, 22]. Furthermore, according to the Circular Economy Action Plan (CEAP) from the European Commission, "since manufacturing items […] spend about 40% on materials, closed loop models can increase profitability, while sheltering from resource price fluctuation" [23] (p. 11), as companies will be re-using or re-manufacturing their own products and waste, returning them to the cycle.

The population will also play an important role in the potential benefits that come from the adoption of this business models. As the people are more committed to sustainability the relationship with customers and the society becomes stronger, attracting new possible clients and markets [24, 25], generating more revenue, along with the ability to increase prices, as "eco-conscious customers are willing to pay premium for sustainable […] products" [21].

While in pursuit of product circularity, enterprises need to review all of their business processes, making those more efficient and decreasing the manpower needed, as companies become more automated, while also improving the quality of the final product [26, 27]. This review can also take the firm to realize that their waste can be re-introduced into the loop by themselves or another company. If the waste serves as a resource to another company, that company will have a local partner facilitating their transition to CE, while creating a new revenue stream for the selling company [28].

This new paradigm can generate new job opportunities, that, in this case, reside primarily in the fields of repair, re-manufacture and production of secondary materials, leading to economic growth of the region while decoupling economic growth from the use of natural resources, in a time where the demand to produce goods is increasing exponentially with the growth of world population. The use of secondary materials generates a lot of benefits, helping to avoid resource scarcity and, as a consequence, the stagnation of global economy, helps countries meet climate commitments set by policymakers and lowers the supply chain vulnerability to geopolitical issues, as the domestic production of the materials will reduce the need for importing virgin materials, this keeping production up even if the supply of these materials is cut [29]. The reduction in pollutants and hazardous materials created by an industry that implements a CEBM, will benefit both the environment and society, improving public health [28]. As with the challenges before, we can also categorize the benefits of these business models (table 2).



© 2024 ITMA. All rights reserved.

**Table 2.** Benefits of the implementation of CEBMs in SMEs

| Category | Benefit | Reference |
|---|---|---|
| Legal Standpoint | Complying with EU Legislation | [21, 22] |
| | Complying with National Climate Commitments | [28] |
| Organizational Standpoint | Improvement in Customer Relationships | [21, 22, 24] |
| | Increase in Profitability | [21, 23] |
| | Lower Manufacturing Costs | [23] |
| | Independence from Foreign Resource Markets | [28] |
| | Increase in Market Share | [21, 24] |
| | Improvement in Business Processes | [27, 30] |
| Cultural Standpoint | Firm is Seen as a Mindful Entity | [24, 28] |
| | Helping Local Firms in the Transition to CE | [28] |
| | Improvement of Public Health | [28] |
| Technical Standpoint | Creation of Job Opportunities | [29] |
| | Increase in Innovation and Knowledge Sharing | [29] |

### *2.3. Practices associated with Circular Economy*

To assess circularity, enterprises need to know the current state of their products and business processes and, for that, data collection is essential. The information gathered about these topics through the constant monitorization can be used to improve the efficiency of the processes and to validate future decisions in a more informed way [31]. To apply some of the practices explained in this topic, data gathering is crucial.

The Life Cycle Analysis (LCA) is a standard, defined in ISO14040 and 14044 and has been identified by the European Commission as the best framework to assess and quantify the environmental profile and impact of products or services [32]. This standard evaluates the entire life cycle of the product or service and was conceived for the linear economy model, although it can be adapted to circular economy by expanding the systems and boundaries and adding multiple material cycles [26]. According to the Society of Environmental Toxicology and Chemistry, there are two main phases in the LCA, the analysis phase, which is divided into Goal definition and scoping and inventory analysis and the Assessment phase or Impact assessment [33].

The goal definition and scoping phase consists in the definition of the scope and end goals which this analysis is considering and aiming towards. This analysis can be conducted at organizational, production or product level, thus defining the scope and the metric unit, that will be used for comparisons in the future. At this stage, a system boundary could also be defined, but as the subject is circular economy, the goal is that the boundary encompasses the whole closed loop, making it so that it must be cradle-to-cradle.

As for the inventory analysis stage, it encompasses the definition and examination of the life cycle inventory (LCI), listing the inputs and outputs of the metric unit being analyzed.



© 2024 ITMA. All rights reserved.

For example, at product level, the LCI may contain information about the raw materials used in production, the percentage of which are reused, and the energy used in the production process as input information, and as output information, the quantity of the inputs that where scrapped or thrown away, not to be used again [32]. This data will then be inferred upon, either quantitative or qualitatively, to conclude about the sustainability of the products or processes being studied.

The assessment phase comprehends the Life Cycle Impact Assessment (LCIA) and the data collected in the LCI can heavily bias this analysis, as this step is an analysis to identify the potential environmental impacts of a system identified in the inventory analysis [34].

Another practice associated to CE is traceability, that, according to ISO 9000:2015 [35], is the "ability to trace the history, application or location of an object", or "when considering a product or a service, traceability can relate to: the origin of materials and parts; the processing history; the distribution and location of the product or service after delivery". Associated to traceability, the Digital Product

Passport (DPP) comes up. The DPP, just like a regular passport, aims to provide information about where a product comes from, where it has been and how it got there, with the addition of information of how it is made and notes about its repairability and dismantling, eliminating the lack of information [36]. To accommodate traceability and the DPP, the process and technology for data gathering is of utmost importance.

When implementing circular or sustainable strategies, the R-Framework is often considered as the ultimate circularity measurement instrument. This framework is an approach that combines the R's policy with circularity. It uses 10 strategies to increase circularity: refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover [37].

## 2. Circularity Roadmap

The adoption of practices to promote circularity encloses a digital journey that companies, in particular SMEs, cannot ignore, and whose success is related to the information governance model adopted within the data ecosystem of the value chain. The framework presented in figure 2, called **CE Information Management Cockpit**, is based on two assumptions: the first is that the digital transformation cannot neglect the DIKW (Data; Information; Knowledge; Wisdom) stack, and: The second considers an incremental and iterative approach, based on maturity levels, wherein the digital maturity is assessed by means of what a SME is able to know at each layer of the stack.

The framework also considers two dimensions of maturity: the first is related to traceability. In this dimension, as the traceability capacity increases, the maturity of the information governance model grows and, consequently, the things that are known to continuously improve the circularity strategy is higher; the second dimension defines the scope and varies at the level of the product, process, or value chain. For each level of the stack, it is possible to evolve at the level of the scope. In this approach, and according to



© 2024 ITMA. All rights reserved.

Shevchenko et al. (2022), when the scope is at the product level, it means that the concern is focused on: i) reassessing the function of the product; ii) optimizing its use, and iii) determining to what extent changing or redefining its function can contribute to increasing circularity [38]. On the other hand, if the scope is at the process level, then the concern focuses, for example, on the ability to increase the life span of a product. Finally, the value chain context focuses on issues related to the organization of the value chain and how to implement collaborative strategies for circularity [39]. The adoption of circular practices evolves as organizations respond to the questions "What to do" and "What to know", as well as when they ensure more circular capability. To be able to answer these questions and to proceed to further implement circular practices, the companies need to know themselves, their processes, and their products and, for that, data collection is one of the key aspects to be invested in to go further with the implementation of these practices. At the most basic level, for example, the organization should ensure that it can collect information about the product and its inputs and outputs, comprehending the analysis phase of the LCA, helping the enterprise to form an overview of their current state in terms of circularity practices. This data can be collected at the level of internal logistics (product and/or process) or at the level of the supply chain. At this level, the organization can generate a circular data inventory, or Life Cycle Inventory, that stores and categorizes the inputs and outputs that result from manufacturing their products, and, depending on the context, it is able to implement and use an industrial data ecosystem for data inter-exchange.

When organizations acquire level 1 capabilities, they might move forward to the next level, wherein the organization understands what Rs it is able to follow. However, it depends on the data scope of the previous maturity level and the related traceability degree. At the information processing level, the organizations should contextualize the data by answering a set of competency questions by completing the assessment phase of the LCA, in which the information collected previously can be analyzed through LCA software to identify possible environmental impacts or deficiencies in their products or processes, for example. At the end, organizations have been developing the capability of building a digital product passport (DPP), by combining the data from the LCI in a structured way to provide all kinds of information about the processes that the product went through during manufacturing and information that suggests how to handle its end-of-life processes, whose detail is dependent on the scope level once again. Together with the DPP, the capability of performing LCA and circularity analysis should be developed. Having developed the DPP, the organization is one step closer to one of the biggest objectives of this roadmap and CE in general, achieving the highest level of traceability possible for their products. Again, both LCA and Circularity indexes are scope dependent. Finally, at the highest level, the organization should be able to implement asset management practices to promote circularity and, at the same time, implement processes for circularity real-time awareness. With this, the enterprise is in position to lead collaborative strategies for circularity.



© 2024 ITMA. All rights reserved.

With the outputs from the analysis and the data collected about the environmental impacts caused by the enterprises processes for production, the current stage of circularity can be accessed. This process should be iterative, evaluating the impacts caused by changes or new variables introduced into the system, i.e., a new material is used in manufacturing, change of a determined machine, resulting in the alteration of the line of production. We can consider that the circularity level or state of the organization is directly correlated with the level of traceability of their products and, as such, improving traceability becomes one of the main objectives of the application of this governance model, along with improving the sustainability of their processes. As traceability is the ability to trace the products to their origin, what processes it went through throughout its life cycle and the products history since leaving the enterprises facilities until its end of life, by improving traceability, the organization is widening its scope of circularity, moving towards the whole value chain, evaluating sustainable practices since the extraction of the materials or how the materials where repurposed, in the internal processes of production and shipment until the end of the product life cycle, when it finally gets recycled or remanufactured. Improving traceability will also benefit every agent that interacts with the product along the value chain, as it will also provide useful information to consumers or anyone responsible for the processes of its end of life.

Given this context, we can categorize companies as product-level, process-level, or value chain-level circular, according to the information possessed by the company when performing the LCA and the information included in the DPP generated by them to accompany their products.

This is the first draft of a governance model that will be further developed as future work, alongside an ontology systematizing vocabulary associated with this governance model and routes to answer competence questions to be posed to companies to assess their circularity level.

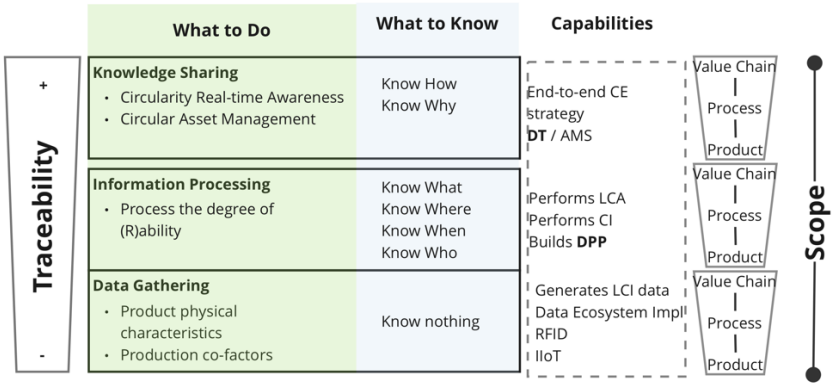


**Figure 1.** CE Information Management Cockpit

## 3. Conclusion



© 2024 ITMA. All rights reserved.

Throughout the research for this paper, various aspects of the circular economy where studied, from the conceptual complexity of circularity to the barriers and benefits of adopting circular practices for SMEs. The gap of lack of models and methods for conducting and managing circular strategies was identified, mainly by small and medium-sized companies. A framework is proposed to guide companies on their journey towards transforming their businesses and consequently their processes to create more circular products/services. The framework was developed based on inputs that come from literature and the participation of authors in a consortium of projects related to industry 4.0 with a focus on circularity and people. As this model is a first draft, it will be further developed and complemented by an ontology, systematizing vocabulary associated with it and a way to answer the competency questions that will be posed to the companies.

**Acknowledgments:** This work has been supported by the European Union under the Next Generation EU, through a grant of the Portuguese Republic's Recovery and Resilience Plan (PRR) Partnership Agreement, within the scope of the project PRODUTECH R3 – "Agenda Mobilizadora da Fileira das Tecnologias de Produção para a Reindustrialização", Total project investment: 166.988.013,71 Euros; Total Grant: 97.111.730,27 Euros.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

[1] D. Reike, W. J. V. Vermeulen, and S. Witjes, '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*, vol. 135, pp. 246–264, Aug. 2018, doi: 10.1016/j.resconrec.2017.08.027.

[2] 'IJERPH | Free Full-Text | Enabling the Circular Economy Transition in Organizations: A Moderated Mediation Model'. Accessed: Feb. 29, 2024. [Online]. Available: https://www.mdpi.com/1660-4601/19/2/677

[3] H. Corvellec, A. F. Stowell, and N. Johansson, 'Critiques of the circular economy', *Journal of Industrial Ecology*, vol. 26, no. 2, pp. 421–432, 2022, doi: 10.1111/jiec.13187.

[4] J. Korhonen, C. Nuur, A. Feldmann, and S. E. Birkie, 'Circular economy as an essentially contested concept', *Journal of Cleaner Production*, vol. 175, pp. 544–552, Feb. 2018, doi: 10.1016/j.jclepro.2017.12.111.

[5] J. Kirchherr, D. Reike, and M. P. Hekkert, 'Conceptualizing the Circular Economy: An Analysis of 114 Definitions', *SSRN Electronic Journal*, vol. 127, Sep. 2017, doi: 10.2139/ssrn.3037579.

[6] 'Towards a circular economy: Business rationale for an accelerated transition'. Accessed: Nov. 22, 2023. [Online]. Available: https://www.ellenmacarthurfoundation.org/towards-a-circular-economy-business-rationale-for-an-accelerated-transition

[7] P. Dewick, A. M. de Mello, J. Sarkis, and F. K. Donkor, 'The puzzle of the informal economy and the circular economy', *Resources, Conservation and Recycling*, vol. 187, p. 106602, Dec. 2022, doi: 10.1016/j.resconrec.2022.106602.



© 2024 ITMA. All rights reserved.

[8] G. Michelini, R. N. Moraes, R. N. Cunha, J. M. H. Costa, and A. R. Ometto, 'From Linear to Circular Economy: PSS Conducting the Transition', *Procedia CIRP*, vol. 64, pp. 2–6, Jan. 2017, doi: 10.1016/j.procir.2017.03.012.

[9] M. Charter, 'Circular economy business models', Farnham, Surrey: Centre for Sustainable Design, 2016, pp. 64–69. Accessed: Nov. 18, 2023. [Online]. Available: https://research.uca.ac.uk/3270/

[10] S. Ritzén and G. Sandström, 'Barriers to the Circular Economy – Integration of Perspectives and Domains', *Procedia CIRP*, vol. 64, pp. 7–12, Jan. 2017, doi: 10.1016/j.procir.2017.03.005.

[11] M. Koszewska, 'Circular Economy — Challenges for the Textile and Clothing Industry', *Autex Research Journal*, vol. 18, no. 4, pp. 337–347, Dec. 2018, doi: 10.1515/aut-2018-0023.

[12] N. Piila, M. Sarja, T. Onkila, and M. Mäkelä, 'Organisational Drivers and Challenges in Circular Economy Implementation: An Issue Life Cycle Approach', *Organization & Environment*, vol. 35, no. 4, pp. 523–550, Dec. 2022, doi: 10.1177/10860266221099658.

[13] V. Rizos *et al.*, 'Implementation of Circular Economy Business Models by Small and Medium-Sized Enterprises (SMEs): Barriers and Enablers', *Sustainability*, vol. 8, no. 11, Art. no. 11, Nov. 2016, doi: 10.3390/su8111212.

[14] F. R. Rinaldi, C. Di Bernardino, V. Cram-Martos, and M. T. Pisani, 'Traceability and transparency: enhancing sustainability and circularity in garment and footwear', *Sustainability: Science, Practice and Policy*, vol. 18, no. 1, pp. 132–141, Dec. 2022, doi: 10.1080/15487733.2022.2028454.

[15] M. Mura, M. Longo, and S. Zanni, 'Circular economy in Italian SMEs: A multi-method study', *Journal of Cleaner Production*, vol. 245, p. 118821, Feb. 2020, doi: 10.1016/j.jclepro.2019.118821.

[16] I. Uvarova, D. Atstaja, and V. Korpa, 'Challenges of the introduction of circular business models within rural SMEs of EU', *International Journal of Economic Sciences*, vol. 9, no. 2, pp. 128–149, 2020.

[17] N. Tura, J. Hanski, T. Ahola, M. Ståhle, S. Piiparinen, and P. Valkokari, 'Unlocking circular business: A framework of barriers and drivers', *Journal of Cleaner Production*, vol. 212, pp. 90–98, Mar. 2019, doi: 10.1016/j.jclepro.2018.11.202.

[18] D. A. Vermunt, S. O. Negro, P. A. Verweij, D. V. Kuppens, and M. P. Hekkert, 'Exploring barriers to implementing different circular business models', *Journal of Cleaner Production*, vol. 222, pp. 891–902, Jun. 2019, doi: 10.1016/j.jclepro.2019.03.052.

[19] Y. Liu and Y. Bai, 'An exploration of firms' awareness and behavior of developing circular economy: An empirical research in China', *Resources, Conservation and Recycling*, vol. 87, pp. 145–152, Jun. 2014, doi: 10.1016/j.resconrec.2014.04.002.

[20] N. Van Buren, M. Demmers, R. Van der Heijden, and F. Witlox, 'Towards a Circular Economy: The Role of Dutch Logistics Industries and Governments', *Sustainability*, vol. 8, no. 7, Art. no. 7, Jul. 2016, doi: 10.3390/su8070647.

[21] J. Gillabel, S. Manshoven, F. Grossi, L. Mortensen, and L. Coscieme, 'Business Models in Circular Economy'. Jan. 28, 2021.

[22] OECD, *Business Models for the Circular Economy: Opportunities and Challenges for Policy*. Paris: Organisation for Economic Co-operation and Development, 2019. Accessed: Feb. 19,



© 2024 ITMA. All rights reserved.

2024. [Online]. Available: https://www.oecd-ilibrary.org/environment/business-models-for-the-circular-economy_g2g9dd62-en

[23] Directorate-General for Research and Innovation (European Commission), *ERA industrial technology roadmap for circular technologies and business models in the textile, construction and energy-intensive industries*. LU: Publications Office of the European Union, 2023. Accessed: Feb. 20, 2024. [Online]. Available: https://data.europa.eu/doi/10.2777/188014

[24] R. Mostaghel and K. Chirumalla, 'Role of customers in circular business models', *Journal of Business Research*, vol. 127, pp. 35–44, Apr. 2021, doi: 10.1016/j.jbusres.2020.12.053.

[25] F. Di Maio, P. C. Rem, K. Baldé, and M. Polder, 'Measuring resource efficiency and circular economy: A market value approach', *Resources, Conservation and Recycling*, vol. 122, pp. 163–171, Jul. 2017, doi: 10.1016/j.resconrec.2017.02.009.

[26] P. K. Dey, C. Malesios, D. De, P. Budhwar, S. Chowdhury, and W. Cheffi, 'Circular economy to enhance sustainability of small and medium-sized enterprises', *Business Strategy and the Environment*, vol. 29, no. 6, pp. 2145–2169, 2020, doi: 10.1002/bse.2492.

[27] A. Sohal, A. A. Nand, P. Goyal, and A. Bhattacharya, 'Developing a circular economy: An examination of SME's role in India', *Journal of Business Research*, vol. 142, pp. 435–447, Mar. 2022, doi: 10.1016/j.jbusres.2021.12.072.

[28] V. Kumar, I. Sezersan, J. A. Garza-Reyes, E. D. R. S. Gonzalez, and M. A. AL-Shboul, 'Circular economy in the manufacturing sector: benefits, opportunities and barriers', *Management Decision*, vol. 57, no. 4, pp. 1067–1086, Jan. 2019, doi: 10.1108/MD-09-2018-1070.

[29] 'The Macroeconomics of the Circular Economy Transition: A Critical Review of Modelling Approaches', OECD Environment Working Papers 130, Apr. 2018. doi: 10.1787/af983f9a-en.

[30] M. Howard, X. Yan, N. Mustafee, F. Charnley, S. Böhm, and S. Pascucci, 'Going beyond waste reduction: Exploring tools and methods for circular economy adoption in small-medium enterprises', *Resources, Conservation and Recycling*, vol. 182, p. 106345, Jul. 2022, doi: 10.1016/j.resconrec.2022.106345.

[31] 'BIM data model requirements for asset monitoring and the circular economy | Emerald Insight'. Accessed: Feb. 29, 2024. [Online]. Available: https://www.emerald.com/insight/content/doi/10.1108/JEDT-10-2019-0284/full/html

[32] S. E. DeRosa and D. T. Allen, 'Comparison of Attributional and Consequential Life-Cycle Assessments in Chemical Manufacturing', in *Encyclopedia of Sustainable Technologies*, M. A. Abraham, Ed., Oxford: Elsevier, 2017, pp. 339–347. doi: 10.1016/B978-0-12-409548-9.10069-7.

[33] I. S. Arvanitoyannis, *Waste Management for the Food Industries*. Academic Press, 2010.

[34] J. B. Guinée, *Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards*. Springer Science & Business Media, 2002.

[35] 'ISO 9000:2015(en), Quality management systems — Fundamentals and vocabulary'. Accessed: Nov. 22, 2023. [Online]. Available: https://www.iso.org/obp/ui/#iso:std:iso:9000:ed-4:v1:en

[36] T. Adisorn, L. Tholen, and T. Götz, 'Towards a Digital Product Passport Fit for Contributing to a Circular Economy', *Energies*, vol. 14, no. 8, Art. no. 8, Jan. 2021, doi: 10.3390/en14082289.

[37] J. Potting, M. P. Hekkert, E. Worrell, and A. Hanemaaijer, *Circular Economy: Measuring innovation in the product chain*. 2017.



© 2024 ITMA. All rights reserved.

[38] T. Shevchenko *et al.*, 'Product-level circularity metrics based on the "Closing–Slowing Future–Past" quadrant model', *Sustainable Production and Consumption*, vol. 34, pp. 395–411, Nov. 2022, doi: 10.1016/j.spc.2022.09.024.

[39] J. A. Garza-Reyes, A. Salomé Valls, S. Peter Nadeem, A. Anosike, and V. Kumar, 'A circularity measurement toolkit for manufacturing SMEs', *International Journal of Production Research*, vol. 57, no. 23, pp. 7319–7343, Dec. 2019, doi: 10.1080/00207543.2018.1559961.



© 2024 ITMA. All rights reserved.