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PhD Thesis

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PhD Thesis

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# Abstract

Circular economy has rapidly gathered momentum within sustainable development initiatives due to its potential for decoupling economic development and growth from resource consumption. Manufacturing companies play a critical role in the implementation of circular economy at the industrial level. Success with this role requires a rethinking of the overall value generation logic and the redefinition of business success, by reconfiguring existing business models or creating new business models for circular economy. The transition of manufacturing companies' business models to circular economy is still limited, with low market penetration across sectors. Among several external and internal barriers, manufacturing companies face shortcomings in capabilities and skills and require knowledge and scientific-based guidance for business modelling within the context of circular economy. So far, academic literature is unable to support companies adequately, due to a core gap related to the lack of systematised practices to provide guidance and advice to manufacturing companies during the design of business models for circular economy.

Based on this gap, a design research methodology was applied in this research, with the objective of developing a systematised framework to provide guidance and advice for managers to design business models for circular economy within manufacturing companies. The methodology comprised four main studies based on the combination of a varied set of methods (e.g. systematic literature review, action research, case studies, expert validation) to prescribe and evaluate required support to fulfil the research objective. Moreover, seventeen manufacturing companies and seven academic experts were engaged in the co-creation and/or evaluation of the proposed supports for circular economy business modelling.

Two main results are presented in this PhD thesis. First, an overview of the state-of-the-art literature about approaches for circular economy and sustainability business model innovation is provided, which includes the systematisation and comparison of more than 90 frameworks, methods and tools. Then, a systematised framework to support circular economy business modelling and cover identified gaps in literature and practice is presented. The framework comprises three main elements: (i) a holistic process model with recommended practices for circular economy business modelling; (ii) business model patterns to support focused ideation and specialised configuration of business models for circular economy within specific manufacturing sectors; and (iii) a high-fidelity prototype expert system to provide advice for circular economy business modelling to manufacturing companies.

The in-depth evaluations within real business scenarios demonstrated that the application of the proposed framework and its elements was successful in supporting most manufacturing companies with the design of business models that can decouple economic value creation from resource consumption. Moreover, companies were able to start implementing and planning the scaling up of pilot projects.

# Dansk Resume

Fænomenet *cirkulær økonomi* har hurtigt taget fart inden for initiativer til bæredygtig udvikling, grundet sit potentiale for afkobling af økonomisk udvikling og vækst fra ressourceforbrug. Fremstillingsvirksomheder spiller en kritisk rolle i implementeringen af cirkulær økonomi på industrielt niveau. Succes med denne rolle kræver en nytænkning af den samlede værdigenereringslogik, samt omdefinering af forretningssucces, ved at rekonfigurere eksisterende forretningsmodeller eller oprette nye forretningsmodeller, der er tilpasset cirkulær økonomi.

Fremstillingsvirksomheder har, endnu kun i begrænset omfang, omlagt deres forretningsmodeller til cirkulær økonomi og der er stadig lav markedsindtrængning på tværs af sektorer. Blandt flere eksterne og interne barrierer kan der nævnes, at fremstillingsvirksomheder mangler kompetencer, viden og videnskabelig baseret assistance i forhold til forretningsmodellering inden for rammerne af cirkulær økonomi. Indtil videre har den videnskabelige litteratur ikke været i stand til at støtte virksomheder tilstrækkeligt på grund af et grundlæggende gab, der er relateret til manglen på systematiseret praksis i vejledning og rådgivning til produktionsvirksomheder under skabelse af forretningsmodeller til cirkulær økonomi. Med udgangspunkt i disse mangler, blev *Design Research Methodology* anvendt i denne forskning, med det formål at udvikle en systematiseret ramme for vejledning og rådgivning af ledere i produktionsvirksomheder, angående skabelse af forretningsmodeller til cirkulær økonomi. Forskningstilgangen omfattede fire hovedundersøgelser baseret på et varieret sæt metoder (f.eks. systematisk litteratursøgning, aktionsforskning, casestudier, ekspertvalidering) til at ordinere og evaluere den nødvendige støtte til at opfylde forskningsmålet. Desuden blev 17 fremstillingsvirksomheder og 7 videnskabelige eksperter inddraget i samskabelse og/eller evaluering af de foreslåede metoder til forretningsmodellering for cirkulær økonomi.

To hovedresultater præsenteres i denne ph.d.-afhandling. For det første gives der en oversigt over avanceret litteratur omhandlende tilgange til cirkulær økonomi og bæredygtig forretningsmodelinnovation, der inkluderer systematisering og sammenligning af mere end 90 rammeværker, metoder og værktøjer. Derefter præsenteres et systematiseret rammeværk til støtte i udvikling af forretningsmodeller for cirkulær økonomi, som samtidig adresserer identificerede mangler i litteratur og praksis. Rammen omfatter tre hovedelementer: (i) en holistisk procesmodel med anbefalet praksis for udvikling af forretningsmodeller for cirkulær økonomi; (ii) et overblik over mønstre i forretningsmodeller, der kan støtte fokuseret idegenerering og specialiseret konfiguration af forretningsmodeller til cirkulær økonomi inden for specifikke produktionssektorer; og (iii) et detaljeret prototypeekspert-system, til at yde rådgivning ang. udvikling af cirkulære forretningsmodeller til produktionsvirksomheder.

De dybdegående evalueringer inden for virkelige forretningsscenarier demonstrerede at anvendelsen af den foreslåede ramme og dennes elementer var velegnet til at støtte de fleste produktionsvirksomheder i design af forretningsmodeller, der kan adskille økonomisk værdiskabelse fra ressourceforbrug. Desuden var virksomheder i stand til at påbegynde implementering og planlægning af opskalering af pilotprojekter.

"The world as we have created it is a process of our thinking.
It cannot be changed without changing our thinking."
- Attributed to Albert Einstein

# Preface

## CIRCit Research Project as Empirical Background

The research documented in this PhD thesis was carried out within the CIRCit project ("Circular Economy Integration in the Nordic Industry for enhanced sustainability and competitiveness"). CIRCit was a three-and-a-half year research project, supported by the Nordic Green Growth Research and Innovation Programme (grant number: 83144) and jointly funded by NordForsk, Nordic Energy Research, and Nordic Innovation.

The research project involved a consortium that spanned research institutions, industry associations, governmental bodies, and manufacturing companies in the five Nordic countries (Denmark, Finland, Iceland, Norway, and Sweden).

The CIRCit consortium consisted of research institutions, industry associations and governmental bodies from the five countries, including the Technical University of Denmark (DTU), Technology Industries of Finland, Innovation Center Iceland, Norwegian University of Science and Technology (NTNU), and Research Institutes of Sweden (RISE).

Moreover, strong collaboration with Nordic manufacturers took place for the co-development and evaluation of the results from this research project.

The ultimate purpose of CIRCit was to develop and roll out circular economy methods and tools within the Nordic industry. CIRCit covered six focus areas: sustainability screening, business modelling, product design and development, smart circular economy, closing the loop, and collaboration and networking. This PhD thesis focuses on the business modelling aspect, taking into consideration the interdependencies with the other focus areas.

Due to this context, this PhD thesis can be characterised as applied research, as opposed to fundamental (basic or pure) research. Hence, it aims at addressing immediate practical problems faced by industrial or business organisations (Kothari, 2004). As such, it reacts to calls for the promotion of impactful academic research that is able to demonstrate the contribution made *to* and *with* businesses (Andreasen, 2011; Wells, 2016). In particular, the main focus of this research is to create *knowledge for action* (Lüdeke-Freund, Bohnsack, et al., 2019) by establishing *a bridge among available knowledge and practice*, so that guidance for the development of circular economy practices within manufacturing organisations can be provided (Kirchherr and van Santen, 2019; Lüdeke-Freund, Bohnsack, et al., 2019).

To achieve the above, close collaboration with manufacturing companies aiming to explore business model innovation for circular economy was necessary during this research project. In total, 17 companies were directly involved in the research presented in this PhD thesis, out of 51 companies in the CIRCit project altogether.

http://circitnord.com

# Acknowledgements


The PhD journey transformed my life in many aspects. Beyond the opportunity to learn with the Nordic culture and values, the deep dive within circular economy (CE) and sustainability topics opened my mind and shifted my perspective about what it means to be a fair society, a great business, a respectable professional/researcher, or a cooperative citizen. This journey was only possible due to fantastic people that I had by my side along the way.

First, my gratitude goes to my supervisor, Daniela Pigosso, who gave me this opportunity. Your solid knowledge and determination as a researcher, professor and entrepreneur are inspiring. I just reached this far thanks to your generosity and contagious optimism. Thank you for believing in people and for helping them to believe in themselves, and to believe that it is possible. Thank you for your patience in our endless discussions, and of course, for the many laughs, rides, and remarkable trips to meetings, conferences and the summer school.

I am also grateful to my co-supervisor, Tim McAloone, who was supportive during the whole journey and managed to balance lightness and decisiveness whenever needed. Your leadership skills are an example to follow. Thanks for your kindness, the fun meetings, for bearing with my linguistic mistakes, for helping with English/Danish, and of course, for your effort in learning Portuguese words (even the less traditional ones such as 'jabuticaba').

I also thank Prof. Giuditta Pezzotta for kindly hosting me during my stay at the University of Bergamo. I am grateful for your readiness to support my research even in the middle of a pandemic (literally). I extend the appreciation to all CELS' professors and colleagues.

During this PhD project, I was extremely honoured to be part of the CIRCit Project. I thank all colleagues from the CIRCit Consortium for the discussions about circular economy and the support with networking with companies and bridging research and practice. Our exciting meetings will be forever in my mind. Moreover, my sincere gratefulness and admiration go to the companies and their inspiring collaborators who participated in this research. Thank you for the trust, openness and for sharing your experience through the many workshops, webinars and interviews. Your collaboration made me believe that a new way of thinking and doing business is possible. In fact, this new way is already here, we just need to make it spread.

I was also lucky to have great colleagues at DTU. I thank Mariia and Fenna, for your support within CIRCit and for sharing your impressive knowledge and passion about science, sustainability and CE. I also thank: Anne for your dedication during your Master thesis and support with CIRCit activities; Koji, Glauco and Vinicius for the insightful conversations and my on-boarding at DTU; Prof. Lucienne Blessing and Christian Weber for the unique experience in Summer School of Engineering Design Research; K&P colleagues for the insightful Friday breakfasts and meetings; my PhD colleagues Camilla, Gianmarco, Ellen, Herle, Hugo, Lorenzo, Louise, Maria, Mikhail, and Sânia, for sharing the room, thoughts, lunches and many laughs; and I extend that to our neighbour researchers Lærke, Niklas, Mathias, Trinne, Tue, Jasper, Julie.

Lastly, I would like to thank my family. First, to my parents, for standing by my side in any circumstances and cheering for my aspirations, even when this means bearing with the distance. Then, to my husband Vitor. Your integrity, courage and wholeheartedly approach to life are inspiring. This journey was only possible due to your generosity and solid emotional support always, and for that, I will be forever grateful. Thank you for sharing dreams with me.

# Thesis Overview

This PhD thesis follows an article-based style, with the articles embedded as appendices. The thesis is structured in five main chapters:

**Chapter 1** introduces the overarching context and motivation for the research (section 1.1), as well as the research gaps (section 1.2), the overall objective and hypothesis that guided the research development (section 1.3), and the correspondent research questions (section 1.4).

**Chapter 2** explains the research methodology and the research structure deployed to answer the research questions and to deliver the key results (section 2.1). Additionally, it details the methods applied throughout the research (section 2.2).

**Chapter 3** presents the research results accompanied by related discussion. The results are fully documented in the appended publications indicated on top of each of the five sections (3.1-3.5). Then, a brief description of the results is provided, followed by a discussion about how the results support or refute the specific hypotheses investigated by this thesis and relate to the available literature.

**Chapter 4** synthesises the discussions and findings by summarising how the key results presented in Chapter 3 answer to the research questions (section 4.1). Moreover, it explains how the individual results compose the systematised framework for circular economy business modelling, which is a vehicle to fulfilling the overall objective of this PhD thesis (section 4.2).

**Chapter 5** provides overall conclusions based on research contributions (section 5.1), limitations (section 5.2), a vision for rolling out the systematised framework for circular economy business modelling presented as a key outcome of this thesis (section 5.3), future research avenues (section 5.4) and final remarks (section 5.5).

An overview of the Appended Publications and Supplementary Publications resulting of this research is available on the next page.

The Appended Publications consist of journal articles that document the bulk of results presented in this thesis.

The Supplementary Publications are not appended to this thesis. However, they can be accessed through the indicated DOI or links in their references and will be referenced in the thesis to support the findings when relevant.

## List of Appended Publications (AP)

**Publication 1**

Pieroni, M.P.P., McAloone, T.C. and Pigosso, D.C.A. (2019), “Business model innovation for circular economy and sustainability: A review of approaches”, Journal of Cleaner Production, Vol. 215, pp. 198-216. https://doi.org/10.1016/j.jclepro.2019.01.036

**Publication 2**

Pieroni, M.P.P., McAloone, T.C.and Pigosso, D.C.A. (2020), “Developing a process model for Circular Economy business model innovation within manufacturing companies”, (Manuscript under review at Journal of Cleaner Production).

**Publication 3**

Pieroni, M.P.P., McAloone, T.C. and Pigosso, D.C.A. (2020), “From theory to practice: systematising and testing business model archetypes for Circular Economy”, (Manuscript under review at Resources, Conservation & Recycling).

**Publication 4**

Pieroni, M.P.P., McAloone, T.C. and Pigosso, D.C.A. (2020), “Circular Economy business model innovation: sectorial patterns within manufacturing companies”, (Manuscript under review at Journal of Cleaner Production).

**Publication 5**

Pieroni, M.P.P, C. McAloone, T. and C. A. Pigosso, D. (2019), “Configuring New Business Models for Circular Economy through Product–Service Systems”, Sustainability, Vol. 11 No. 13, p. 3727. https://doi.org/10.3390/su11133727

**Publication 6**

Pieroni, M.P.P., McAloone, T.C., Borgianni, Y., Maccioni, L, Pigosso, D.C.A. (2020), “An expert system for Circular Economy business modelling: advising manufacturing companies in decoupling value creation from resource consumption”, (Manuscript under review at Journal of Cleaner Production).

## List of Supplementary Publications (not included in the thesis)

**Publication 7**

Pieroni, M.P., Pigosso, D.C.A. and McAloone, T.C. (2018), “Sustainable Qualifying Criteria for Designing Circular Business Models”, Procedia CIRP, The Author(s), Vol. 69 No. May, pp. 799–804. https://doi.org/10.1016/j.procir.2017.11.014

**Publication 8**

Pieroni, M., Pigosso, D. and McAloone, T. (2018), “Exploring the synergistic relationships of circular business model development and product design.”, International Design Conference- DESIGN 2018, pp. 2715–2726. https://doi.org/10.21278/idc.2018.0202

**Publication 9**

Pieroni, M.P., McAloone, T. and Pigosso, D. (2019), “Business model innovation for circular economy: integrating literature and practice into a conceptual process model”. In S Wartzack & B Schleich (eds), Proceedings of the Design Society: 22nd International Conference on Engineering Design (ICED19). Cambridge University Press, pp. 2517-2526, Delft, Netherlands. https://doi.org/10.1017/dsi.2019.258

**Publication 10**

Blomsma, F., Pieroni, M., Kravchenko, M., Pigosso, D.C.A., Hildenbrand, J., Kristinsdottir, A.R., Kristoffersen, E., et al. (2019), “Developing a circular strategies framework for manufacturing companies to support circular economy-oriented innovation”, Journal of Cleaner Production, Vol. 241, p. 118271. https://doi.org/10.1016/j.jclepro.2019.118271

**Publication 11**

Pieroni, M.P., Blomsma, F., McAloone, T.C. and Pigosso, D.C.A. (2018), “Enabling circular strategies with different types of product/service-systems”, Procedia CIRP, Elsevier B.V., Vol. 73 No. May, pp. 179–184. https://doi.org/10.1016/j.procir.2018.03.327

**Publication 12**

Pieroni, M.P.P., McAloone, T.C. & Pigosso, D.C.A. (2019), “Configuring new business models for circular economy: from patterns and design options to action”. In F Lüdeke-Freund & T Froese (eds), Proceedings of the 4th International Conference on New Business Models: New Business Models for Sustainable Entrepreneurship, Innovation, and Transformation. Europe Business School , pp. 74-89, Berlin, Germany.

**Publication 13**

Pieroni, M.P.P., McAloone, T.C. and Pigosso, D.C.A. (2020), “Defining the requirements for a tool to support Circular Economy business model innovation within manufacturing companies”, International Design Conference - DESIGN 2020. (Manuscript in press).

**Publication 14**

Pieroni, M.P.P., Hjort Jensen, T., Pigosso, D.C.A. & McAloone, T.C. (2020), *Circular Economy Business Modelling: CIRCit Workbook 2*, ISBN: 978-87-7475-602-6, Technical University of Denmark, 72 p. https://orbit.dtu.dk/en/publications/circular-economy-business-modelling-circit-workbook-2

# Abbreviations and Acronyms

| | |
|---|---|
| AP | Appended publication |
| AR | Action research |
| BM | Business model |
| BMI | Business model innovation |
| CE | Circular economy |
| CEBMI | Circular economy business model innovation |
| CEBM | Circular economy business model |
| CEBMn | Circular economy business modelling |
| CEBMES | Circular economy business modelling expert system |
| Comp. | Companies |
| DRM | Design Research Methodology |
| DS-I | Descriptive study I |
| DS-II | Descriptive study II |
| Exp. | Academic experts |
| MDS | Multi-dimensional scaling analysis |
| OH | Overall hypothesis |
| PS | Prescriptive study |
| R | Result |
| RC | Research clarification |
| RQ | Research question |
| SH | Specific hypothesis |
| SLR | Systematic literature review |
| SME | Small and medium enterprises |

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# 1 Introduction

The introductory chapter presents the overarching context and motivation for the research documented in this PhD thesis (section 1.1). This is followed by the description of the research gaps (section 1.2). Lastly, the specific objective and hypothesis that guided the research development are introduced (section 1.3), along with the deployed research questions (section 1.4).

## 1.1 Context and motivation

Sustainable development has become increasingly urgent and a recurrent topic in the agendas of different actors in our society. From one end, pressing problems such as growing inequality, the deterioration of natural resources, and climate change have exposed the limits of the current profit-oriented socioeconomic system (Häyhä et al., 2016; Steffen and Smith, 2013). As one of the responses, nations across the globe adopted the Sustainable Development Goals (SDGs), which represent an ambitious call for action and international cooperation to propose and implement solutions to end poverty, protect the planet, and guarantee peace and prosperity (United Nations, 2015). From the other end, companies are increasingly perceiving and exploring the market potentials and promises of a sustainability-oriented business strategy (Breuer et al., 2018; Schaltegger et al., 2016).

The sustainability of natural resources receives special attention within national and international societies and organisations, with about half of the SDGs focusing on environmental issues (UNEP, 2015). Several environmental initiatives being developed internationally aim to promote a resource-efficient and low-carbon economy, for example, the European Green Deal (European Commission, 2019; Niero et al., 2017). Within those initiatives, circular economy (CE) has rapidly gathered momentum and assumed a central role as a way of slowing down the exploitation of resources at a rate that respects Earth's capacity while still boosting economies (European Commission, 2015; WBCSD, 2013).

CE proposes a vision for decoupling economic development and growth from resource consumption (EMF, 2015; Ghisellini et al., 2016). Its ultimate aim is to reduce natural resource degradation, waste generation and pollution at the same time as keeping economic development and growth. Although primarily concerned with the economic prosperity and environmental aims, CE can also contribute to achieving other sustainable development targets related to social issues, such as ending hunger, sustainable food production, and eliminating poverty by generating jobs at a local level (Geissdoerfer et al., 2017; Kirchherr et al., 2017; Schroeder et al., 2019).

The implementation of CE initiatives requires fundamental changes in the societal, industrial and consumption foundations (Böhringer and Rutherford, 2015). At the industrial level, manufacturing companies have a critical role in CE implementation, due to their relevance concerning usage of materials and energy, generation of by-products and waste, contribution to employment and gross domestic product, and potential influence to define the products' life cycle (i.e. from raw material extraction and manufacturing to use and end-of-use) (Lieder and Rashid, 2016; McAloone and Bey, 2009). The terms manufacturing or manufacturers, when addressed in this thesis, refer to secondary manufacturing companies with a degree of control over their supply chain, excluding primary production or contract manufacturers.

The adoption of CE by manufacturers entails a new logic away from the ‘take-make-use-dispose’ industrial and consumption dogma (Lieder and Rashid, 2016). This new logic aims at providing and maintaining products with the highest value and for as long as possible, while consuming as few resources (e.g. materials or energy) as possible (EMF, 2015). In practice, the new logic requires systemic innovation within companies, which surpasses technological or product innovation and involves the overall value generation and redefinition of business success (Blomsma et al., 2019; Lieder and Rashid, 2016). Such redefinition of value generation and business success can occur at the level of companies’ strategies, more specifically, at the level of their business models. Hence, manufacturing companies need to develop capabilities to *design business models for circular economy*, which might include both *reconfiguring their existing business models* (BM) or *creating new business models for circular economy* (Khan et al., 2020; Schulte, 2013).

A circular economy business model (CEBM) describes how one organisation or an ecosystem of organisations creates, delivers, and captures value by (i) slowing, (ii) closing or (iii) narrowing flows of energy and materials (Nußholz, 2017; Oghazi and Mostaghel, 2018).

(i) Slowing the flows of resources entails extending or intensifying the use time of products, which can be achieved, for example, by long-life design, sharing of products, or product-life extension services.

(ii) Closing the flows of resources envisions the recycling of resources from products post-use into sourcing and production.

(iii) Narrowing the flows of resources aims at achieving resource efficiency, for example, by reducing the use of materials per product (Bocken et al., 2016).

Despite the importance of new business models for CE (Lieder and Rashid, 2016), their market penetration is still currently limited, and they account for no more than 5-10% of revenues for most manufacturing sectors (OECD, 2018; Ritala et al., 2018; Urbinati et al., 2017). Several external barriers have contributed to this limited market penetration, such as customers’ preferences for ‘new’ products, regulatory restrictions, or lack of infrastructure (de Jesus and Mendonça, 2018; Kirchherr et al., 2018; OECD, 2018). Internal organisational barriers are also relevant, for example, shortcomings in capabilities and skills of manufacturing companies to execute innovation of business models for CE (Bocken and Geradts, 2019; Chiappetta Jabbour et al., 2019; Guldmann and Huulgaard, 2020; Khan et al., 2020; Kirchherr et al., 2018; De los Rios and Charnley, 2017). More specifically, designing and implementing business models for CE leads to additional uncertainties regarding financial value creation and complexity of operationalisation, when compared to traditional business models (Bocken et al., 2018; Lieder and Rashid, 2016). Hence, manufacturing companies require knowledge and science-based guidance for business model innovation within the context of CE (Bocken and Geradts, 2019; Khan et al., 2020; Lieder and Rashid, 2016).

Specific research about CE business model innovation exists for around five years, and can thus be considered an ‘emerging’ research field (Diaz Lopez et al., 2019; Nußholz, 2017). The field is still in a conceptualisation stage and is characterised by fragmented and sometimes incongruent literature (Merli et al., 2018; Nußholz, 2017; Pieroni et al., 2019a). The CE business model innovation body of knowledge has developed so far with seminal works arguing for the relevance of the topic (Linder and Williander, 2017) or outlining the concept (Lewandowski, 2016; Nußholz, 2017). Some works have focused on the development of approaches (i.e. methods and tools) to support companies in the adoption of

CE business models (Bocken et al., 2019; Rosa et al., 2019), including a CE standard (BSI, 2017). However, the application of such approaches by manufacturing companies faces two major challenges.

First, there seems to exist a misalignment between the needs of manufacturers and the priorities of academic publications. While some companies are already ‘pushing’ CE solutions as a way to position themselves as frontrunners among competitors or being ‘pulled’ by the market and public procurement requirements for the transformation of their business models (European Commission, 2014, 2018), researchers are focusing on understanding and describing theoretical advances of CE business model innovation (Kirchherr and van Santen, 2019; Pieroni et al., 2019a). CE business model innovation approaches proposed so far by academic publications remain conceptual, being essentially descriptive, with limited empirical demonstration, and therefore also limited advice to practitioners (Bocken et al., 2019; Kirchherr and van Santen, 2019; Lieder and Rashid, 2016; Pieroni et al., 2019a). According to an analysis carried by Kirchherr and van Santen (2019) on more than 160 articles about CE (indexed in Scopus from 2006 to 2019), less than 40% of publications include robust empirical demonstrations, and only 20% of publications include advice to businesses.

The second challenge for manufacturers is the fact that existing CE business model innovation approaches are still scattered. In particular, they lack systematisation of managerial practices for CE business model innovation in a holistic structure. Managerial practices comprise specific types of management activities to support the execution of a business process, and that may adopt varied methods (or techniques) and tools (PMI, 2013). Moreover, the available approaches have a granular discussion level with focus on the early development stages of CEBMs instead of processes that cover all innovation stages, from ideation to implementation (Bocken et al., 2019; Khan et al., 2020; Pieroni et al., 2019a). Additionally, institutional and strategic aspects for CE business model innovation (such as rules, norms, beliefs, targets for growth), and analytical and decision-support activities are not explicitly considered (Chiappetta Jabbour et al., 2019; Ünal, Urbinati, Chiaroni, et al., 2019).

Based on the aforementioned challenges of manufacturers with CE business model innovation, a specific research gap is formulated, and a scope is defined to guide the research execution.

## 1.2 Research gap and scope

The major challenge faced by manufacturing companies within CE business model innovation and considered the **major research gap** in this thesis is:

*The lack of a systematised framework that can provide guidance and advice to manufacturing companies for the design of business models for circular economy.*

A *framework* is a planned association among managerial practices and models (i.e. group of practices that represent the ideal scenario for conducting business processes) (ABPMP, 2013). As a model, a framework abstracts from reality; however, it is less rigorous than a model regarding the relationships among its elements (Teece, 2007). A framework can comprise various elements. In this research, the *framework* consists of a process model, with practices that include activities, supporting tools and expected capabilities from users (e.g. mindset and attitudes).

*Design* includes either reconfiguring existing business models or creating new business models for CE. It comprises activities to conceptualise, detail, and evaluate the economic and resource decoupling potential of CEBMs.

The previously presented major research gap is the cornerstone for the development of the research objectives, hypothesis and questions that guide this research, which are presented in sections (1.3 and 1.4).

**The topic of this PhD thesis** is embedded in the broader scope of corporate strategy, and more specifically within the realm of *strategic-planning* and *strategic thinking* (Figure 1).

Strategic-planning is the process to develop a company's strategies to achieve certain purposes (Abraham, 2012). Strategic thinking drives the strategic-planning process and entails coming up with several alternative business models with good value propositions to deploy the company's strategy (Abraham, 2012), which in the scope of this PhD thesis is CE implementation.

Additionally, the topic of this thesis is influenced by *dynamic capabilities*, i.e., the company's ability to integrate, build, and reconfigure internal competences to address changes in the business environment (Teece, 2017). The strength of a company's dynamic capabilities helps to shape their proficiency in business model innovation (Kindström et al., 2013; Teece, 2017). Moreover, dynamic capabilities are strongly related to change in values and mental models, which are fundamental for an impactful implementation of CE (Bocken and Geradts, 2019; Khan et al., 2020).

Within these areas and through the lens of the *business model innovation* body of knowledge, this research focuses on the *design of business models for circular economy within manufacturing companies*, which is addressed in this thesis by the term '*circular economy business modelling (CEBMn)'*.

In this thesis, the term business model innovation (BMI) comprises the process of BM design (e.g. search, ideation, experimentation), as well as the influencing aspects (e.g. transformation, ecosystem), and its outcomes (i.e. the innovative BM itself) (Foss and Saebi, 2017). Business modelling is comprised within BMI; however, it is particularly focused on the process (i.e. set of activities, methods, tools, mindset) of designing business models that intend to promote innovation within organisations (Bocken et al., 2013; Rohrbeck et al., 2013).

The organisational transformation promoted by CE business modelling activities or the implementation of CEBMs was observed as context for the interpretation of results. However, the success of the transformation itself was considered out of the scope of this PhD thesis, due to the extended timeframe required for its completion. Moreover, the thesis focuses on CE business modelling with a company-centric perspective, even though it has the potential to prompt manufacturers to steer changes in the ecosystem.

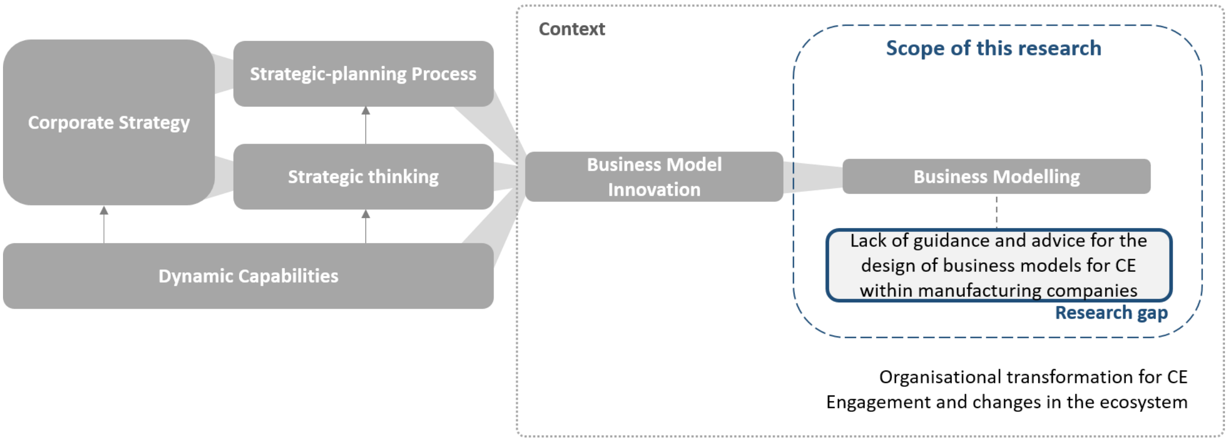


Figure 1 – Research scope.

The maturity of knowledge of a particular topic (i.e. exploratory, descriptive, analytical/explanatory and normative/prescriptive) tends to determine the nature of research questions (Åhlstrom, 2016) (Figure 2).

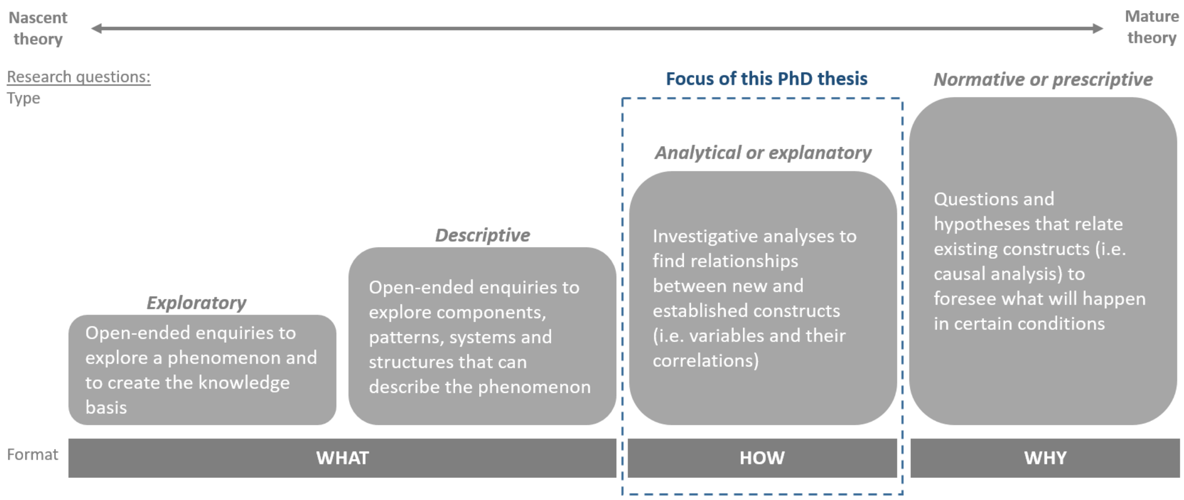


Figure 2 – Nature of research questions according to the research field maturity.

This PhD thesis aims to push research in CE business model innovation field from the descriptive to the analytical stage of maturity, in an attempt to converge practical and literature gaps. Hence, the objective and research questions deployed for this PhD thesis focus on the “HOW”, i.e. exploring the relationships between new and established constructs.

## 1.3 Objective and hypothesis

The high-level *aim* of this PhD thesis is to enable manufacturing companies to decouple economic value creation from resource consumption, by promoting wider adoption of CE (*effect*) through enhancement of their readiness to design and implement business models for CE (*output*) (Figure 3).

To do that, the **specific overarching objective** of this research is to:

*Develop a systematised framework to provide guidance and advice for managers to design business models for CE within manufacturing companies.*

Particularly, the systematised framework intends to provide guidance and advice by triggering managers within manufacturing companies: (i) to design business model alternatives that are more likely to reach expected benefits for CE, and (ii) to foresee the viability and feasibility of implementing those alternatives (Lieder and Rashid, 2016). Managers with a specific interest in the framework were initially identified as: (a) sustainability managers, (b) business developers or strategy managers, (c) product managers and (d) product development managers.

Based on this, the **overall hypothesis (OH)** investigated is that:

*The systematisation of a framework for CE business modelling can provide useful and applicable guidance and advice for the design of business models with enhanced circularity potential.*

*Useful guidance* means that the framework can produce the expected outputs by companies, and *applicable guidance* implies that the framework can be used in a specific context.

*Circularity potential* in the context of this PhD thesis means the extent to which a BM can decouple economic value creation from resource consumption. More specifically, this means the *extent to which a BM can create and sustain long-term economic value (e.g. market share, long-term profit margin) while reducing overall resource consumption within business activities.*

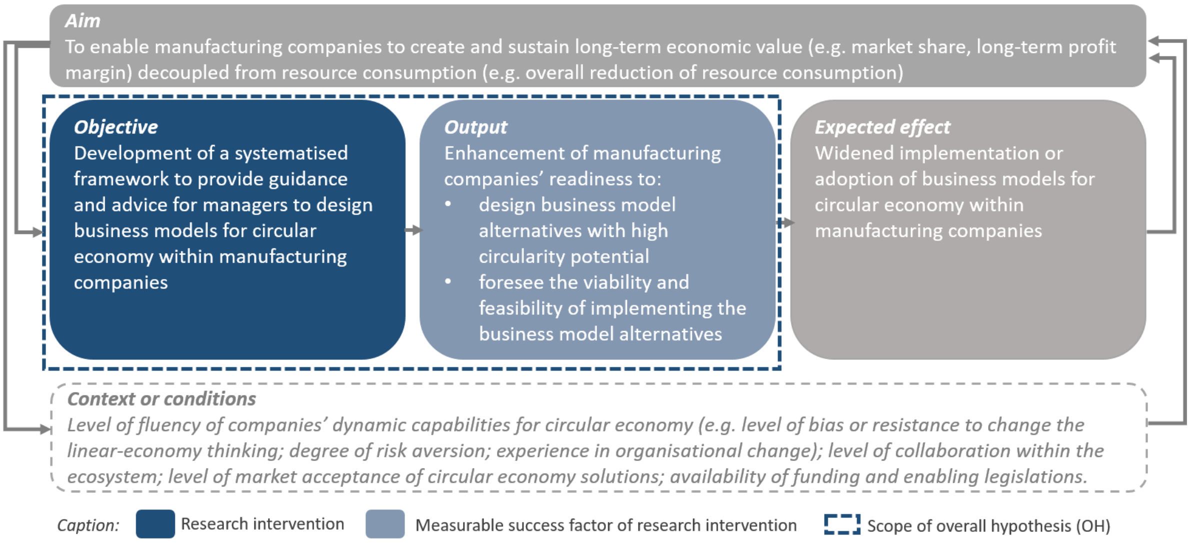


Figure 3 – Research objective, output, effect, aim and scope of hypothesis.

## 1.4 Research questions

Three research questions (RQ) form the structure of this thesis, based on the research gaps, research objective and hypothesis of this PhD thesis. Each research question was detailed in sub-questions (e.g. RQ1-a) to organise the execution of the research activities. The set of questions and sub-questions are:

*RQ1: How to identify and* ***systematise*** *the existing approaches in academia and practice that can support business model innovation in the context of CE?*

- RQ1-a: What are the existing approaches in academia and practice for business model innovation in the context of CE?
- RQ1-b: How do they support companies across the stages of the CE business modelling process?

*RQ2: How can a systematic process model be developed to* ***guide*** *CE business modelling within manufacturing companies?*

- RQ2-a: What are the academic and practical requirements for a systematic process model that aims to guide CE business modelling within manufacturing companies?
- RQ2-b: How can the requirements be translated into a process model?
- RQ2-c: What is the usefulness and applicability of the process model within manufacturing companies?

A *process model* provides a collection of organised practices and supporting aspects that represent and instruct how the execution of a process should occur (Adrodegari et al., 2018; Pieroni et al., 2019a; Smirnov et al., 2012). Process models can deal with the complexities of business processes, **guiding** how work should be done (Smirnov et al., 2012).

*RQ3 - How can an expert system be developed to provide* ***advice*** *to manufacturing companies to design business models for CE?*

- RQ3-a: What are the requirements for an expert system for CE business modelling within manufacturing companies?
- RQ3-b: How do existing CE business models look like in manufacturing companies?
- RQ3-c: How do contextual aspects of sectors influence CE business model design?
- RQ3-d: How to translate the requirements and advice about CE business model design into a useful and applicable expert system for manufacturing companies?

An *expert system (ES)* is a tool that uses databases of expert knowledge to offer **advice** and decision-making support in specific areas. Usually presented as a computer-based system, an ES is designed to emulate the decision-making ability of a human expert to solve complex organisational problems by reasoning through bodies of knowledge (Liao, 2005).

# 2 Research Methodology

The second chapter explains the research methodology underpinning this PhD thesis and the research structure deployed to answer the research questions and deliver the key results (section 2.1). Additionally, it details the methods applied throughout the research (section 142.2).

## 2.1 Design Research Methodology (DRM)

The methodological framework adopted in this PhD thesis was the Design Research Methodology (DRM) proposed by Blessing and Chakrabarti (2009). The DRM describes a rigorous scientific approach that indicates a variety of “methods and guidelines to be used as a framework” for planning and implementing research in the design field (Blessing and Chakrabarti, 2009, p. 9).

DRM enables a process of identifying a need in the design field and developing a solution to fulfil this need. DRM is adequate for the scope of this PhD thesis because it favours applied research in two main aspects. First, it allows for an iterative research process, which enables flexibility in the application of varied research methods in real industrial settings. Moreover, it encourages the use of empirical data as a means of understanding and interacting with practical reality, which increases the probability of producing useful results to practice (Blessing and Chakrabarti, 2009).

The generic DRM framework describes four main stages: *research clarification, descriptive study I, prescriptive study, and descriptive study II.* The stages and their application in this PhD thesis are explained in the sections 2.1.1 to 2.1.5.

### 2.1.1 Research clarification

The first stage of research clarification (RC) aims to explain the need in the field and the research problem. Initial evidence or indications to support assumptions regarding the existing situation and research problem are explored to enable the formulation of a realistic research goal. The clarification and exploration of evidence are achieved mainly with literature review and analysis (Blessing and Chakrabarti, 2009). Specifically for this PhD thesis, this was carried as exploratory literature review on the topics:

i. Circular economy;
ii. Business model innovation;
iii. Sustainable business model innovation; and,
iv. Circular economy business model innovation (i.e. which includes CEBMn).

This study supported the development of the overall research project design, including research gaps and scope of contributions (presented in section 1.2); aim, objective and hypothesis (presented in section 1.3); research questions (presented in section 1.4); methodological approach and project structure (presented in sections 2.1 and 2.2).

### 2.1.2 Descriptive study I

The descriptive study I (DS-I) seeks to enhance the understanding of the research phenomenon identified in the previous stage by describing the existing situation and the research/practical problem. The main deliverable of this stage is a detailed description of the phenomenon under investigation and its influencing factors and causes. With this, DS-I enables gathering insights that contribute to the development of the *support* and how the *support* will be evaluated later on. The *support* is a prescription that suggests how design tasks should be carried out for a certain purpose. It can include any means, aids and measures able to improve design, such as methodologies, procedures, methods, techniques, software tools, guidelines, knowledge bases, or checklists (Blessing and Chakrabarti, 2009).

In this PhD thesis, the DS-I stage adopted a review-based (i.e. theory-driven), exploratory (i.e. enables the development of hypotheses for further investigation) and qualitative approach (i.e. investigation about the nature of phenomena) (Åhlstrom, 2016; Blessing and Chakrabarti, 2009; Yin, 2011). This enabled addressing the first research question (section 1.4) with an investigation and systematisation of approaches for CE business model innovation from literature. They comprised specific approaches for CE business modelling (i.e. the process), however, conceptual frameworks (i.e. promoting common understanding or conceptual alignment about sustainability/CE BMI) were also considered. Moreover, hypotheses were developed about how to use the systematised approaches and emerging insights to propose a support that can guide CE business modelling within manufacturing companies.

### 2.1.3 Prescriptive study

The prescriptive study (PS) stage aims to develop (i.e. conceptualise, elaborate, realise and evaluate) a support to address the research and practical problems and improve the existing situation identified in the previous stages. The development of the support involves more than the simple derivation of findings from previous stages. Creativity and imagination are required and can be prompted by specific problem solving and empirical development methods (Blessing and Chakrabarti, 2009).

This PhD thesis encompassed four comprehensive prescriptive studies (i.e. A, B, C and D). They included the conceptualisation, description, elaboration and realisation of varied types of support, so that at least their core functionalities could be evaluated for their potential to fulfil the design requirements. The prescriptive studies covered:

- *PS-A*: *development of the systematised process model* for CE business modelling (CEBMn) within manufacturing companies. The need for new studies to develop complementary types of support – i.e. *PS-B*, *PS-C* and *PS-D* – was identified during the realisation of PS-A.
- *PS-B: systematisation of CEBM archetypes* to assist ideation during the design of CEBMs.
- *PS-C*: *development of sectorial CEBM patterns* to assist ideation and configuration of CEBMs.
- *PS-D*: *development of an expert system tool* that can provide structured advice for the execution of the CE business modelling (CEBMn) process within manufacturing companies.

### 2.1.4 Descriptive study II

The descriptive study II (DS-II) stage evaluates how well the proposed support was able to address the research and practical problems and improve the existing scenario. In addition, DS-II clarifies the actual applicability and usability of the support. Empirical studies are frequently used in this stage to obtain an understanding of how the actual support performs in a real setting where the phenomenon occurs.

Four descriptive studies II (i.e. A, B, C and D) were conducted in this research to evaluate the respective results of the prescriptive studies A, B, C and D (explained in section 2.1.3). Two types of evaluation criteria are possible in this stage: application and success. An application evaluation assesses the usefulness, applicability and usability of the support against its original purpose (i.e. the support can be used and can produce the expected outputs). A success evaluation assesses the ability of the support in enabling the achievement of the expected outcomes or long-term results. Application evaluations were carried for all descriptive studies II in this research (i.e. A, B, C and D). This is because a larger timeframe would be required to evaluate the success of CE business modelling activities.

### 2.1.5 DRM application in this PhD thesis

In applied research like the one presented by this thesis, plans of following a methodology sometimes differ from the dynamic reality of the ‘real world’ of companies.

To cope with that, DRM allows flexibility in the application of stages, which can be carried iteratively or parallel to each other (e.g. conduct prescriptive and descriptive studies in parallel with several companies at different periods to progressively co-develop and refine the support). Moreover, a variety of research methods can be applied in each stage.

Figure 4 illustrates how the *research questions and sub-questions* of this PhD thesis were addressed by varied *methods in each DRM stage*, generating the *key research results (R1-R5)* presented within an *article-based strategy (Appended Publications 1-6).*

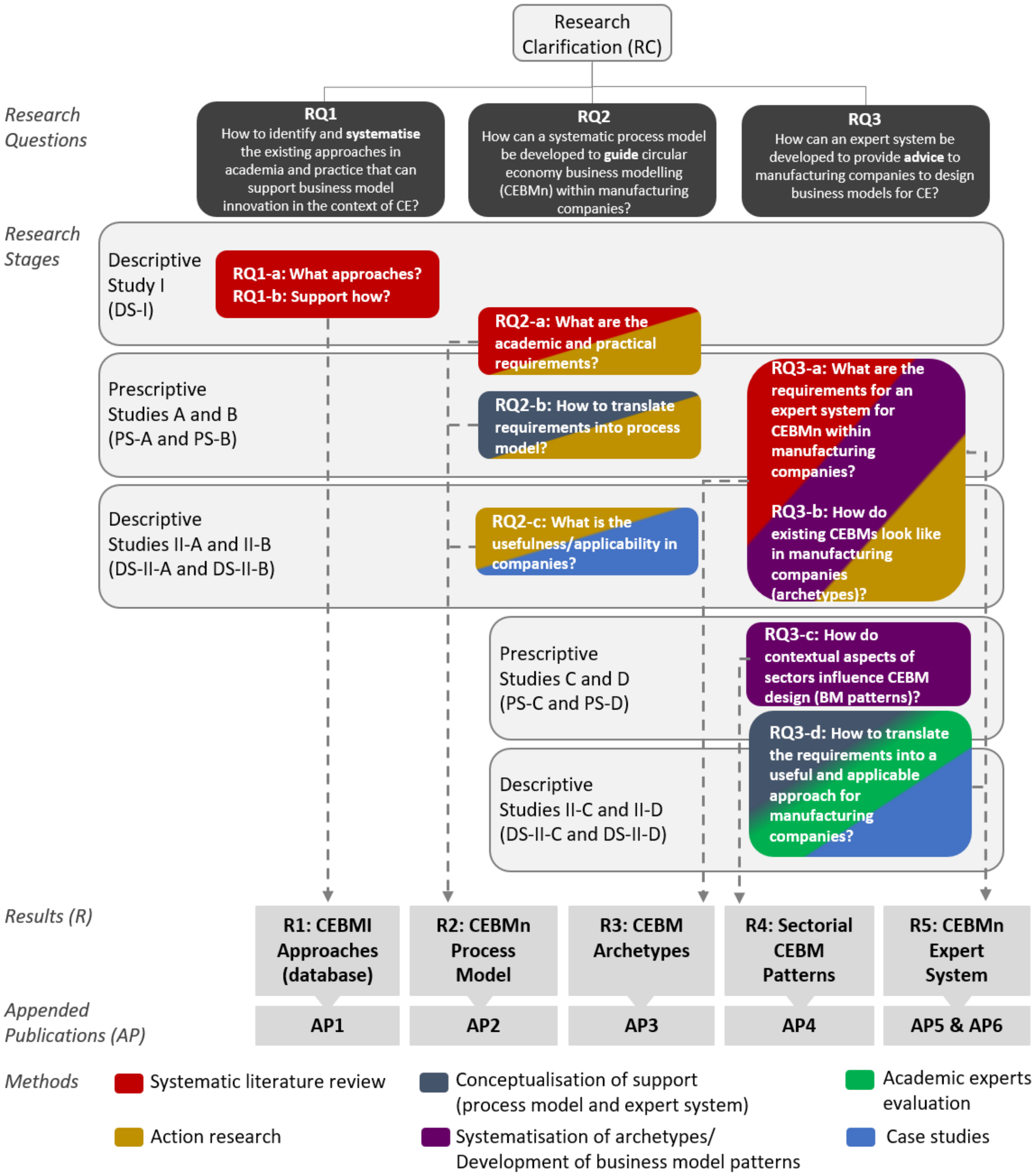


Figure 4 – Research questions, stages, methods, results (R) and appended publications (i.e. journal articles).

A detailed description of the activities executed to deliver the *research results* (R1-R5) is available in Appendix A. Table 1 provides an overview of the *six journal articles* that form the backbone for the research argumentation to answer the three research questions and sub-questions. The *methods* applied in each research stage are explained in section 2.2.

Table 1 – Contribution of publications to research questions (RQ 1-3) and sub-questions (indicated as letters in the columns on the right side of the table - i.e. a, b, c, d).

| Publications | Reference | RQ 1 | RQ 2 | RQ 3 |
|---|---|---|---|---|
| ***Appended publications (AP1-AP6) (i.e. journal articles)*** | | | | |
| **1** | Pieroni, M.P.P., McAloone, T.C. and Pigosso, D.C.A. (2019), "Business model innovation for circular economy and sustainability: A review of approaches", Journal of Cleaner Production, Vol. 215, pp. 198-216. https://doi.org/10.1016/j.jclepro.2019.01.036 | a<br>b | | |
| **2** | Pieroni, M.P.P., McAloone, T.C. and Pigosso, D.C.A. (2020), "Developing a process model for Circular Economy business model innovation within manufacturing companies", (Manuscript under review at Journal of Cleaner Production). | | a<br>b<br>c | |
| **3** | Pieroni, M.P.P., McAloone, T.C. and Pigosso, D.C.A. (2020), "From theory to practice: systematising and testing business model archetypes for Circular Economy", (Manuscript under review at Resources, Conservation & Recycling). | | | b |
| **4** | Pieroni, M.P.P., McAloone, T.C. and Pigosso, D.C.A. (2020), "Circular Economy business model innovation: sectorial patterns within manufacturing companies", (Manuscript under review at Journal of Cleaner Production). | | | c |
| **5** | Pieroni, M.P.P, C. McAloone, T. and C. A. Pigosso, D. (2019), "Configuring New Business Models for Circular Economy through Product–Service Systems", Sustainability, Vol. 11 No. 13, p. 3727. https://doi.org/10.3390/su11133727 | | | a<br>d |
| **6** | Pieroni, M.P.P., McAloone, T.C., Borgianni, Y., Maccioni, L, Pigosso, D.C.A. (2020), "An expert system for Circular Economy business modelling: advising manufacturing companies in decoupling value creation from resource consumption", (Manuscript under review at Journal of Cleaner Production). | | | a<br>d |
| ***Supplementary publications (not appended in this thesis)*** | | | | |
| **7** | Pieroni, M.P., Pigosso, D.C.A. and McAloone, T.C. (2018), "Sustainable Qualifying Criteria for Designing Circular Business Models", Procedia CIRP, The Author(s), Vol. 69 No. May, pp. 799–804. https://doi.org/10.1016/j.procir.2017.11.014 | | a | |
| **8** | Pieroni, M., Pigosso, D. and McAloone, T. (2018), "Exploring the synergistic relationships of circular business model development and product design.", International Design Conference- DESIGN 2018, pp. 2715–2726. https://doi.org/10.21278/idc.2018.0202 | | a | |
| **9** | Pieroni, M.P.P., McAloone, T. and Pigosso, D. (2019), "Business model innovation for circular economy: integrating literature and practice into a conceptual process model". In S Wartzack & B Schleich (eds), Proceedings of the Design Society: 22nd International Conference on Engineering Design (ICED19). Cambridge University Press, pp. 2517-2526, Delft, Netherlands. https://doi.org/10.1017/dsi.2019.258 | | a<br>b | |
| **10** | Blomsma, F., Pieroni, M., Kravchenko, M., Pigosso, D.C.A., Hildenbrand, J., Kristinsdottir, A.R., Kristoffersen, E., et al. (2019), "Developing a circular strategies framework for manufacturing companies to support circular economy-oriented innovation", Journal of Cleaner Production, Vol. 241, p. 118271. https://doi.org/10.1016/j.jclepro.2019.118271 | | a<br>b<br>c | |
| **11** | Pieroni, M.P., Blomsma, F., McAloone, T.C. and Pigosso, D.C.A. (2018), "Enabling circular strategies with different types of product/service-systems", Procedia CIRP, Elsevier B.V., Vol. 73 No. May, pp. 179–184. https://doi.org/10.1016/j.procir.2018.03.327 | | a | b<br>c |
| **12** | Pieroni, M.P.P, McAloone, T.C. & Pigosso, D.C.A. (2019), "Configuring new business models for circular economy: from patterns and design options to action". In F Lüdeke-Freund & T Froese (eds), Proceedings of the 4th International Conference on New Business Models: New Business Models for Sustainable Entrepreneurship, Innovation, and Transformation. Europe Business School, pp. 74-89, Berlin, Germany. | | | a<br>d |
| **13** | Pieroni, M.P.P., McAloone, T.C. and Pigosso, D.C.A. (2020), "Defining the requirements for a tool to support Circular Economy business model innovation within manufacturing companies", International Design Conference - DESIGN 2020. (Manuscript in press). | | | a |
| **14** | Pieroni, M.P.P., Hjort Jensen, T., Pigosso, D.C.A. & McAloone, T.C. (2020), *Circular Economy Business Modelling: CIRCit Workbook 2*, ISBN: 978-87-7475-602-6, Technical University of Denmark, 72 p. https://orbit.dtu.dk/en/publications/circular-economy-business-modelling-circit-workbook-2 | | | d |

## 2.2 Research methods

This section explains the methods applied in the different research stages as illustrated by Figure 4, including: systematic literature review (section 2.2.1); action research (section 2.2.2); case studies (section 2.2.3); conceptualisation of support (section 2.2.4); systematisation of archetypes (section 2.2.5; development of business model patterns (section 2.2.6); and academic experts evaluation (section 2.2.7).

### 2.2.1 Systematic literature review

Systematic literature review (SLR) scientifically enhances the validity of assertions in a certain research field. SLR can improve the degree of reliability on approaches for building new methods and tools. Consequently, it contributes to building evidence-based bodies of knowledge (de Almeida Biolchini et al., 2007).

SLR was applied in the Descriptive Study I of this research and followed a protocol based on Biolchini et al. (2007), which included three activities: *(i) data collection, (ii) data analysis* and *(iii) data reporting* (explained in Appendix A and Appended Publication 1).

### 2.2.2 Action research

Action research (AR) aims to propose solutions to organisational problems while building theory from observing and interacting with practice (Mathiassen, 2017). In combination with other research methods, AR provides relevant scientific-based opportunities to bridge the gap between theory and practice (Gill and Johnson, 2002; Mathiassen, 2017). Hence, it was highly applicable to the research stages of Prescriptive Studies A and B of this research.

Although AR usually helps the development of a support in practice, it is also possible to apply AR for testing existing frameworks (Baskerville, 1999; Neely et al., 2000; Puhakainen and Siponen, 2010). The AR cycles for testing follow a similar approach as the AR cycles for empirical development, however they involve reduced (or minimum as possible) intervention and participation of researchers. This approach of AR for theory testing was applicable to the research stages Descriptive Studies II-A and II-B, when the proposed support were mature already and hypotheses were being tested.

The AR applied in this research followed guidelines proposed by Mathiassen (2017) and adopted a cyclical process of three activities (Coughlan and Coghlan, 2002): *(i) diagnosing, (ii) planning and taking action* and *(iii) evaluating action* (explained in Appendix A and Appended Publications 2 and 3).

### 2.2.3 Case studies

Case studies can be applied for varied research purposes such as exploration, theory building, theory testing and theory refinement (Voss et al., 2002).

Case studies were applied in this research during the Descriptive Studies II-A, II-C and II-D, with the purpose of theory testing. Similar applications of case studies are observed in the literature to test complex tasks such as strategy implementation (Voss et al., 2002). This method was appropriate during DS-II-A to test the application of the stage ‘Transform’ of the CEBMn process model. The sage ‘Transform’ focuses on the implementation of CEBMs proposed during the stages ‘Sense’ and ‘Seize’ of the CEBMn process model. Moreover, it was appropriate during the stages DS-II-C and DS-II-D to test the independent application of

CEBM patterns and the expert system for CE business modelling by manufacturing companies.

The case studies applied in this research encompassed three activities (Dul and Hak, 2008): *(i) cases selection*, *(ii) data collection* and *(iii) data analysis* (explained in Appendix A and Appended Publications 4 and 6).

### 2.2.4 Conceptualisation of support (e.g. process model and expert system)

The conceptualisation of support relied on design research (Blessing and Chakrabarti, 2009) and envisioned different methods with alternating cycles of theoretical and empirical development.

Conceptualisation envisions the identification of a requirements plan, which is one of the first steps for developing a product or software (Boehm, 1984; Chakrabarti et al., 2004), and the same logic can be applied for developing design methods or tools (Blessing and Chakrabarti, 2009). A requirement is a "characteristic which a designer is expected to fulfil through the eventual design" (Chakrabarti et al., 2004, p. 22). Requirements can be divided into different categories and levels depending on how they can influence the users' satisfaction about the product, software, methods, or tools (Matzler and Hinterhuber, 1998). In this research, three categories and two relevance levels of requirements were considered (Kano et al., 1984). The categories included: (i) the way the tool is developed; (ii) usability and application; and (iii) content. The relevance levels were defined as:

1. Must-be criteria (i.e. minimum requirements): when not fulfilled will cause dissatisfaction and resistance from users, however, they will not impress the users if they are present.
2. Attractive criteria (i.e. nice-to-have requirements): when fulfilled lead to impression or over satisfaction in users, however, there is no dissatisfaction if they are not present.

Conceptualisation was applied to develop two types of support. A process model for CE business modelling was developed in stage PS-A (explained in Appendix A, Appended Publication 2 and Publication 9). Additionally, an expert system for CE business modelling was developed in stage PS-D (explained in Appendix A, Appended Publication 6 and Publication 13).

### 2.2.5 Systematisation of archetypes

Archetypes can be compared to 'theoretical prototypes' (Helkkula et al., 2018). In the case of archetypes of business models, they describe how to design and configure specific elements to transform business models according to a specific purpose (e.g. CE, sustainability) (Bocken et al., 2014). In a context in which companies are learning about CE business model innovation, archetypes and accompanying typologies (i.e. structures organising the archetypes with a certain indication of their relationship) are important to stimulate empirical research and trigger ideation (Doty and Glick, 1994).

From the SLR performed in stage DS-I (explained in Appendix A), archetypes were identified as the most popular conceptual tools for business model innovation. More than 16 sets of archetypes were identified. However, they lack consolidation, organisation in a pragmatic structure to support ideation sessions for CEBM innovation, and empirical demonstration of their applicability and usefulness (Bocken et al., 2019; Rosa et al., 2019). Therefore, a systematisation of CEBM archetypes was required and performed in the stage

Prescriptive Study B. It comprised alternating cycles of theoretical and empirical development, which are thoroughly explained in Appendix A and Appended Publication 3.

### 2.2.6 Development of business model patterns

The concept of business model patterns was identified as an emerging alternative approach to support CEBM design and configuration (Lüdeke-Freund, Bohnsack, et al., 2019; Lüdeke-Freund, Stefan, et al., 2019; Pieroni et al., 2019b). A business model pattern describes a "combination of configuration options, which repeatedly occurs in successful business models" (Amshoff et al., 2015). In other words, it describes a solution provided by the configuration of a business model to tackle certain business challenges – e.g. digitalisation, sustainability issues. Business model patterns enable a detailed and organised decomposition and representation of the business model architecture by including sub-models, elements, variables, and configuration/design options (Lüdeke-Freund, Bohnsack, et al., 2019). The application of business model patterns considers the complex interconnections among the pieces (i.e. elements, variables, and configuration/design options) of a business model. Hence, business model patterns were developed during stage PS-C and adopted as the core for the development of the expert system for CE business modelling during the stage PS-D.

Available business model patterns for CE or sustainability-related issues were identified in the SLR performed in DS-I (Kwon et al., 2019; Lüdeke-Freund et al., 2018; Lüdeke-Freund, Stefan, et al., 2019). However, they presented gaps that would not fulfil the need for specific advice for the creation of the expert system. For instance, available works are still conceptual, lacking a clear prescription about how to use the patterns in practice. Additionally, they remain generic, disregarding relevant sectorial specificity for CE (Wells, 2016). Lastly, they provide limited information about the interrelationship and combination of business model patterns.

Amshoff et al. (2015) proposed a methodology to develop emerging business model patterns as a consequence of technological disruptions. This methodology was adapted in this research to develop business model patterns that arise due to CE implementation in specific sectors. The methodology is based on an inductive approach that enables the identification and characterisation of business model patterns based on real application in cases, analysed retrospectively. It comprised seven activities based on Amshoff et al. (2015): *(i) selection of relevant manufacturing sectors, (ii) identification of CEBM cases in each sector, (iii) selection of a business model framework for the analysis of cases, (iv) analysis and characterisation of CEBMs from cases, (v) identification of CEBM patterns, (vi) documentation of patterns in a standardised structure* and *(vii) identification of CEBM pattern combinations* (explained in Appendix A and Appended Publication 4).

### 2.2.7 Academic experts evaluation

Academic experts evaluation can enhance the research with the identification of impressions and suggestions for improvements with an emphasis on increasing the consistency of the proposed support (Pigosso et al., 2013). Experts in a determined field can be identified by their period of activity and intensity of contributions (e.g. publications) (Laumann et al., 2016).

The evaluation by academic experts was applied in this research during the stage DS-II-C to evaluate the content, format (e.g. clarity and cognition), and logic of combination of CEBM patterns. This perspective was complemented by case studies (section 2.2.3) that focused on the evaluation of the usefulness and applicability of CEBM patterns in practical and real settings.

The evaluation by academic experts comprised three activities: *(i) experts selection*, *(ii) evaluation*, and *(iii) evaluation analysis* (explained in Appendix A).

# 3 Results and Discussion

This chapter presents the results of this PhD thesis accompanied by related discussion. It is organised according to the key results: R1 – CEBM innovation approaches (section 3.1); R2 – CEBMn process model (section 3.2); R3 – CEBM archetypes (section 3.3); R4 – CEBM Patterns (section 3.4) and R5 – CE business modelling expert system (section 3.5).

The detailed results are available in the appended publications indicated on the top of each section. Then, a brief description of key results is presented, followed by a discussion about how the results address the research questions, confirm or refute specific hypotheses investigated by this PhD thesis, and relate to the available literature.

## 3.1 R1 - Circular economy business model innovation approaches

This section presents the results of the systematisation of approaches for CEBMI.

*<u>The results summarised in this section are available in details on Appended Publication 1:</u> Pieroni, M.P.P., McAloone, T.C., Pigosso, D.C.A., 2019. Business model innovation for circular economy and sustainability: A review of approaches. J. Clean. Prod. 215, 198–216.*

In total, 92 approaches were identified from the sample of publications, being 44% conceptual frameworks, 14% methods (including process models) and 42% tools. The approaches were registered in the database according to: their name; description; bibliographic information (author, publication source and year); stage of support to the BM innovation process (i.e. Sense, Seize or Transform); nature of data; BM innovation characteristics (boundaries of analysis, level of abstraction, and time-related view); and representation style. The complete database can be downloaded from the article's publisher at: https://doi.org/10.1016/j.jclepro.2019.01.036.

The creation of the database **addressed the first research question**[1] by demonstrating how available approaches to support CEBM innovation can be identified and systematised from literature and practice.

Key findings emerged from the analysis and comparison of approaches, such as (see Appended Publication 1 for a complete view of findings):

- Most approaches are either theoretical (45%) or experimental (50%), which reinforces the research gap and the *need for advancing empirical research*;
- Approaches are *unsystematised and not prepared to fulfil the so-called design-implementation gap*, as they marginally address the implementation stage. Most of the identified approaches support sensing (understanding opportunities) and seizing (translating opportunities in BM configurations) and only 20% address the transforming stage (i.e. activities of piloting, preparing the organisational capabilities for change, and implementing the new BMs);
- Most approaches recommend the use of qualitative data for manoeuvring decision-making. However, they *lack proactive advice (even qualitative) and sparsely recommend the use of quantitative evidence* that could enhance the confidence level of decision-makers within manufacturing companies.

[1] RQ1: How to identify and systematise the existing approaches that can support BMI in the context of CE?

These findings are consistent with similar SLR studies about CEBM innovation approaches that emerged afterwards. Bocken et al. (2019) point to an opportunity of co-creating systematic and quantitative tools, which can support all phases of the CBMI process, in close collaboration with practitioners. Rosa et al. (2019) also highlight the need for an empirical line of action to support the design of CEBMs.

These insights and the remaining findings available in Appended Publication 1 regarding types of approaches indicated that a systematised and holistic support to guide CEBMI within manufacturing companies could adopt the format of a *process model*. Process models are important for CEBMI, and in particular, CE business modelling (CEBMn), since they can deal with complexities of business processes, instructing how work should be done systematically and for repeatability (Smirnov et al., 2012). When designing and implementing CEBMs, manufacturing companies need to constantly monitor and balance the update of value propositions and business expansion to fulfil changing customers' needs and needs from multiple customers along the different cycles during the product lifetime (e.g. as new, upgraded or remanufactured for technical products or cascaded ingredients for bio-based products) (Nußholz, 2018). Consequently, managerial practices for redesigning or innovating business models are demanded more frequently, becoming more complex to manage and strategically more important (Bocken et al., 2018; Guldmann and Huulgaard, 2020; Khan et al., 2020). Process models could offer an adequate structure to fulfil these needs and cover the gaps identified in this study by enabling process repeatability, reduced complexity, and holistic coverage of innovation stages.

The development of such a process model for CEBMn is the scope of the next section 3.2.

## 3.2 R2 - CEBMn process model

This section provides an overview of the results of the conceptualisation (section 3.2.1) and the evaluation (section 3.2.2) of the CEBMn process model.

Based on the deeper understanding of the field obtained with R1 (section 3.1), a specific hypothesis (SH-1) was proposed to be investigated during the conceptualisation and evaluation of the CEBMn process model:

*SH-1: A systematised process model can guide business modelling for CE within manufacturing companies of varied sectors and sizes.*

A process model can provide a collection of organised practices and supporting aspects to represent and instruct how the execution of the complete business modelling process should occur (Adrodegari et al., 2018; Pieroni et al., 2019a; Smirnov et al., 2012).

*<u>The results summarised in this section are available in details on Appended Publication 2[2]:</u> Pieroni, M.P.P., McAloone, T.C., Pigosso, D.C.A., 2020. Developing a process model for Circular Economy business model innovation within manufacturing companies. (Manuscript under review at Journal of Cleaner Production).*

[2] The CEBMn process model was addressed as 'CEBMI process model' in the Appended Publication 2.

### 3.2.1 Concepualisation of the CEBMn process model

The systematic literature review and database of approaches (presented in section 3.1) enabled the identification of 16 process models, 115 tools and 12 requirements for the development of CEBMn approaches.

A conceptual process model (v.1) was proposed based on the comparison and consolidation of the unique elements of the identified process models and the prioritisation of tools according to the defined requirements. The conceptual process model contained four stages (i.e. Prepare, Sense, Seize, Transform) with practices for CEBMn at the operational and institutional/strategic levels to achieve 21 deliverables. The operational level comprised 29 activities and 30 tools. The institutional/strategic level comprised 5 decision gates and 13 change enablers/catalysers.

The application of the process model (v.1) in action research cycles with selected manufacturing companies (A-G in Table 2) enabled the identification of four major improvements to *structure and activities*, and other four major modifications to *tools*. The incorporation of the aforementioned improvements resulted in the final version of the process model (v.final), which comprised 14 deliverables, 14 activities, 8 decision gates, 10 change enablers/catalysers, and 14 tools.

Table 2 - Companies participating in activities related to R2 and R3.

| Company | Sector | Size | Duration of AR (months) | Interval until interviews (months) |
|---|---|---|---|---|
| **A** | Electronic equipment | Small and Medium Enterprises (SME) (i.e.< 249 employees) | 5 months | Not included |
| **B** | Heavy machinery | Large (i.e.>250 employees) | 9 months | 12 |
| **C** | Furniture | SME | 2 months | 15 |
| **D** | Electronic equipment | SME | 2 months | 14 |
| **E** | Furniture | SME | 1 month | 10 |
| **F** | Clothing | SME | 1 month | 6 |
| **G** | Medical devices | Large | 2 months | 6 |

Figure 5 illustrates the visual representation of the main structure of the process model (v.final). Visual representations for the sub-models of each stage (i.e. Prepare, Sense, Seize and Transform) are presented on Appended Publication 2. The final tools are available for download at: http://circitnord.com/wp02-circular-economy-business-modelling/.

The conceptualisation of the CEBMn process model **addressed the second research question[3], particularly the sub-questions 'a'[4] and 'b'[5]** by demonstrating which theoretical and practical requirements should be considered in a systematised CEBMn approach. Moreover, it demonstrated how such requirements could be translated into functionalities and elements (e.g. visual representation, detailed guidelines, supporting tools) that enable application by manufacturing companies.

[3] RQ2: How can a systematic process model be developed to guide CEBMn within manufacturing companies?
[4] RQ2-a: What are the academic and practical requirements?
[5] RQ2-b: How to translate requirements into a process model?

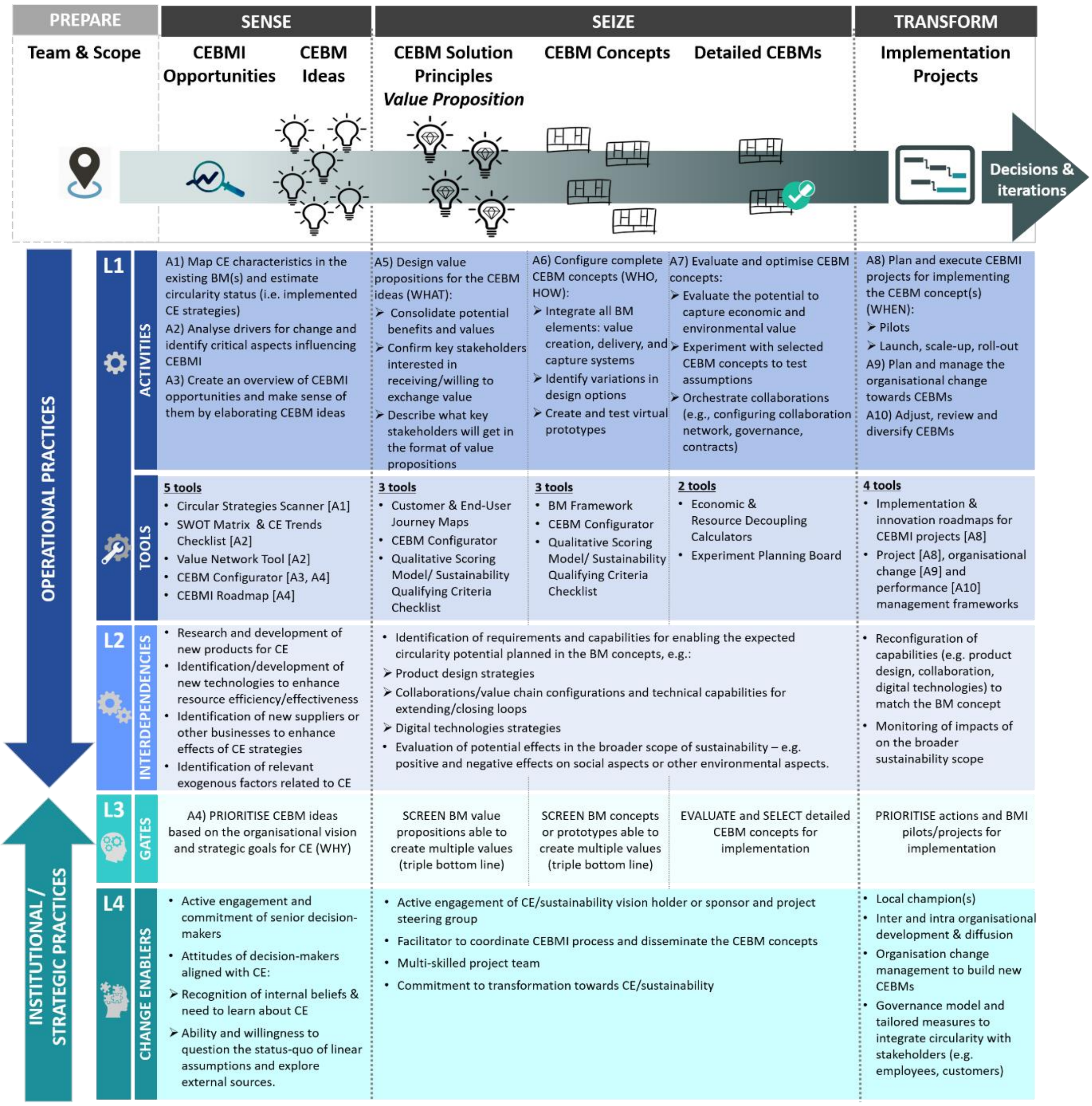


Figure 5 – CE business modelling process model (v.final) (Source: Appended Publication 2).

## 3.2.2 Evaluation of the CEBMn process model

The evaluation of the CEBMn process model is presented in three parts: evaluation of operational aspects (section 3.2.2.1), evaluation of institutional/strategic aspects (section 3.2.2.2), and evaluation of overall usefulness, applicability and improvements (section 3.2.2.3).

### 3.2.2.1 Operational aspects

The manufacturing companies engaged in the evaluation of the CEBMn process model (v.f) considered the final version of the stages **'Sense' and 'Seize'** useful and with clear *activities and structure*. This was demonstrated by the increased and sustained satisfaction level of companies regarding the previous version of the process model (v.1) (see detailed graph on Appended Publication 2). Hence, the process model was considered sufficient about its *structure and activities* for 'Sense' and 'Seize'. Moreover, by following the activities of those two stages and by applying the available *tools*, companies achieved *results* (detailed in Appendix D) that they judged as satisfactory or very satisfactory.

The manufacturing companies (B-G in Table 2) participating in the case studies for the evaluation of the stage **'Transform'** of the CEBMn process model considered the *structure* clear (detailed results on Appendix E). However, none of the companies was able to complete all *activities* of 'Transform' (Figure 6). This was expected due to the relatively high effort and time required for the implementation of CEBMs. Moreover, two companies (F and G in Table 2) claimed that they were not ready to start the stage 'Transform' after the completion of the stage 'Seize' due to restrictions encountered in the value chain and collaborations (e.g. influence of established actors, absence of local providers). Hence, they had to iterate the execution of the CEBMn process and start a new round of activities for 'sensing' and 'seizing' CEBMs, focusing on different value propositions and products.

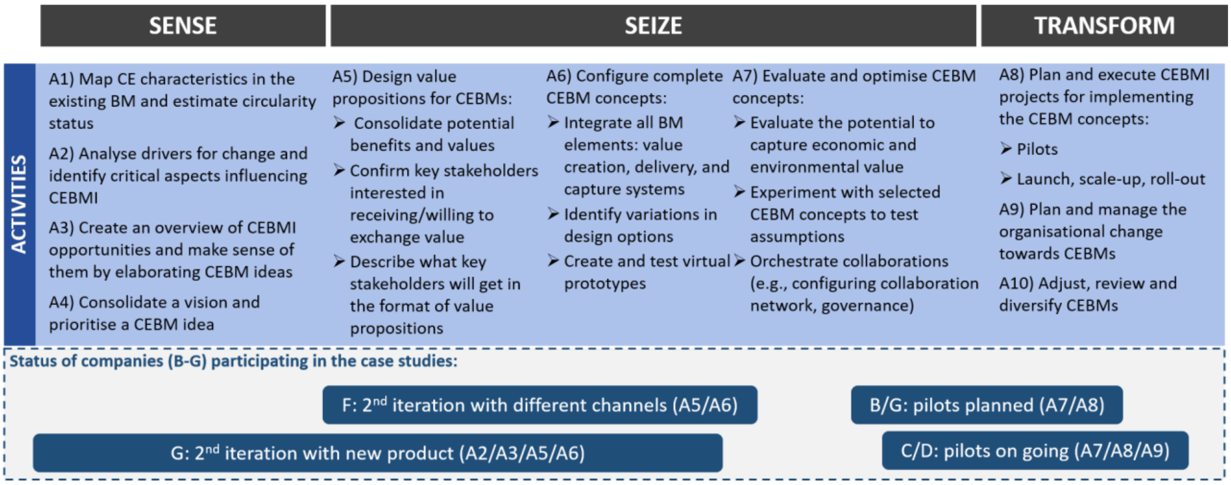

Figure 6 –Status of execution of the CE business modelling process by companies (Legend: A – activity).

The key insights from the evaluation of the stage 'Transform' were (detailed in Appendix E):

- *Results* and *tools* deployed in the stages 'Sense' and 'Seize' supported the generation of substantial arguments and evidence that encouraged the implementation of CEBM pilots in companies.
- Companies continued to rely on and refine the outcomes obtained through four tools: *(i) Economic and Resource Decoupling Calculators; (ii) CEBM Framework; (iii) CEBM Configurator (high-fidelity prototype); and (iv) CEBM Innovation Roadmap.*
- All companies that managed to engage in the *activities* of the stage 'Transform' were successful in either planning (B and E) or implementing (C and D) at least one *CEBM pilot* (see Appendix D for details) – e.g. two of the companies were able to collaborate to create a spinout to scale-up a CEBM configuration.

#### 3.2.2.2 Institutional/strategy aspects

Testimonies from companies revealed that the application of the CEBMn process model's activities and tools triggered change to certain *institutional/strategic aspects* that can favour CEBMs design and implementation. For example: enhancement of alignment from different functional units/departments around a similar CEBM vision or idea; change to the mental models and mindset of participants towards CE-thinking; and achievement of internal buy-in.

On the other hand, a lack of readiness was observed within some companies, to cope with some of the institutional aspects recommended for CEBMn. Particularly in large organisations, a mindset towards short-term business results (e.g. profitability and market penetration) and the need for certainty in facts and information even in the early stage of idea generation impaired the process application and the perception of the companies about the satisfaction level with *obtained results*. Bocken and Geradts (2019) identified similar barriers for sustainable BMI, such as the tendency of corporations to maximise shareholder value and avoid uncertainty in their strategic decisions.

The practical application revealed inherent limitations of the CEBMn process model to the extent that it can contribute to stimulating change and CE transformation. Even though some requirements regarding *institutional/strategic aspects* were made explicit to companies by the CEBMn process model, they were not embraced or deployed. Probably, this is associated to a lack of organisational design aspects conducive to dynamic capabilities that can help the effectuation of CEBMs, enhancing the results of the CEBMn process model, for example: management philosophy (e.g. values, beliefs, and assumptions underlying leadership and decision-making); incentive alignment; governance (Bocken and Geradts, 2019; Kindström et al., 2013). Therefore, other approaches should be explored concomitantly or even previously to the application of the CEBMn process model to enable boosting its results.

#### 3.2.2.3 Overall usefulness, applicability and improvements

After the evaluation, a detailed guideline based on the final version of the CEBMn process model was created to help the independent application by manufacturing companies. This guideline is available on Supplementary Publication 14 (Table 1) and can be downloaded from: https://orbit.dtu.dk/en/publications/circular-economy-business-modelling-circit-workbook-2.

The evaluation of the CEBMn process model **addressed the second research question[6] and specifically the sub-question 'c'[7]** by demonstrating the usefulness and scope of application for the process model.

Regarding the *usefulness*, manufacturing companies highlighted two key contributions of the CEBMn process model:

(i) The CEBMn process model's *activities and structure* prompted the maturation of existing CEBM ideas into viable and implementable configurations by offering support to:
   a. Deal with the complexity of CEBMn/CEBMs (e.g. pondering economic and resource efficiency gains);
   b. Embrace ambiguities (i.e. come to decisions despite lack of some facts);
   c. Organise results for dissemination and implementation (e.g. education of employees, communication with suppliers and investors).

(ii) The CEBMn process model provided a source of inspiration for best practice CEBMs, activating insights about new CEBM configurations that enable breaking industry's business as usual 'recipes' (Matthyssens et al., 2006).

Regarding the *boundaries of application*, the satisfactory use of the CEBMn process by varied organisations points towards its potential applicability in different manufacturing industry sectors and sizes (see Appended Publication 2 for more details). This provided

[6] RQ2: How can a systematic process model be developed to guide CEBMn within manufacturing companies?
[7] RQ2-c: What is the usefulness and applicability of the process model within manufacturing companies?

**evidence to sustain the first specific hypothesis (SH-1)**, confirming that *a systematised process model can guide business modelling for circular economy within manufacturing companies of varied sectors (i.e. electrical and electronic equipment and appliances; heavy machinery; medical devices; furniture and textile/apparel) and sizes (i.e. SMEs and large organisations).* However, further testing especially in large companies and corporations, and other sectors within and beyond manufacturing (e.g. construction, services and extractive industries) shall occur to refine further the boundaries of application for the CEBMn process model (Gill and Johnson, 2002).

Lastly, despite the positive acceptance of *overall activities and structure* of the CEBMn process model, modifications in supporting *tools* were still requested by companies, since gaps in existing tools could be impairing the satisfaction with *results* achieved. In particular, companies recommended that *tools* should be *proactive and precise in suggesting CEBM solutions* as opposed to available tools in literature incorporated by the CEBMn process model. The recommendations proposed that tools should:

(i) Allow *repeatability of the process model to assist iterations, simulation and comparison of alternative CEBM configurations* – i.e. companies recommended a structured framework to help the iteration of steps and an automated workflow enabling the interfacing of tools (i.e. which output from one tool could serve as input to another) to support the CEBM reviews and adaptations during the stage 'Transform'.

(ii) Cover flex*ible and simple ways of measuring resource decoupling and economic potentials* for the CEBMs.

(iii) Include *support to overcoming barriers for CEBM implementation* – i.e. a series of internal and external actions were recommended by companies to be used as a CEBM Barrier-Action Checklist during the stage 'Transform' (see Appendix E).

The development of tools to address some of the aforementioned improvements is the scope of sections 3.3, 3.4 and 3.5.

## 3.3 R3 - CEBM archetypes

This section introduces the results of the systematisation and empirical development of the CEBM archetypes (section 3.3.1), and the evaluation (section 3.3.2) of the CEBM archetypes.

Specific hypotheses (SH-2 and SH-3) were formulated to be investigated during the systematisation and evaluation of the CEBM archetypes:

*SH-2: CE business model archetypes can support manufacturing companies from varied sectors and sizes with ideation during the design of CEBMs; and*

*SH-3: Generic archetypes accompanied by generic case examples are enough to support ideation during the design of CEBMs.*

<u>*The results summarised in this section are available in details on Appended Publication 3:*</u> *Pieroni, M.P.P., McAloone, T.C., Pigosso, D.C.A., 2020. From theory to practice: systematising and testing business model archetypes for Circular Economy. (Manuscript under review at Resources, Conservation and Recycling).*

### 3.3.1 Systematisation and empirical development of CEBM archetypes

The systematisation of CEBM archetypes was based on 16 publications identified from the systematic literature review and the database of CEBM innovation approaches (see section 3.1). After comparison and consolidation of the available CEBM archetypes identified in the 16 publications, *22 unique CEBM archetypes* emerged. A *typology framework* was created to organise and support the documentation of the archetypes. The typology enabled the distribution of archetypes in seven categories:

- In the downstream architecture: (i) dematerialised or efficiency; (ii) collaborative consumption; (iii) product-service systems; (iv) long life; and (v) next life;
- In the upstream architecture: (vi) circular production and distribution; and (vii) circular sourcing.

The application of the archetypes in the format of an *ideation card deck* in action research with manufacturers (B, C and D in Table 2) in section 3.2) enabled the compilation of *improvement opportunities* for the use of CEBM archetypes. In particular, companies required a contextualisation of archetypes to match the solutions or changes proposed to the business models with recurrent types of resource inefficiency problems (i.e. sources of structural waste) in specific industry sectors.

The systematisation of the CEBM archetypes **addressed the third research question[8] and specifically the sub-question 'b'[9]** by demonstrating how existing CEBMs look like in manufacturing companies. Moreover, it revealed that practitioners call for specialised sectorial approaches that can address beyond the generic level of discussions and tools dominant in literature so far. These observations are consistent with findings from recent literature reviews on CEBMI field (Pieroni et al., 2019a; Rosa et al., 2019).

### 3.3.2 Evaluation of CEBM archetypes

The evaluation of the CEBM archetypes **addressed the third research question, and specially the sub-question 'd'[10]** by exploring the usefulness and applicability of a well disseminated approach based on *archetypes ideation cards* to support ideation activities (A3) of the CEBMn process model in practice.

Regarding the *usefulness*, the application of the *CEBM* archetypes ideation card deck in case studies with another three manufacturing companies (E, F and G in Table 2 in section 3.2) revealed that the adopted approach could support the ideation activities (A3) of the CEBMn process model. However, certain limitations were mentioned. In addition to confirming the improvement opportunities previously identified during the systematisation and empirical development of the CEBM archetypes (section 3.3.1), such as the need for sectorial specialisation, the companies in this study recommended additional improvement opportunities, such as the need for:

(i) Homogenisation and standardisation of the structure of archetypes to help the combination, clustering and creation of complete CEBM configurations that cover all elements (see explanation on Table 2 of Appended Publication 3 about how different archetypes affect or represent different elements of a CEBM);

[8] RQ3 - How can an expert system be developed to provide advice to manufacturing companies to design CEBMs?
[9] RQ3-b: How do existing CEBMs look like in manufacturing companies?
[10] RQ3-d: How to translate the requirements/advice about CEBM design into a useful and applicable expert system?

(ii) A prescriptive approach to support companies in selecting or prioritising the archetypes that could fit more adequately with their context, to address specific types of structural waste or overcome specific CEBM barriers;

(iii) Simpler terminology in archetypes – i.e. descriptions oriented to practice.

Regarding the *boundaries of application*, the satisfactory use of the CEBM archetypes by various organisations points to its potential applicability to different manufacturing sectors and sizes. This evaluation provided **evidence to sustain the second specific hypothesis (SH-2)** investigated in this research, confirming that *circular economy business model archetypes can support manufacturing companies from varied sectors and sizes with ideation during the design of CEBMs.* However, it also provided evidence to **invalidate the third specific hypothesis (SH-3)** by showing that g*eneric archetypes accompanied by generic case examples were NOT enough to support ideation during the design of CEBMs,* since the abovementioned improvement opportunities suggest the need for a different type of approach. These recommendations that emerged from practical observations contradict some guidelines provided by literature, which argues for the development of generic tools (Bocken et al., 2019). However, they were expected and seemed reasonable for CEBMI, since the evaluations of the economic and resource decoupling potentials of BMs are highly contextual (Wells, 2016). Recent works in CE literature highlight the importance of contextual factors in determining the nature of value creation (Ünal, Urbinati, Chiaroni, et al., 2019) and point to the need of enhanced rigour regarding the structure of business model archetypes (Ertz et al., 2019). The development of a different type of tool that can better support companies with ideation during the design of CEBMs is the scope of section 3.4.

## 3.4 R4 – Sectorial CEBM patterns

This section introduces the results of the development (section 3.4.1) and the evaluation (section 3.4.2) of the sectorial CEBM patterns.

Based on findings obtained in R3 (section 3.3), it was identified the need to develop a new type of content to support the stages ‘Sense’ and ‘Seize’ of the CEBMn process model, so that detailed and contextualised solutions for specific sectorial challenges could be recommended to manufacturing companies. Context-specific solutions are important to reduce uncertainties in CEBMs (Wells, 2016). The concept of *business model patterns* (section 2.2.6) was considered relevant to fulfil the need for contextualised and detailed solutions.

Therefore, a new specific hypothesis (SH-4) was created for investigation:

*SH-4: Sectorial business model patterns and combinations can enhance the effectiveness of CE business modelling.*

<u>*The results summarised in this section are available in details on:*</u>

<u>Appended Publication 4:</u> *Pieroni, M.P.P., McAloone, T.C., Pigosso, D.C.A., 2020. Circular Economy business model innovation: sectorial patterns within manufacturing companies. (Manuscript under review at Journal of Cleaner Production).*

<u>Appended Publication 5:</u> *P. P. Pieroni, M., C. McAloone, T., C. A. Pigosso, D., 2019. Configuring New Business Models for Circular Economy through Product–Service Systems. Sustainability 11, 3727. https://doi.org/10.3390/su11133727.*

### 3.4.1 Development of the sectorial CEBM patterns

The development of the sectorial CEBM patterns intended to counteract two core gaps previously encountered in the use of CEBM archetypes during the design of CEBMs:

1st core gap

Incompleteness of archetype-based approaches to support the design of whole CEBMs (i.e. comprising CE characteristics in all elements). This indicates that a potential connection among archetypes that address different regions of elements of a BM could be explored to achieve a complete CEBM design and synergies for resource decoupling. Nevertheless, these connections or combinations have not been identified in literature yet.

According to Lüdeke-Fraund et al. (2019), a business model patterns language is an approach that can provide an enhanced level of standardisation and completeness in the design of CEBMs. However, the patterns language shall be properly developed for that purpose and shall comprise:

(i) a formalised structure for documentation with a clear definition of the abstraction level (e.g. single elements of the BM, group of elements of the BM, complete BM);

(ii) systematisation of the connections or potential combinations between different BM patterns to enable the description of complete BMs.

2nd core gap

Lack of sectorial specialisation, also inexistent in literature. This gap was confirmed by companies participating in the AR cycles, which faced difficulties in assimilating ideas that could be applied in their sector but were illustrated with an example from a very different sector (e.g. application in the heavy machinery sector with cases of textiles/clothing). In the CE context, different sectors or types of products are responsible for distinct types of structural waste, requiring different solutions and enabling different types of value creation, which are based on specific configurations of business models and operations in practice (Ünal, Urbinati, Chiaroni, et al., 2019; Wells, 2016).

Through multi-dimensional scaling analysis (MDS) of more than 180 CEBM cases, this research stage enabled the creation of *208 CE business model patterns for six manufacturing sectors with accompanying recommendations of combinations among patterns (i.e. within single sectors).* An example of a complete list of patterns for the furniture sector can be visualised on Appended Publication 4.

The development of the sectorial CEBM patterns **answered the third research question[11] and specifically the sub-question 'c'[12]** by demonstrating how contextual aspects of different manufacturing sectors can influence the design of CEBMs. Moreover, it demonstrated how a versatile system can be generated that goes beyond simple and generic CEBM pattern lists currently available in the literature (Lüdeke-Freund, Bohnsack, et al., 2019; Lüdeke-Freund, Stefan, et al., 2019).

A pre-testing of the low-fidelity prototype developed for the application of the *sectorial CEBM patterns* with company E (Table 2 in section 3.2) revealed positive effects in the CEBM design process when compared to the use of *CEBM archetype ideation cards*

[11] RQ3: How can an expert system be developed to provide advice to manufacturing companies to design CEBMs?
[12] RQ3-c: How do contextual aspects of sectors influence CEBM design?

(complete results on Appended Publication 5). Companies from the same manufacturing sector (i.e. furniture) experienced different efficiency in the transformation of CEBM ideas into CEBM configurations depending on the approach used. Company C (Table 2 in section 3.2) used the *CEBM archetype ideation cards* while Company E (Table 2 in section 3.2) used the *sectorial CEBM patterns* to support their design processes of CEBMs (i.e. activities 3, 4 and 5 of the CEBMn process model). The application of the *CEBM patterns* seemed to introduce organisation, focus, and enhance problem-oriented ideation for Company E. This resulted in fewer ideas being generated, however they were closer to a complete version of a CEBM (i.e. considering all elements) than the ones generated by Company C.

These effects pointed to the usefulness of the sectorial CEBM patterns to address the needs of companies identified during the action research cycles (presented in sections 3.2.2.3 and 3.3.2). Moreover, it provided **initial evidence to sustain the fourth specific hypothesis (SH-4)** investigated in this research, indicating that *sectorial business model patterns and combinations can enhance the effectiveness of CEBMn.* This encouraged a complete evaluation of the performance of the sectorial CEBM patterns with a broader sample of companies and academic experts, as demonstrated in the next section **Error! Bookmark not defined.**3.4.2.

### 3.4.2 Evaluation of the sectorial CEBM patterns

The *academic experts* participating in the evaluation of the CEBM patterns for the sectors heavy machinery and electrical/electronic equipment and appliances provided positive feedback about the patterns' content, considering most patterns with (details on Appendix F):

- adequate name;
- clear descriptions of context and CE problems that try to be solved with the pattern;
- clear descriptions of solutions proposed by the CEBM pattern;
- clear and comprehensive suggestions of configuration options for the BM elements addressed by the patterns, which comprised either downstream or upstream architecture;
- coherent recommendations about combinations.

Complementarily, most *participants within the manufacturing companies* engaged in the evaluation of the CEBM patterns for the sectors furniture, heavy machinery, and electrical/electronic equipment and appliances (Table 3) provided positive feedback about the patterns. They considered the CEBM patterns as (details on Appended Publication 4):

- comprehensive to address the CE problems in their existing BMs;
- applicable to their context with the need for moderate effort for customisation;
- able to suggest logical and applicable patterns combinations;
- able to provide visibility of the viability of the CEBM configurations;
- able to stimulate straight-forward exploration of ideas for designing new CEBMs.

Table 3 - Companies participating in activities related to R4 and R5.

| Company | Sector | Size | R4: CEBM Patterns | R5: CE Business Modelling Expert System |
|---|---|---|---|---|
| **H** | Electrical/electronic equipment/appliances | SME | ✓ | ✓ |
| **I** | Heavy machinery | SME | ✓ | ✓ |
| **J** | Furniture | Large | ✓ | ✓ |
| **K** | Furniture | SME | ✓ | ✓ |
| **L** | Furniture | SME | ✓ | ✓ |
| **M** | Furniture | SME | | ✓ |
| **N** | Agricultural and food products | Large | | ✓ |
| **O** | Generic (Outdoor goods) | Large | | ✓ |
| **P** | Generic (Outdoor goods) | SME | | ✓ |
| **Q** | Generic (Construction) | SME | | ✓ |

The evaluation of the CEBM patterns **addressed the third research question**[13] **, and specifically, the sub-question 'd'**[14] by exploring the usefulness and applicability of an approach based on CEBM patterns to support ideation and configuration activities of the CEBMn process model (activities 3, 5 and 6) in practice.

Regarding the *usefulness*, the CEBM patterns benefited manufacturing companies by:

- Enabling straight-forward exploration of ideas;
- Promoting the discovery of new ideas for CEBMs that companies had not anticipated (especially SMEs);
- Providing inspiration and benchmarking with cases that supported the ideation and design of CEBM configurations (testimonials examples: "cases were helpful in disseminating the ideas within the company" and "helped understanding how CEBMs can function in practice");
- Revealing a need for different types of collaborations to close resources loops;
- Enabling the visibility of alternative CEBMs for exploration (i.e. assessment and experiments) that boosted strategic CE-thinking (see section 1.2).

Despite the positive evaluation, academic experts [Exp.] and companies [Comp.] recommended a series of *improvement opportunities* for the CEBM patterns such as the need for:

- Enhanced consistency and differentiation in the configuration options allocated for Value Delivery and Service Offering elements of the CEBM patterns [Exp.];
- Enhanced precision in the description of CEBM patterns context and CE problem, strengthening the focus on the economic hurdles on top of resource inefficiency, especially in the heavy machinery sector [Exp./Comp.] (see graph on Appendix F);
- Enhanced precision in the description and completeness in configuration options of elements Value Creation, Partnerships and Collaborations and Benefits for Partners, especially in the heavy machinery sector [Exp.] (see graph on Appendix F);
- Addition of some CEBM patterns [Comp.];

[13] RQ3: How can an expert system be developed to provide advice to manufacturing companies to design CEBMs?
[14] RQ3-d: How to translate the requirements/advice into a useful and applicable expert system?

- Merger/exclusion of some CEBM patterns due to overlapping or need to analyse more cases to increase robustness/evidence (4 in Heavy Machinery and 3 in electrical/electronic equipment and appliances) [Exp./ Comp.];
- Inclusion of additional cases (recommended by experts), complementary configuration options for different elements of the CEBM patterns and combinations among patterns [Exp./ Comp.];

Additionally, the companies suggested improvements for the application procedure of CEBM patterns to enable their combination for configuration of complete CEBMs, such as the need for:

- Support for the selection of core CEBM patterns to start forming the combinations;
- Adequate criteria for narrowing down choices of final CEBM configurations (after alternative combinations of patterns are proposed);
- Development of specific use guidelines varying according to the scope of application of the CEBM patterns – e.g. redesign/transform the existing BM into a CEBM or design a completely new CEBM that will reflect and implement a future strategy of the company.

Regarding the *applicability*, recommendations provided by the CEBM patterns were positively perceived and valid in a set of companies from three different sectors (e.g. furniture, heavy machinery, and electrical/electronic equipment/appliances) and sizes (i.e. SMEs and large manufacturers), and beyond the original cases (i.e. more than 30 in each sector) that served as inspiration for the development of the patterns. Moreover, the robustness of the content being recommended by the CEBM patterns was positively evaluated by academic experts in the two evaluated sectors (heavy machinery, and electrical/electronic equipment/appliances). On top of that, as demonstrated in section 3.4.1, the sectorial CEBM patterns enabled superior effectiveness of the ideation process than CEBM archetypes when applied in companies from the same sector (i.e. furniture).

The collection of observations aforementioned provided enough **evidence to sustain the fourth specific hypothesis (SH-4)** explored in this research, confirming that *sectorial business model patterns and combinations can enhance the effectiveness of CEBMn.* However, further testing, especially in large companies and other sectors within and beyond manufacturing (e.g. construction, service and extractive industries), is important to refine the boundaries of application of the hypothesis and to explore whether usability preferences according to different contexts exist (Gill and Johnson, 2002).

The analysis and incorporation of the improvement opportunities mentioned above, especially the improvements regarding the application procedure of combining patterns led to the development of the CE Business Modelling Expert System. These results are presented in the next section 3.5.

## 3.5 R5 - CE business modelling expert system (CEBMES)

This section introduces the results of the conceptualisation (section 3.5.1) and the evaluation (section 3.5.2) of the high-fidelity prototype for the CE Business Modelling Expert System.

The expert system aims to support the application of the CEBMn process models by manufacturing companies, as identified by the suggestions of improvements in the results section R2 (section 3.2). Hence, a specific hypothesis (SH-5) was created to be investigated:

*SH-5: An expert system that provides advice for CEBM design and enables simulation of alternative CEBM configurations can enhance the application of the CEBMn process model within manufacturing companies.*

*The results summarised in this section are available in details on:*

*Appended Publication 5[15]: P. P. Pieroni, M., C. McAloone, T., C. A. Pigosso, D., 2019. Configuring New Business Models for Circular Economy through Product–Service Systems. Sustainability 11, 3727. https://doi.org/10.3390/su11133727*

*Appended Publication 6: Pieroni, MPP, McAloone, L., Borgianni, TC, Maccioni, Y, Pigosso, DCA 2020, 'An expert system for Circular Economy business modelling: advising manufacturing companies in decoupling value creation from resource consumption', (Manuscript under review at Journal of Cleaner Production).*

### 3.5.1 Conceptualisation of the CEBMES high-fidelity prototype

The systematic literature review (presented in section 3.1) and the improvement opportunities collected during the evaluation of the CEBMn process model (shown in section 3.2.2.3) enabled the identification of 13 conceptual requirements and 9 practical requirements for the development of the CEBMES. These requirements enabled the definition of 9 key functions for the CEBMES and detailed descriptions about input and output for the deployment of each function (details on Supplementary Publication 12 listed in Table 1).

A pre-test of the usefulness of functionalities of the CEBMES was carried with Company E (Table 2 in section 3.2) through the application of a low-fidelity prototype (details on Appended Publication 5). This application pointed to the usefulness of the functionalities of the CEBMES, and encouraged a complete evaluation of its performance with a broader sample of companies, as demonstrated in the next section 3.5.2.

To allow this evaluation, an improved high-fidelity prototype of the CEBMES was developed based on the key functionalities. The prototype was created in Excel spreadsheets, following the architecture illustrated in Figure 7. It comprised four modules and seven steps. Each step correlates with a different spreadsheet of the CEBMES that is visible to the users (i.e. front-end). Moreover, auxiliary spreadsheets containing explanations and cases are provided to support the users in interpreting the results of the main interfaces. Spreadsheets for calculations (i.e. back-end) or databases (i.e. knowledge bases) are invisible for the users.

The complete description of the CEBMES functionalities ('F' in Figure 4) and the logic across its modules is available in the Appended Publication 6. A version of the CEBMES high-fidelity prototype can be downloaded from the university repository (https://doi.org/10.11583/DTU.11798655).

The development of the CEBMES high-fidelity prototype addressed **the third research question[16] and specifically the sub-question 'a'[17]** by demonstrating which requirements should compose an expert system for CEBMn. Moreover, it partially addressed **sub-question 'd'** by showing how requirements can be transferred into a practical approach to generate knowledge for action (Lüdeke-Freund, Bohnsack, et al., 2019).

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[15] CEBMES was addressed as 'CE Driven BM Configurator' or 'CEBM Configurator' in Appended Publications 2/5.

[16] RQ3: How can an expert system be developed to provide advice to manufacturing companies to design CEBMs?

[17] RQ3-a: What are the requirements for an expert system for CEBMn within manufacturing companies?

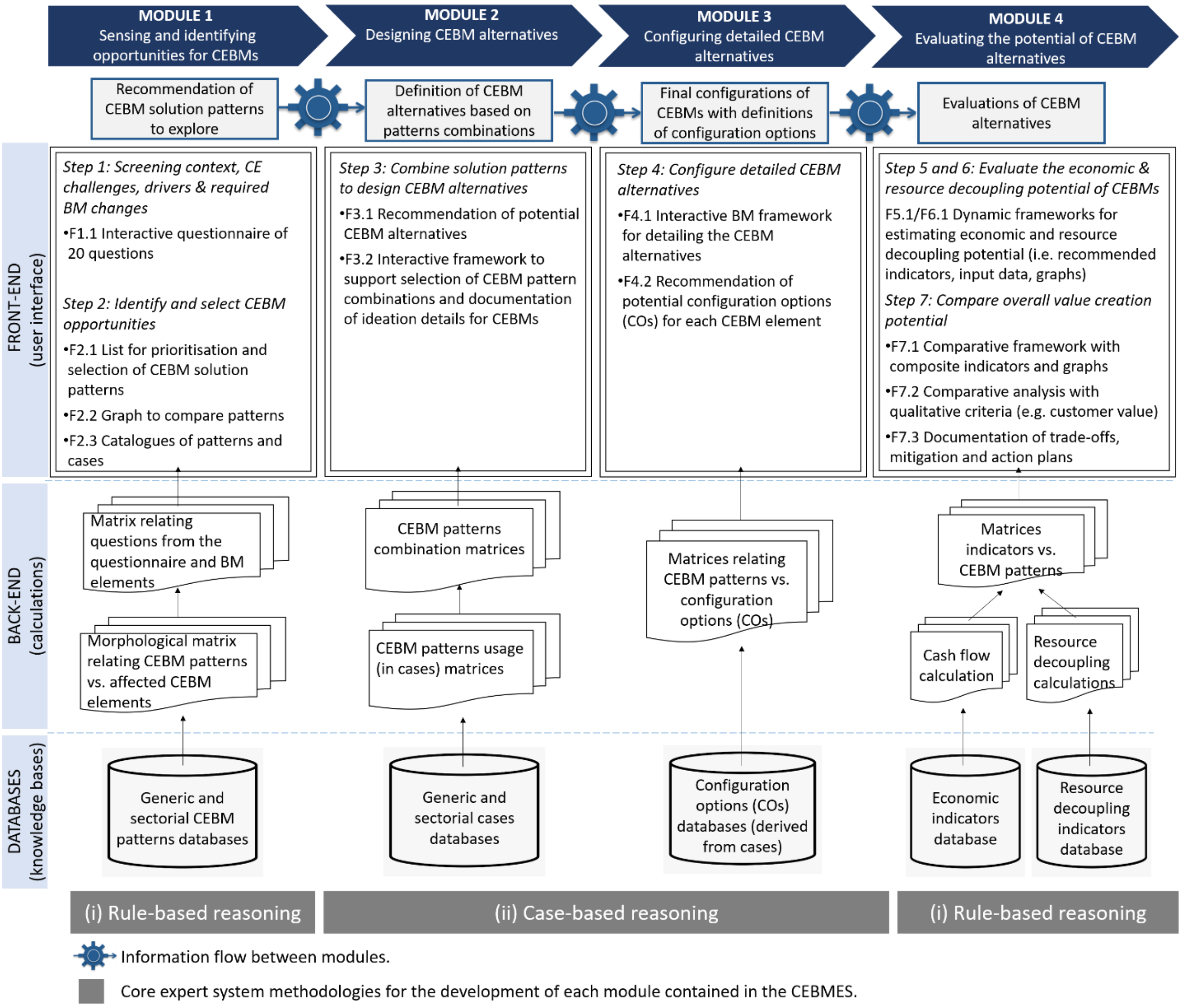

Figure 7 – Architecture of the CE Business Modelling Expert System (Legend: F – functionality /Source: Appended Publication 6).

### 3.5.2 Evaluation of the CEBMES high-fidelity prototype

Most *manufacturing companies* engaged in the evaluation of the CEBMES (Table 3 in section 3.4) perceived that it provided a logical sequence of steps that helped to design and mature CEBM configurations (details on Appended Publication 6). Most of the companies could only complete steps 1, 2, 3 and 4 of the CEBMES due to: (i) a need of further maturing the CEBM configurations with iterations of the process, or (ii) difficulties to obtain data to complete the evaluations of economic and resource decoupling potentials (i.e. focus of steps 5, 6 and 7). These companies perceived these initial steps as relatively easy to use. Only three companies were able to complete all steps, including steps 5, 6 and 7. These companies perceived the final steps (5-7) as difficult to go through, due to the very detailed level of information and the extensive requirements for quantitative data (e.g. for estimating economic and resource decoupling potentials).

Improvement opportunities identified by companies were documented to drive further development of the CEBMES in a more flexible platform (described in sections 5.2 and 5.3).

The evaluation of the CE Business Modelling Expert System **addressed the third research question[18] , and specifically, the sub-question 'd'[19]** by demonstrating how the developed expert system can fulfil the conceptual and practical requirements for CEBMn, as well as its usefulness and scope of application.

Regarding the *usefulness*, manufacturing companies highlighted several contributions of the CEBMES, such as that it:

- Served as 'a side consultant' for trained facilitators, providing inspiration and recommendations of CE business modelling practices in specific manufacturing sectors;
- Generated information that could populate interactive frameworks (e.g. cards, business model framework) suitable for group discussions and flexible to 'live changes';
- Enabled strengthening proposals of CEBM configurations before seeking for external funding or sponsors within the organisations;
- Enabled the confirmation of assumptions with a structured framework;
- Provided a logic structure that prompted decision-making and prioritisation, despite uncertainties of CEBM innovation;
- Provided a framework for accounting decisions.

Regarding the *scope of application*, the satisfactory use of the CEBMES by varied organisations points to its applicability to different manufacturing companies' sizes and sectors (see Appended Publication 6 for more details). Moreover, recurrent characteristics observed that could favour the application of the CEBMES were:

- Users were usually business developers, sustainability and product managers;
- Companies and users were willing to be trained to use the CEBMES independently;
- Companies and users were willing to trigger CE-thinking within their organisations (i.e. 'breaking industry recipes' (Matthyssens et al., 2006) and the silo/organisational-centric view); therefore, they were willing to engage a multifunctional team (e.g. sales, marketing, finances, procurement, manufacturing, operations and logistics, engineering and product design, business innovation, digital technologies, services operations or after-sales, corporate social responsibility);
- Companies had an existing scope (i.e. selected product or initial CEBM idea) for which they wished to strengthen proposals of CEBM configurations.

This collection of observations provided **evidence to sustain the fifth specific hypothesis (SH-5)** investigated in this research, confirming that *an expert system that provides advice for CEBM design and enables simulation of alternative CEBM configurations can enhance the application of the CEBMn process model within manufacturing companies*. Despite the collected evidence, further testing in other sectors within and beyond manufacturing (e.g. construction, service and extractive industries) is important to refine the boundaries of

[18] RQ3: How can an expert system be developed to provide advice to manufacturing companies to design CEBMs?
[19] RQ3-d: How to translate the requirements/ advice into a useful and applicable expert system?

application of the hypothesis (Gill and Johnson, 2002). Moreover, it is relevant to explore how the sequence of application of steps could vary depending on the contextual particularities of companies (e.g. maturity in CEBM innovation, intention to reconfigure existing BM or develop new CEBM, size of companies).

# 4 Discussion of Consolidated Results

This chapter synthetises the research findings by discussing how the key results presented in chapter 3 answer to the research questions (section 4.1). Moreover, it explains how the individual results compose the systematised framework for CEBMn, which is a vehicle to fulfilling the overall objective of this PhD thesis (section 4.2).

## 4.1 Answers to research questions

*RQ1: How to identify and* ***systematise*** *the existing approaches in academia and practice that can support business model innovation in the context of CE?*

In section 3.1, the available knowledge about CEBMI practices that emerged from 92 approaches was **systematised** and organised according to CEBMn stages (i.e. Sense, Seize and Transform) in the *database of CEBM innovation approaches [R1]*. The approaches and practices comprised by the database [R1] provided the foundations for the development of the CEBMn process model [R2], in terms of selected activities, expected deliverables, recommended tools, and decision gates. Moreover, the database [R1] can enable flexibility for the future applications of the CEBMn process model to different contexts (i.e. beyond sectors tested in this thesis), by acting as a pool of alternatives for approaches and practices. Lastly, the procedure demonstrated in the Appended Publication 1 for identifying and systematising the CEBMI approaches into the database, could be replicated with a certain frequency to maintain the database updated with state of the art literature and approaches.

*RQ2: How can a systematic process model be developed to* ***guide*** *CE business modelling within manufacturing companies?*

In section 3.2, the development of the *CEBMn process model [R2]* was presented. The process model provides **guidance** to manufacturing companies about what they should do to execute CE business modelling. This is achieved through a holistic structure that recommends systematised managerial practices for CE business modelling from design to implementation (i.e. Sense, Seize and Transform). The practices include, for example, suggested activities and tools that were adapted or improved from the database of CEBM innovation approaches [R1], and guidelines for using the CEBMn process model [R2]. The procedure presented in the Appended Publication 2 demonstrates how the CEBMn process model [R2] was developed and tested by combining systematised literature (from R1) with practical insights obtained from action research and case studies with manufacturing companies. This procedure could be reproduced for the future applications of the CEBMn process model [R2] to different contexts (i.e. beyond sectors tested in this thesis).

*RQ3 - How can an expert system be developed to provide* ***advice*** *to manufacturing companies to design business models for CE?*

To provide specific **advice** to manufacturing companies and support the execution of the CEBMn process [R2], three main tools were developed and presented in sections 3.3, 3.4 and 3.5. They support different stages of the CEBMn process (i.e. Sense, Seize and Transform).

*CEBM archetypes [R3]* were used to inspire the design of CEBM ideas during stage Sense. They served as a stepping-stone in the conceptualisation of the *systematised framework for CEBMn* (explained in section 4.2), since companies requested a different type of support with more contextualised advice after testing the CEBM archetypes [R3]. Hence, the CEBM archetypes (R3) were substituted by the sectorial CEBM patterns [R4].

The *sectorial CEBM patterns [R4]* are more comprehensive, specialised and sophisticated than the CEBM archetypes [R3], providing advice about how to design and configure CEBMs for specific sectors (i.e. furniture; electrical/electronic equipment/appliances; heavy machinery; medical devices/equipment; textile/apparel and food) during the stages Sense and Seize of the CEBMn process [R2]. Instead of providing only a list of CEBM possibilities, the patterns comprise **specific and versatile advice** about their relationships and combinations. However, they lacked a flexible and useful means to enable the presentation of advice to companies.

Hence, activities and tools (i.e. templates) from the CEBMn process model [R2] were combined with CEBM patterns [R4] into the *CE business modelling expert system [R5]*, which offers varied types of **advice** along the whole CEBMn process [R2]. Beyond supporting the stages Sense and Seize with recommendations of selection and combination of specific CEBM patterns [R4] for companies, the CEBMES can support the stages Seize and Transform with estimations of the CEBMs' potential for creating value decoupled from resource consumption.

Figure 8 illustrates the relationships between the five key results and their contributions to answering the research questions. The overall *systematised framework for CEBMn*, composed by the combination of some of the individual results, is explained in section 4.2.

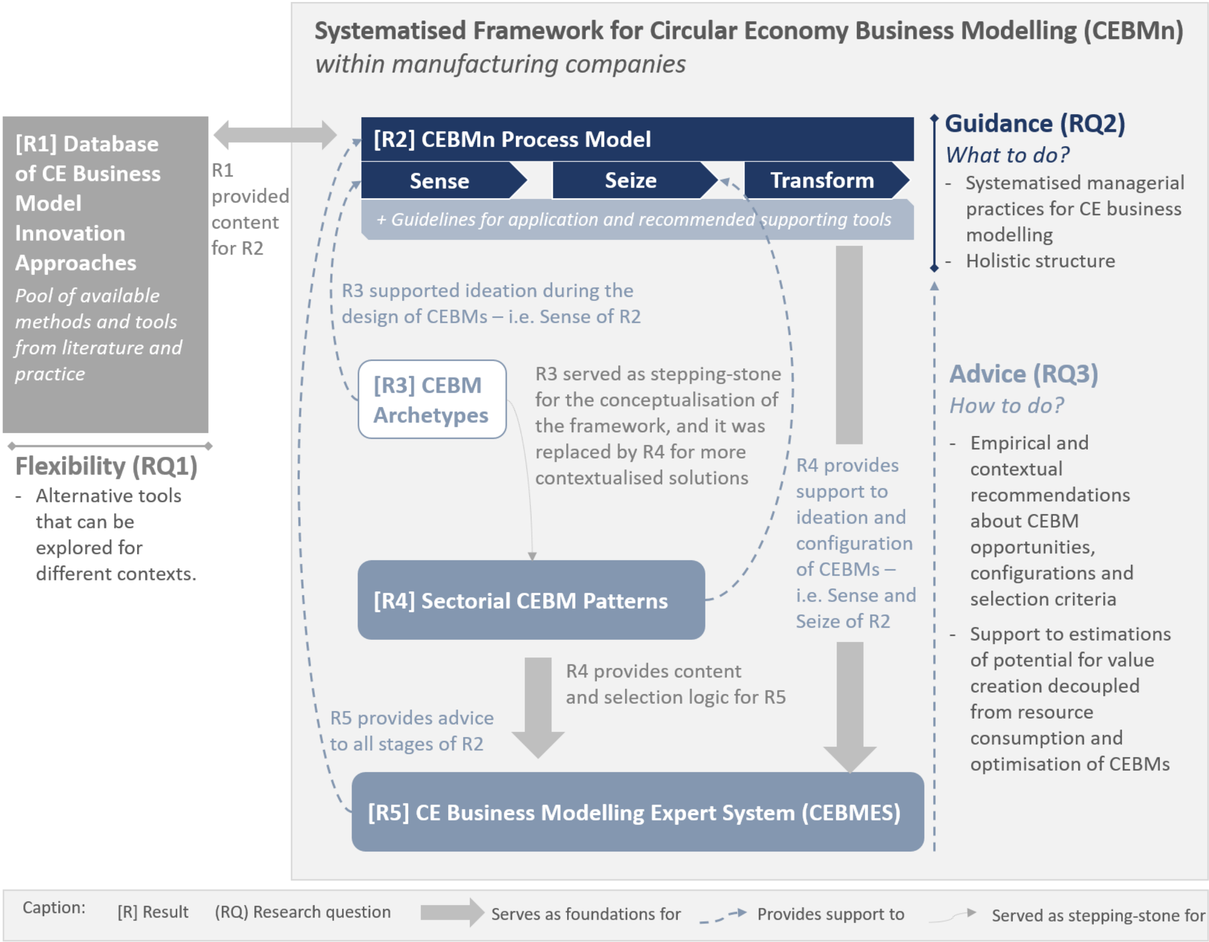


Figure 8 – Consolidated result of the PhD thesis.

## 4.2 Systematised framework for CE business modelling

On top of the five individual results (R1-R5), this PhD proposes a combination of three main results in a **systematised framework for CE business modelling (CEBMn)** (illustrated in Figure 8): *the CEBMn process model [R2]*, the *sectorial CEBM patterns [R4]* and the *CE business modelling expert system [R5]*.

The CEBMn process model [R2] offers structured **guidance** through a systematic approach that is useful for manufacturing companies that have the ambition to transition their BMs to CE or that already have a CEBM idea but lack the overall picture of how to mature it and demonstrate the economic and resource decoupling potential to encourage its dissemination, communication and implementation.

Complementarily, the CEBM patterns [R4] and the CE business modelling expert system [R5] offer **advice** and a way to safeguard and prompt CE practices during the business modelling process execution, avoiding linear biases and informing about possible market trends based on benchmarking with success cases of CEBMs in manufacturing industries. The CE business modelling expert system [R5] enables pre-fill logics for the companies, which takes them beyond the workshop level (i.e. a 'sticky-notes' stage) and encourages them to move forward in evaluating the CEBMs and planning for experimentation and implementation (Bocken et al., 2019; Pieroni et al., 2019a). With this, the CE business modelling expert system [R5] presented potential to be used as a 'side consultant' for

CEBMn, which can inspire companies with new ideas and endorse design choices to achieve business models with potential to create and capture more value for CE.

Based on the three aforementioned elements, the framework offers a complementary perspective about *what are the steps required for designing business models for CE (guidance)* and *how to execute those steps to achieve reasonable CEBMs that have a potential for economic and resource decoupling gains simultaneously (advice)* (indicated on the right side of Figure 8).

The systematised framework for CEBMn represents the main vehicle to tackle manufacturing companies' challenges and to fulfil the objective of this PhD thesis, which is *to develop a systematised framework to provide **guidance** and **advice** for managers to design business models for CE within manufacturing companies.*

# 5 Conclusion

## 5.1 Research contributions

This PhD thesis was driven by the challenge faced by manufacturing companies in transitioning their businesses to promote value creation decoupled from resource consumption as a way of contributing to circular economy. The research was motivated by a core gap found in the literature of circular economy business model innovation: *the lack of a systematised framework able to provide guidance and advice to manufacturing companies for the design of business models* for *circular economy.*

Based on this gap, a design research methodology was applied with a set of methods (e.g. systematic literature review, action research, case studies, expert validation) and engaging seventeen manufacturing companies and seven academic experts with the objective of *developing a systematised framework to provide guidance and advice for managers to design business models for circular economy within manufacturing companies.*

The core contribution presented by this PhD thesis is the *systematised framework to support circular economy business modelling,* which comprises three elements (Figure 8 in chapter 4):

- a holistic *process model* with operational and institutional/strategic practices recommended for CE business modelling with accompanying guidelines for its application and recommended tools;
- *business model patterns* to support focused ideation and specialised configuration of business models for CE through sectorial-driven insights;
- a *high-fidelity prototype expert system* to support the application of the process model in manufacturing companies with proactive advice for CE business modelling.

The theoretical research and empirical application of the systematised framework within seventeen manufacturing companies answered the three research questions (documented in section 4.1). Additionally, they enabled the collection of evidence that sustains the overall research hypothesis. For instance, most companies were successful in applying the CEBMn process model (section 3.2) and the CE business modelling expert system (section 3.5). This indicates the potential usefulness and applicability of the systematised framework for CEBMn to manufacturing companies from different sizes (i.e. SMEs and large) and sectors (i.e. heavy machinery, electrical/electronic equipment/appliances, furniture). Moreover, the potential of the elements of the systematised framework for CEBMn in supporting the implementation of CEBM pilots was demonstrated through the studies with manufacturing companies (section 3.2), which points to the usefulness of the presented results. Hence, this research supports the overall hypothesis that *the systematisation of a framework for CE business modelling can provide useful and applicable guidance and advice for the design of business models with enhanced circularity potential*.

The results presented in this PhD thesis lead to a series of specific contributions to knowledge and practice, as detailed in sections 5.1.1 and 5.1.2.

### 5.1.1 Scientific contributions to knowledge

From an academic perspective, this PhD thesis has contributed to CEBM innovation literature by systematising approaches and practices in *a database* and a *process model* that go beyond available comparable works in the literature and answering to calls for holistic support for the strategic management of CEBM innovation through (Bocken et al., 2019; Khan et al., 2020; Ünal, Urbinati and Chiaroni, 2019):

- Coverage of all CEBM innovation stages (i.e. from sensing opportunities, seizing viable CEBMs, and transforming the organisation to implement the CEBMs);
- Consideration of links with other business processes (e.g. product development; sales; procurement);
- Inclusion of activities and tools that prompt considerations for improving the sustainability performance of CEBMs;
- A formalisation of procedures for decision-support, thereby prompting and guiding companies in balancing core organisational objectives with CE objectives;
- Recommendation of behaviours, mindset and attitudes that can act as catalysers for CEBM innovation.

Moreover, the PhD thesis contributed to systematising, organising and developing knowledge for action in CE by providing (Kirchherr and van Santen, 2019; Lüdeke-Freund, Bohnsack, et al., 2019):

- Consolidation and structuring of *CEBM archetypes* according to a framework that highlights the nature of CE value generation (i.e. downstream and upstream architecture, and the type of value delivered, created or captured) (Urbinati et al., 2017);
- A useful and novel *CEBM pattern* structure, language, and recommendations for combination, which strengthen discussion at the required level of granularity for implementation of CEBMs by focusing on purpose and sectorial contextualisation (Lüdeke-Freund, Bohnsack, et al., 2019; Wells, 2016);
- A clear procedure for the *continuous development of CEBM patterns* and potential to expand to other sectors;
- Identification of requirements, deployment of functions and definition of an architecture (i.e. front-end, back-end and databases levels of information) for a novel *expert system* able to provide advice for manufacturing companies regarding CEBMs design and evaluation.

### 5.1.2 Contributions to practice

In addition to the contributions to knowledge documented in the six Appended Publications, this PhD thesis has contributed to practice and industry in diverse sectors (e.g. furniture, heavy machinery, electrical/electronic equipment/appliances, textile, medical devices, agriculture and food). The first contribution was the systematised framework to guide (with a *process model*) and advice (with an *expert system*) manufacturing companies in circular economy business modelling. The application by manufacturing companies engaged in this research demonstrated that the framework could help companies to:

- Strengthen and mature existing CEBM ideas into viable and implementable configurations;

- Embrace ambiguities by pushing participants to come to decisions even when uncertainties were high;
- Deal with the complexity of CEBM innovation and CEBMs by pondering economic and resource efficiency gains;
- Organise results and business proposals to help dissemination and implementation (e.g. education of employees, communication with suppliers and investors).

Moreover, the systematised framework helped some of the manufacturing companies by providing a source of inspiration for best practice CEBMs in multiple sectors (with *CEBM patterns*), which:

- Prompted the discovery of new ideas for CEBMs that companies had not previously anticipated (especially for SMEs);
- Stimulated the adoption of CEBMs with larger impact, which can help companies to sustain value creation while promoting resource decoupling.

Finally, concrete results were observed within the seventeen manufacturing companies engaged in this research through the action research and case studies, such as:

- Increased knowledge about CEBM opportunities and configurations was observed within these companies;
- Increased level of articulation about CE business modelling was noted, which resulted in their accomplishment of CEBM proposals accompanied by estimations of economic and resource decoupling potentials and concrete plans for improving or implementing the CEBMs;
- Some companies were even able to advance in the implementation of CEBM pilots, engaging customers, collaborating with current and new partners across value chains, and even establishing a spin-out company to scale up the designed CEBMs.

## 5.2 Limitations

Specific limitations for each result of this PhD thesis are detailed in the appended publications. In this section, the overall limitations of the consolidated research result (i.e. the systematised framework for CEBMn) are discussed.

From the perspective of industry, a limitation is a gap between the particular challenges of each manufacturing company (i.e. particular needs of a specific customer segment, varied intentions and ambitions with CE) and the proposed systematised framework for CEBMn, which aims to be comprehensive for coping with varied CEBM configurations that can address different companies' contexts within specific manufacturing sectors. Achieving a balance in the levels of specificity and details was challenging. The framework (i.e. mainly through the CE business modelling expert system) goes one step further in specificity than previous approaches since it provides sectorial recommendations. However, these recommendations are not too detailed regarding other specificities (e.g. needs of B2B versus B2C) as an intent to be applicable to several companies within a specific sector, and potentially reaching a larger volume of users. The choice of prioritising enhanced specificity in the sectorial perspective poses another limitation for the expert system dissemination, restricting its applicability to certain sectors in the current version presented in this research. A vision for tackling this limitation to roll out the expert system to other sectors is discussed in the next section 5.3.

## 5.3 A vision for rolling out the systematised framework for CEBMn

A noteworthy interest from industry in the systematised framework for CEBMn was observed during its application with manufacturing companies engaged in this research. The framework's potential was acknowledged not only by industrial experts but also by academic experts involved in the evaluations, and by consulting companies that had contact with the framework in dissemination workshops of the research project CIRCit (explained in the Preface). Therefore, its broader dissemination and rollout to industry is recommended.

However, before steering the rollout, the implementation of improvements recommended by companies and academic experts to refine the framework deserves further attention. Moreover, testing of the framework to refine the boundaries of its applicability is needed with more companies within specific manufacturing sectors (especially the ones with limited coverage in the empirical studies of this thesis, e.g. textile, medical devices, agriculture and food) and beyond manufacturing sectors (e.g. services, construction, raw materials extraction). Simultaneously, further development of supplementary materials that can complement the user guidelines presented in Publication 12 is needed (e.g. video tutorials, course material, adaptations for application).

The focus of enhancements and testing should be on two elements of the systematised framework. Starting with the *CEBM patterns*, enhanced precision in the descriptions of context and CE problems, as well as enhanced consistency for the definition of configuration options for different CEBM elements are needed in specific sectors (e.g. heavy machinery, electrical/electronic equipment/appliances). Moreover, the collection of CEBM patterns should be simplified to avoid overlapping in some sectors, and additional configuration options and exemplary cases should be explored to refine the collections (e.g. agriculture and food). Regarding the exploration of additional cases, an automated procedure based on the methodology discussed in section 3.4 and Appended Publication 4 should be developed to enable continuous update of the CEBM cases database. This would transform the CEBM patterns database into a dynamic growing and adaptable repository of practices, clearly reflecting developments in the field and sectors.

The automation of the maintenance procedure for the CEBM patterns database could be optimised when combined with further research regarding the second focus element, which is the *CE business modelling expert system*. A web-based platform should be developed to enhance the usability of the expert system by manufacturing companies. The expert system could use artificial intelligence to source cases from varied sectors and update the economic and resource decoupling indicators according to reliable and specialised online databases, enabling quick adaptations to different sectors. Moreover, the web-based version of the CEBMES should explore and enhance the flexibility of recommendations according to multiple contextual aspects of companies (e.g. type of customer segment or strategic intention for CEBMn and CEBM innovation). Simultaneously, it should introduce more specific selection criteria in the early stage of design to support companies in identifying and deprioritising BM ideas that seem promising from an economic point of view but present a limited potential for resource decoupling.

Beyond enabling enhanced flexibility for applicability in different contexts, the web-based version of the expert system could allow integration and alignment with other strategic management practices and systems within companies, such as higher-level sustainability frameworks (e.g. sustainability performance assessments; Sustainable Development Goals) or portfolio management of strategic projects.

## 5.4 Future research avenues

Several opportunities for future research were identified during this research. This section provides a vision for promising research avenues that could span from the results presented by this PhD thesis.

CE business modelling from the ecosystem perspective

One area that could benefit from further exploration is the engagement of external actors from the business ecosystem into the CE business modelling process. Much of the existing research on CE business model approaches focus on single companies' perspectives. This research showed that the perspective of collaborations was fundamental to enable the design and mainly the implementation of CEBMs. Manufacturing companies that were successful in implementing CEBM pilots either had to proactively engage and steer their suppliers and customers to change their own BMs or they had to find or create new entities (i.e. spin-out) across value chains. Hence, a future research question worth exploring is: how can manufacturing companies boost the performance of CE business modelling and the subsequent implementation of CEBMs through an ecosystem perspective (i.e. joint design of business models within the ecosystem)?

Overcoming external barriers and scaling CEBMs

Pivoting solutions to overcome external barriers that appeared during the implementation of CEBMs was fundamental. A potential opportunity for future research consists of systematically exploring and expanding possible actions that can support companies to foresee and act proactively to overcome barriers and scale-up CEBMs. Examples of research questions to trigger this exploration could be: How to enable scaling and increased market acceptance of different CEBM types beyond niche markets to enable a higher and systemic impact for resource decoupling? How can uncooperative customers be convinced to adopt the CEBM solutions? How can inexistent actors or roles in the value chain be developed? How to deal with certain types of restrictive legislations?

Measuring circularity improvement

Another related subject is the monitoring of circularity improvement during and after the scaling and implementation of CEBMs. Existing research on business model innovation lacks quantitative evaluation or assessment of BMs performance in respect to circularity (and its link to sustainability). The calculators embedded in the CE business modelling expert system (section 3.5) for the measurements of economic and resource decoupling gains based on the calculation of different indicators according to specific CEBM configurations are an initial attempt or demonstration of how to estimate the circularity potential of business models. The selection and eventual aggregation of indicators to measure the circularity level of CEBMs could be further explored and spanned beyond the estimation of CEBM proposals' potential, to be applied during and after the implementation of CEBMs. A research question to guide the exploration is: How to track the circularity performance improvement during and after the implementation of CEBMs?

Dynamic capabilities and maturity in CE business model innovation

Another topic that could be further explored is related to conducive dynamic capabilities to enhance CEBM innovation and CE business modelling performance and maturity within manufacturing companies. Research about the interface of CEBMI and dynamic capabilities is still scant. Limitations in dynamic capabilities impair the execution of the CEBMn process and the effectuation of resulting CEBMs. Especially for large organisations, a short-term orientation for business results and the need for certainty in facts and information hampered their exploration of BM possibilities that could concretely disrupt the linear dogma. Further research could explore how the development of dynamic capabilities for CEBMI can occur concomitantly or even previously to the execution of CE business modelling processes and to what extent this could boost the results of the process and the circularity potential of the proposed CEBMs. Possible research questions to explore are: How can companies assess and develop dynamic capabilities to boost their CEBM innovation performance and maturity? How can maturity/proficiency in CEBM innovation affect the circularity potential of companies' BMs?

## 5.5 Final remarks

The research presented in this PhD thesis has provided a critical view of how a systematised framework of managerial practices for CE business modelling can provide guidance and advice to manufacturing companies. While acknowledging the potential of such a systematised framework to enhance the capabilities of companies in designing and foreseeing the viability and feasibility of CE business models, this thesis has also highlighted the complexity of fully realising the potential of such a framework. For the manufacturing industry, the widened adoption of CE business models is not 'a given', even when it 'feels as' the right choice.

This thesis has shown that the readiness of manufacturing companies to design and implement CE business models will not improve without challenges. Several conditions need to be in place to encourage manufacturing companies to dare to change and to disrupt the existing linear roots. For example, knowledge and adequate support to spot the potential for long-term economic value decoupled from resource consumption; conducive dynamic capabilities from decision-makers and investors; or availability of funding. However, if CE is expected to continue to play a major role in realising the ambitious targets for sustainable development in our society (e.g. European Green Deal, Sustainable Development Goals), a new strategic way of thinking and doing business for CE needs to become a reality as soon as possible. The main results of this PhD thesis, i.e. the systematised framework for CEBMn and in particular the CE business modelling expert system, represent a concrete proposal to steer manufacturing companies in the direction of CE-thinking, by providing knowledge and adequate support for CEBMn.

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# Appendix A – Detailed research activities

This section provides an overview of the activities executed to deliver the results (R1-R5) of this PhD thesis. Figure A1 summarises how the DRM stages and methods contributed to achieving the individual key results (presented in chapter 0).

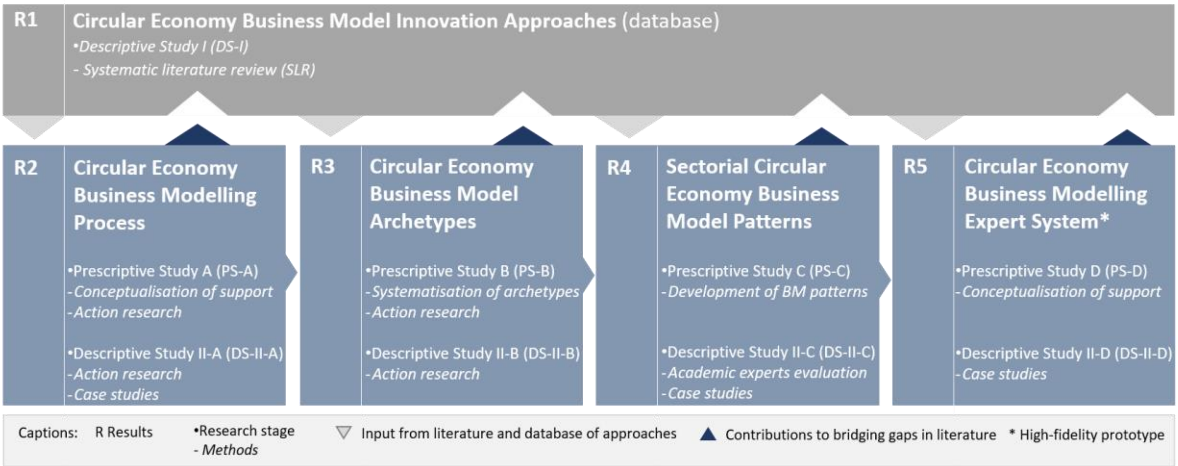


Figure A1 – Overview of research stages and methods to deliver the key results (R) presented by the PhD thesis.

## 1. R1 – Circular Economy Business Innovation Approaches

The first result was obtained with the execution of Descriptive Study I (DS-I) and included the activities (documented on **Appended Publication 1**):

1.1 *Do a* *<u>systematic literature review (SLR)</u>* (section 2.2.1) of academic and grey literature about sustainability and circular economy business model innovation, including the steps:

1.1.1 Data collection:

- Search in Scopus and Web of Science;
- Backward snowballing with cross-referencing (Wohlin, 2014);
- Search in grey literature  to include practitioners' publications (e.g. the Ellen MacArthur Foundation World Business Council for Sustainable Development) (Adams et al., 2017; Tranfield et al., 2003);
- Evaluation and selection of publications based on inclusion criteria;

1.1.2 Data analysis and reporting:

- Application of content analysis and coding techniques (Dresch et al., 2015) to organise the retrieved approaches according to:
    - three stages of business model innovation based on the dynamic capabilities framework (Teece, 2007):
        (i) *Sense*: identification of opportunities and generation of business model ideas (i.e. abstract and frequently focused on some core elements that describe a BM) ;
        (ii) *Seize:* design and testing of new business model configurations (i.e. detailed description of all elements of a BM and their relationships, allowing evaluations of economic and resource decoupling potentials);

(iii) *Transform:* building new capabilities and implementation of organisational change.

- three groups of characteristics to enable their comparison and documentation in the database:
  (i) Data nature;
  (ii) Characteristics of the business model approach, including boundaries of analysis, level of abstraction, and time-related view; and,
  (iii) Representation style.

The main result was (Figure A2):

*R1: Database of 92 approaches (i.e. conceptual frameworks, methods and tools) for CE business model innovation (presented in section 3.1).*


Figure A2 – Methods and research stages to achieve R1.

## 2. R2 – Circular Economy Business Modelling (CEBMn) Process

The second result was obtained with the execution of PS-A and DS-II-A and comprised the activities (documented on **Appended Publication 2**):

<u>Prescriptive Study A (PS-A)</u>

2.1 *Theoretical development and <u>conceptualisation</u> of the CEBMn process model (v1)* (research method is presented in section 2.2.4), including the steps:

2.1.1 Consolidation of database including process models, potential supporting tools, and development requirements for CEBMn approaches;

2.1.2 Comparison of process models and unification of stages, representation style, and elements (i.e. activities, deliverables, tools, decision gates, and change enablers);

2.1.3 Organisation of elements according to business modelling process stages – i.e. Sense, Seize and Transform (Teece, 2007);

2.1.4 Prioritisation of supporting tools according to development requirements for CEBMn approaches – i.e. this was necessary to minimise overlap and enable empirical application as more than 115 tools were identified in step 2.1.1.

2.2 *Empirical development based on <u>action research (AR)</u>* (research method is presented in section 2.2.214) to refine the core functionalities of the process model (v.1), *s*ince many of the approaches identified in the catalogue that emerged in activity 2.1 were still not thoroughly tested (Bocken et al., 2019; Pieroni et al., 2019a). It comprised the steps:

2.2.1 Diagnosing:

- Definition of the practical research problem;

- Selection of Nordic manufacturing companies to participate in the study (Table 2 in section 3.2) –varied sectors and company sizes were considered to explore the contextual implications and application boundaries of the process model (Ünal, Urbinati and Chiaroni, 2019);

2.2.2 Planning and taking action:

- Application of the process model, its activities and tools in the selected companies with a series of workshops and organised in two phases:
  - Phase I: use of the process model (v.1) in two companies (A and B). Modifications based on the identified improvement opportunities were incorporated into the process model for the test in subsequent AR cycles.
  - Phase II: a revised version of the CEBMn process model (v.2) was applied with two additional companies (C and D).

2.2.3 Evaluating action:

- Collection and analysis of data through triangulation with four data sources to enhance reliability and reduce the risk of bias (Gill and Johnson, 2002; Yin, 2011):
  (i) journal with researchers' observations and post-reflections (different researchers whenever possible as an additional measure to reduce bias);
  (ii) recordings with verbal feedback;
  (iii) results of the process model application; and,
  (iv) standardised questionnaires answered by participants in companies, with a combination of Likert-scale and open-ended questions, which measured the satisfaction level of participants with the (i) structure and activities, (ii) tools, and (iii) results of the process model;
- Identification and documentation of improvement opportunities for the process model (both for Phase I and Phase II);
- Assessment and incorporation of improvements into the final version of the CEBMn process model (v.final).

Descriptive Study II-A (DS-II-A)

2.3 *Evaluation of the CEBMn process model for the stages 'Sense' and 'Seize' based on action research cycles for theory testing* (section 2.2.2), comprising the steps:

2.3.1 Diagnosing:

- Engagement of additional three Nordic manufacturing companies from the previously selected sample (E, F and G in Table 2 in section 3.2);

2.3.2 Planning and taking action:

- Application of the CEBMn process model (v.final) in three AR cycles with the selected companies;

2.3.3 Evaluating action:

- Collection and analysis of data through triangulation with four data sources (same methods for triangulation as in step 2.2.3);
- Development of guidelines in the format of a workbook for the application of the CEBMn process model;

- Identification and documentation of improvement opportunities for some of the tools accompanying the process model, as well as key insights and hypotheses for further research (see studies B, C and D).

2.4 *Evaluation of the CEBMn process model for the stage 'Transform' with <u>case studies</u>* (section 2.2.3), comprising the steps:

2.4.1 Cases selection:

- Engagement of a set of companies that had participated in the AR cycles (B, C, D, E, F, and G in Table 2 in section 3.2) to enable monitoring the 'Transform' stage;

2.4.2 Data collection:

- Preparation of the interview protocol (see Appendix B) to explore retrospectively:
    - (i) the application of the stage 'Transform' in the real organisational settings;
    - (ii) the usefulness of the process model in supporting the implementation of the proposed CEBMs;
    - (iii) influencing factors that could affect the application and outcomes of the implementation of CEBMs, such as:
      (a) Level of experience of companies in CE implementation;
      (b) Engagement of multiple functional areas and senior decision makers;
      (c) Degree of openness to change and risk aversion;
      (d) Existence of a favourable infrastructure and practices (i.e. governance model with the ecosystem of stakeholders; performance management system); and,
      (e) Presence of external barriers and enablers.
      Factors 'a, b, c, and d' were identified from the SLR carried in the DS-I, and factor 'e' was deployed from three publications about barriers and enablers for CEBM innovation (Guldmann and Huulgaard, 2020; de Jesus and Mendonça, 2018; Kirchherr et al., 2018).
- Structured interviews with selected companies' participants after the application of the stage 'seize' of the CEBMn process model (see Table 2 in section 3.2);

2.4.3 Data analysis:

- Consolidation and analysis of the answers collected in the interviews;
- Identification of insights, common barriers and enablers, and improvement opportunities for the stage 'Transform' of the CEBMn process model.

The main result was (Figure A3):

*R2: CEBMn process model and accompanying guidelines for its application (presented in section 3.2).*

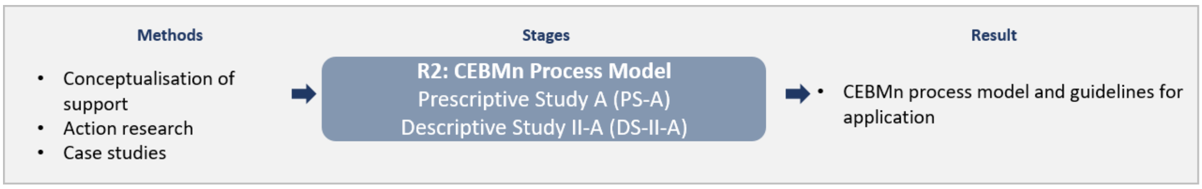


Figure A3 – Methods and research stages to achieve R2.

## 3. R3 – Circular Economy Business Model (CEBM) Archetypes

The third result was obtained with the execution of stages PS-B and DS-II-B, and comprised the activities (documented on **Appended Publication 3**):

<u>Prescriptive Study B (PS-B)</u>

3.1 *Theoretical development and <u>systematisation of CEBM archetypes</u> and typology framework* (section 2.2.5), comprising the steps:

- 3.1.1 Identification of CEBM archetypes from the database of approaches (R1) and complemented by approaches from another literature review (Rosa et al., 2019);
- 3.1.2 Documentation of CEBM archetypes according to four characteristics - i.e. (i) label, (ii) description, (iii) case examples and (iv) source of resource decoupling;
- 3.1.3 Comparison and consolidation into a unified typology - i.e. set of archetypes.

3.2 *Empirical development of the CEBM archetypes based on <u>action research</u>* (section 2.2.2), comprising the steps:

3.2.1 Diagnosing:

- Engagement of three Nordic manufacturing companies previously selected (B, C and D in Table 2 in section 3.2);
- Development of a deck of cards representing the CEBM archetypes based on design heuristics (Daly et al., 2012; Leahy et al., 2018);
- Development of guidelines to enable the use of the archetypes during the application of the CEBMn process model in the AR cycles;

3.2.2 Planning and taking action:

- Application of the CEBM archetypes in three AR cycles with the selected companies, until the level of saturation in the identification of new improvement opportunities, was reached;

3.2.3 Evaluating action:

- Collection and analysis of data through triangulation with four data sources (similar to step 2.2.3):
  - Questionnaire for the evaluation of the archetypes focused on the satisfaction level of the participants regarding (i) usefulness of results; and (ii) applicability of the card deck;
- Identification and documentation of improvement opportunities for the CEBM archetypes;
- Assessment and incorporation of improvements into the final version of the CEBM archetypes (v.final).

<u>Descriptive Study II-B (DS-II-B)</u>

3.3 *Evaluation of the CEBM archetypes based on <u>action research cycles for theory testing</u>* (section 2.2.2), comprising the steps:

3.3.1 Diagnosing:

- Engagement of additional three Nordic manufacturing companies from the previously selected sample (E, F and G in Table 2 in section 3.2);

3.3.2 Planning and taking action:

- Application of the CEBM archetypes (v.final) in three AR cycles with the selected companies;

3.3.3 Evaluating action:

- Collection and analysis of data through triangulation with four data sources (same methods for triangulation as in step 2.2.3);
- Identification and documentation of improvement opportunities for the CEBM archetypes, as well as key insights and hypotheses for further research (studies C and D).

The main result was (Figure A4):

*R3: A set of 20 systematised circular economy business model (CEBM) archetypes and an accompanying typology framework (presented in section 3.3).*

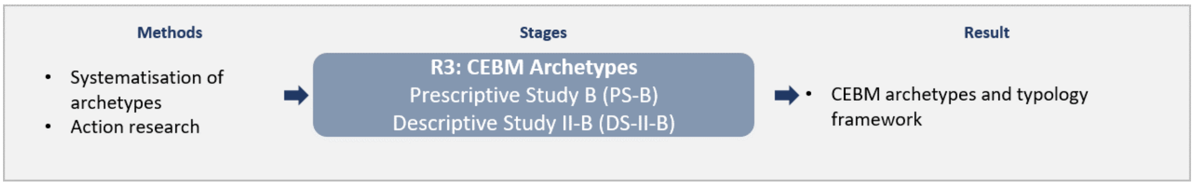


Figure A4 – Methods and research stages to achieve R3.

## 4. R4 – Sectorial Circular Economy Business Model (CEBM) Patterns

The fourth result was obtained with the execution of stages PS-C and DS-II-C, and comprised the activities (details on **Appended Publication 4**):

Prescriptive Study C (PS-C)

4.1 *Execute the development of sectorial business model patterns for CE* (section 2.2.6), comprising the steps:

4.1.1 Selection of six manufacturing sectors (Table A1) – i.e. to explore their contextual particularities;

4.1.2 Identification and documentation of more than 180 CEBM cases from secondary sources - i.e. Ellen MacArthur Foundation (EMC) and the Circle Economy databases;

4.1.3 Proposition of a framework to represent the CEBMs – i.e. based on three frameworks identified through systematic literature review in R1 (Biloslavo et al., 2018; Kraaijenhagen et al., 2016; Urbinati et al., 2017);

4.1.4 Analysis and characterisation of CEBM cases with the support of the CEBM framework (step 4.1.3) with the detailing of variables (i.e. levers for active BM design) and configuration options (i.e. alternatives for a BM variable);

4.1.5 Application of multi-dimensional scaling analysis (MDS) (Amshoff et al., 2015; Borg and Groenen, 2005) to cluster repeating configuration options (i.e. CEBM patterns) and to identify the CEBM pattern maps for each sector;

4.1.6 Documentation of CEBM pattern catalogues for each sector;

4.1.7 Identification of combination matrices, defining the recommendation of CEBM patterns and their likelihood of combination for each sector;

4.2 *Development and pre-testing of a low-fidelity prototype with company E (Table 2 in section 3.2) to enable the application of the CEBM patterns by companies during DS-*

*II-B* (Table 3 in section 3.4). These results are fully documented on Appended Publication 5.

Table A1 – Cases per sector.

| Manufacturing sectors | Number of cases |
|---|---|
| Electrical and electronic equipment and appliances | 30 |
| Furniture | 42 |
| Heavy machinery | 25 |
| Medical devices and equipment | 16 |
| Textile and apparel | 39 |
| Agricultural and food products | 36 |

<u>Descriptive Study II-C (DS-II-C)</u>

4.3 *Evaluation of the sectorial CEBM patterns by <u>academic experts</u>* (section 2.2.7), comprising the steps:

4.3.1 Selection of seven academic experts (profile of experts detailed on the supplementary file available in Appendix F):

- Expertise in varied topics: (i) business model innovation; (ii) circular economy and sustainability; (iii) product-service/systems and servitisation (i.e. relevant for the reconfiguration of the downstream architecture of CEBMs); and (iv) reverse logistics and operations (i.e. relevant for the reconfiguration of the upstream architecture of CEBMs);
- Expertise in two industry sectors that were comprised by the expert system – i.e. heavy machinery and electrical/electronic equipment/appliances. These sectors required further exploration due to the limited coverage or representation by companies during action research cycles.

4.3.2 Evaluation:

- Introduction meeting and distribution of 7-8 CEBM patterns to each expert based on their expertise (i.e. topics and sector);
- Individual evaluation and reply to evaluation forms (available in Appendix C);
- One-on-one interviews to clarify and confirm the interpretations of the researcher regarding the feedback provided by experts;

4.3.3 Analysis of the evaluations:

- Identification and documentation of insights and improvement opportunities for the CEBM patterns.

4.4 *Evaluation of the sectorial CEBM patterns with <u>case studies for theory testing</u>* (section 2.2.3), comprising the steps:

4.4.1 Cases selection:

- Selection of Northern European manufacturing companies from varied sectors (Table 3 in section 3.4) and limited experience in CE;

4.4.2 Data collection:

- Development of structured questionnaires containing a combination of Likert-scale and open-ended questions to evaluate 7 criteria for the CEBM patterns (details on Appended Publication 4);
- Demonstration of the low-fidelity prototype developed for the CEBM patterns in a webinar for training the selected companies;

- Independent application of the CEBM patterns with the prototype by the companies chosen to support their CEBMn activities within six weeks;
- Interview to explore the feedback from companies and collect resulting documents;

4.4.3 Data analysis:

- Consolidation and analysis of the collected data (from the questionnaires, documents and interviews), including:
  - *Histograms with quantitative data* to show the performance of the CEBM patterns;
  - *Content analysis and clustering of qualitative data* (Dresch et al., 2015) (i.e. questionnaire and comments from interviews).

The main result was (Figure A5):

*R4: 208 circular economy business model patterns for six manufacturing sectors (i.e. food; textile and apparel; furniture; electrical and electronic equipment and appliances; medical devices and equipment; and heavy machinery) (presented in section 3.4).*

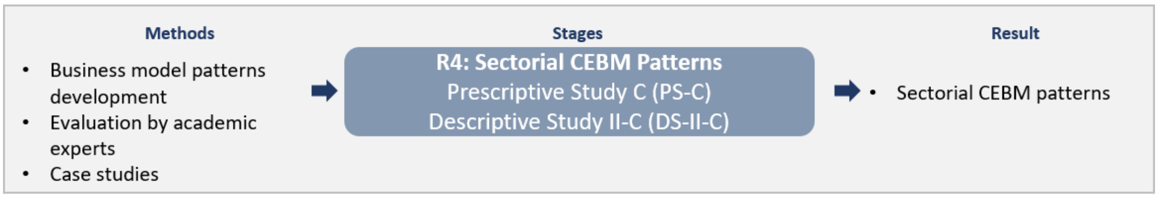


Figure A5 – Methods and research stages to achieve R4.

## 5. R5 – Circular Economy Business Modelling Expert System (CEBMES)

The fifth result was obtained with the execution of stages PS-D and DS-II-D, with the activities (complete details on **Appended Publications 5 and 6**):

<u>Prescriptive Study D (PS-D)</u>

5.1 *<u>Conceptualisation</u> of the circular economy business modelling expert system (CEBMES)* (section 2.2.4), comprising the steps:

5.1.1 Identification of requirements for the expert system:

- Identification of conceptual requirements based on gaps that emerged from the comparison of approaches (DS-I) and a similar SLR about tools for CEBM innovation (Bocken et al., 2019);
- Identification of practical requirements based on improvement opportunities from AR cycles (section 2 of this Appendix A);
- Categorisation of requirements in ‘must-be’ or ‘attractive’ depending on the degree of importance for the characteristics judged by literature and users;
- Detailing of more specific requirements – i.e. indications of how to implement;

5.1.2 Deployment and specification of the main functions of the expert system based on the final set of requirements;

5.1.3 Development of a high-fidelity prototype to test the core functionalities of the expert system in practice.

Descriptive Study II-D (DS-II-D)

5.2 *Evaluation of the CEBMES with* *case studies for theory testing* (section 2.2.3), comprising:

5.2.1 Cases selection:

- Selection/engagement of Northern European manufacturing companies from varied sectors and limited experience in CE (Table 3 in section 3.4);

5.2.2 Data collection:

- Development of structured questionnaires containing a combination of Likert-scale and open-ended questions to evaluate 49 criteria for the expert system (details on Appended Publication 6);
- Demonstration of the high-fidelity prototype developed for the CEBMES in three-hour webinar for training the selected companies;
- Independent application of the expert system by the companies chosen to support their CEBMn activities within six weeks;
- Interview to explore the feedback from companies and collect resulting documents;

5.2.3 Data analysis:

- Consolidation and analysis of the collected data (from the questionnaires, documents and interviews), including:
  - *Histograms with quantitative data* to show the performance of the CEBMES regarding different criteria (see Appended Publication 6);
  - *Statistical analysis* to explore contextual conditions of the companies that favoured or disfavoured the application of the expert system;
  - *Content analysis and clustering of qualitative data* (Dresch et al., 2015) (i.e. questionnaire and comments from interviews).

The main result was (Figure A6):

*R5: High-fidelity prototype of the CEBMES (presented in section 3.5).*

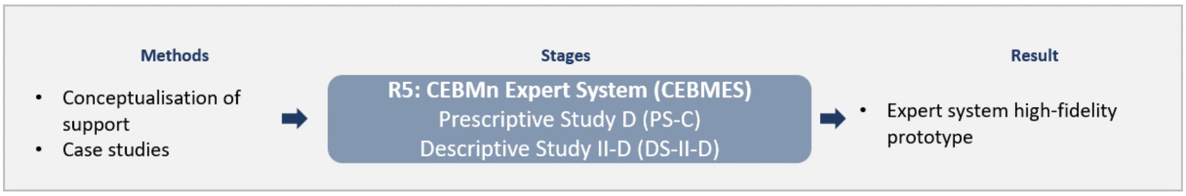


Figure A6 – Methods and research stages to achieve R5

# Appendix B – Interview protocol for case studies

Table B1 presents the interview protocol to guide the case studies for the evaluation of the stage ‘Transform’ of the CEBMn Process Model (section 2 in Appendix A).

Table B1 – Interview protocol for case studies.

| | |
|---|---|
| Observed process | Transform stage of the CEBMn process model<br>Post-action research intervention |
| Setting | Companies reflecting and commenting on retrospective facts |
| Company | |
| Participants | |
| 1 - How experienced do you judge your organisation with circular economy or sustainability implementation/initiatives (i.e. several projects; previous experiences) in a scale from 1 to 4?<br>*1 - Beginner (e.g. first time you implement such a project/initiative)*<br>*4 - Very experienced (e.g. several projects concluded and previous experiences)* | |
| 2.1 - Did you continue to use the process and tools after the interventions in action research?<br>2.2 - How did you use it?<br>2.3 - To what extent did it support the generation of substantial arguments for the business and environmental cases to implement the BMs for CE? | |
| 3.1 - To what extent the collection of evidence (e.g. information and visualisations about economic, resource decoupling, customer value potential) enabled by the process model supported the company in moving forward with the implementation of the BM configurations (e.g. experimenting to verify assumptions, approving the business case in the company´s governance, obtaining findings)?<br>3.2 - Was there a need to adapt? | |
| 4.1 - How many participants from your company were directly involved in further exploration, experimentation and implementation?<br>4.2 - Which functional areas?<br>4.3 - Which roles? | |
| 5.1 - How successful was the implementation of the business model configurations (s) developed in the project with the support of the process model?<br>5.2 - If not, why not? What were the challenges?<br>5.3 - If yes, how was it? What were the challenges and important factors? | |
| 6.1 - Which other factors were important for the implementation process?<br>- Barriers/ enablers / success / lessons learned<br>6.2 - What about the following barriers (Guldmann and Huulgaard, 2020; de Jesus and Mendonça, 2018; Kirchherr et al., 2018):<br><br><u>Market:</u><br>• Market demand is unclear for circular business models<br>• Customer benefits and acceptance are uncertain<br>• Relevance limited to some customers and product types<br>• Changing fashion trends can be a challenge for long-life products<br>• Low status of products from recycled materials and repaired, reused, refurbished or remanufactured products (might damage image)<br>• Low price of virgin raw materials versus higher price of secondary raw materials derived from recycling waste materials<br>• Uncertainty about the residual value of products<br><br><u>Financial:</u><br>• Lack of availability of capital<br>• Lack of credit access for financing or (external) funding<br>• Lack of adequate tools for investments in CE projects<br>• Unclear business case and little evidence of financial and environmental benefits and<br>• CE initiatives are generating cost instead of return on investment<br>• Lengthening time to market<br>• Risk of cannibalisation: sales of new products versus repaired, reconditioned and remanufactured products<br><br><u>Technological:</u><br>• Lack of advanced technologies for the reuse of waste materials and by-products<br>• Original spare parts are difficult or impossible to attain<br>• Frequent design changes that hinder product reuse and remanufacturing<br>• Repairs impaired by proprietary product designs, parts glued together and other physical product attributes<br>• Products and buildings are complex and not designed with end-of-life reuse or recycling in mind resulting in a low value at end-of-life<br><br><u>Value chain</u><br>• Lack of platforms for reuse of waste materials over multiple cycles and sectors<br>• Investments in existing manufacturing facilities and value chain<br>• Quality control of returned goods<br>• Consistency of flow of return goods - demand and planning difficulty | |

- Lack of information systems
- Dispersed & complex value chains (lack of green suppliers & long distances)
- Difficulty to involve external stakeholders and establishing cross-collaboration
- It takes time to build new partnerships and mutual trust
- Lack of knowledge or competencies in the value chain

Organisational and cultural (dynamic capabilities):

- Difficulty attaining top management buy-in and commitment
- Difficult to promote the circular economy agenda
- Prevailing linear business model structures and thinking & resistance to change
- Incentive structure and performance metrics supporting linear business models
- Lack of resources, knowledge or competencies in-house
- Lack of external experts with the knowledge to help training
- Financial, legal and operational risk increased / lack of tools to assess
- Special product design required for maximum profitability

Legislative:

- Bureaucracy to apply legislation on sustainability
- Lack of incentives to encourage the consumption of recycled materials and products
- Lack of government support in the form of training, funding, legislation
- Uncertain response times from public administrations and uncertainty about legislation in this field
- Lack of clear guidelines to define sustainability in SMEs
- Lack of coordination of regulations/policies at EU, national, regional and local levels
- Lack of concrete, coherent, strict legislation, e.g. legislative framework that enhances the reuse/recycling
- Labour-intensive reuse and recycling activities expensive
- Legislation hinder, e.g. legislation on sales of waste materials and on cross-border
- Warranty legislation hinders the use of reused spare parts
- Public procurement policies not sustainability-oriented

7.1 -Which areas of the company were affected (i.e. had to implement initiatives) for implementation for fitting with the new business model configurations for circular economy?
- Product design or Engineering
- Digital / Information Technology
- Procurement
- Marketing and Sales
- Manufacturing
- Operations and Logistics
- Services and After Sales
- Finances

7.2- Explain how

8.1 - To what extent were senior decision makers actively engaged during the implementation?
8.2- To what extent did you engage or defined a steering group or sponsor for the project?

9.1 - To what extent did you identify resistance to change form participants engaged in the process of BM innovation/design (e.g. difficulties to explore different ideas; difficulties to think out of the linear or current logic)?
9.2 - To what extent did you establish change management actions or plan?

10.1 - How do you interact with the new ecosystem of stakeholders?
10.2 - Do you have new activities in the company due to that?
10.3 - Is there a governance to interact with the new involved stakeholders? How?

11.1 - How do you measure or monitor the effects of implementation?
11.2 - Did you implement a new performance management system?

12.1 - Can you measure already impacts on the business outcomes (i.e. economic or environmental)?
12.2 - How were they affected? Could you provide examples?

# Appendix C – Forms for evaluation with academic experts

Figures C1 and C2 present the forms applied to guide the evaluation of the CEBM patterns by academic experts (section 4 of Appendix A).

**Validation by Experts - Part 1: CONTENT of Circular Economy Business Model patterns**

**Instructions:** provide your feedback to each of the aspects of the pattern by indicating a grade (1 to 4). Provide your comments for improvement in the indicated field below or directly on the template of the pattern.

| *Pattern Name* | *Context and CE problem* | *Solution* | *Examples of cases* |
|---|---|---|---|
| **To what extent is the name adequate?** | **To what extent is the context clear and matching the pattern name?** | **To what extent is the solution clear and matching the pattern name?** | **To what extent do cases illustrate the pattern?** |
| 1 – Inadequate<br>2 – Improvements required<br>3 – Adequate<br>4 - Very adequate | 1 – Not clear<br>2 – Improvements required<br>3 – Clear<br>4 – Very clear | 1 – Not clear<br>2 – Improvements required<br>3 – Clear<br>4 – Very clear | 1 – Inadequate<br>2 – Improvements required<br>3 – Adequate<br>4 - Very adequate |
| *Suggestions for improvement:* | *Suggestions for improvement:* | *Suggestions for improvement:* | *Suggestions of other cases:* |

**To what extent are the configuration options in each element below…**

| | | |
|---|---|---|
| E04- Target Customer<br>**Clear (i.e. readable and understandable)?**<br>1 – Not clear<br>2 – Improvements required<br>3 – Clear<br>4 – Very clear<br>**Sufficient/comprehensive?**<br>1 – Not *sufficient*<br>2 – Improvements required<br>3 – Sufficient<br>4 - Very sufficient<br>*Suggestions for improvement:* | E09 – Value Delivery<br>**Clear?**<br>1 – Not clear<br>2 – Improvements required<br>3 – Clear<br>4 – Very clear<br>**Sufficient/comprehensive?**<br>1 – *Not* sufficient<br>2 – Improvements required<br>3 – Sufficient<br>4 - Very sufficient<br>*Suggestions for improvement:* | E07 – Service Offerings<br>**Clear?**<br>1 – Not clear<br>2 – Improvements required<br>3 – Clear<br>4 – Very clear<br>**Sufficient/comprehensive?**<br>1 – Not *sufficient*<br>2 – Improvements required<br>3 – Sufficient<br>4 - Very sufficient<br>*Suggestions for improvement:* |
| E05 – Benefits for customers<br>**Clear?**<br>1 – Not clear<br>2 – Improvements required<br>3 – Clear<br>4 – Very clear<br>**Sufficient/comprehensive?**<br>1 – Not sufficient<br>2 – Improvements required<br>3 – Sufficient<br>4 - Very sufficient<br>*Suggestions for improvement:* | E08 – Revenue mechanisms<br>**Clear?**<br>1 – Not clear<br>2 – Improvements required<br>3 – Clear<br>4 – Very clear<br>**Sufficient/comprehensive?**<br>1 – Not sufficient<br>2 – Improvements required<br>3 – Sufficient<br>4 - Very sufficient<br>*Suggestions for improvement:* | E06 – Product Offerings<br>**Clear?**<br>1 – Not clear<br>2 – Improvements required<br>3 – Clear<br>4 – Very clear<br>**Sufficient/comprehensive?**<br>1 – Not sufficient<br>2 – Improvements required<br>3 – Sufficient<br>4 - Very sufficient<br>*Suggestions for improvement:* |

Figure C1 – Evaluation form for CEBM patterns content and format.

**Validation by Experts - Part 2: COMBINATION LOGIC of Circular Economy Business Model patterns**

**Introduction:** Complementarily to the database of CEBM patterns, pattern combinations were developed to indicate CEBM patterns' relationships. The combinations logic indicates other highly recommended patterns (dark green) and potential patterns to be considered (yellow) as observed in CEBM cases. Patterns selected by light yellow colour or not selected can also be chosen, even though they appeared sparsely or not at all in the observed CEBM cases.

| UPSTREAM ARCHITECTURE<br>*value creation processes and partnerships* | DOWNSTREAM ARCHITECTURE<br>*offerings, customer interface, value delivery processes, and revenue mechanisms* |
|---|---|
| ? - In d - HPU0301 - Service and support network or team for life-extension activities (e.g. upgrading, refurbishing/retrofitting) | **HPD0101 - Data-driven services for tracking, tracing and maintenance management of equipment or vehicles fleets** - ? - In d |
| ? - In d - HPU0302 - Own reverse operation for refurbishment | HPD0102 - Data-driven services for sustainability performance management (e.g. monitoring fuel-burn, managing resource consumption) of equipment or vehicles fleets - ? - In d |
| ? - In d - HPU0303 - Own remanufacturing operation | HPD0103 - Data-driven services for managing productivity, safety and controlling jobsite operations - ? - In d |
| ? - In d - HPU0304 - Internal recycling process (e.g. metal, plastics, wood) | HPD0201 - Experience or result as a service (e.g. light as a service, cool rooms as a service) - ? - In d |
| ? - In d - HPU0305 - Service delivery management | HPD0202 - Function as a service (e.g. material handling as a service) - ? - In d |
| ? - In d - **HPU0306 - Development and management of digital marketplace and logistics operation** | HPD0301 - Peer-to-peer equipment lending, renting, sharing or trading services based on commissions - ? - In d |
| ? - In d - HPU0307 - Development and management of digital technologies and services | **HPD0302 - Peer-to-peer equipment lending, renting, sharing or trading services based on listing fees** - ? - In d |
| ? - In d - HPU0401 - Collaboration with technology providers for recycling materials or products | HPD0303 - Equipment or machinery as through-life care services in customizable time-based contracts - ? - In d |
| ? - In d - HPU0402 - Collaboration with original material supplier recyclers (e.g. steel) | HPD0304 - Access to equipment and machinery in short-term contracts - ? - In d |
| ? - In d - HPU0403 - Collaboration with financing companies | HPD0305 - Access to equipment and machinery in short-term contracts with additional services for life-extension - ? - In d |
| ? - In d - **HPU0404 - Collaboration with insurance companies** | HPD0401 - Sales of equipment and machinery with through-life care services - ? - In d |
| ? - In d - **HPU0405 - Collaboration with freight forwarders or transportation companies** | HPD0501 - Incentivised buy-back of equipment, machinery or vehicles - ? - In d |
| ? - In d - HPU0406 - Collaboration with service chains or technicians | HPD0502 - Sales of equipment, machinery or vehicles as 'next-life' (e.g. certified used, refurbished or remanufactured) - ? - In d |
| ? - In d - HPU0407 - Collaboration with equipment dealers | HPD0503 - Additional services to add 'new life cycles' for machinery, equipment, vehicles, components or parts (e.g. rebuilds, retrofits) - ? - In d |
| ? - In d - HPU0408 - Collaboration with Original Equipment Manufacturers (OEM) | |
| ? - In d - HPU0409 - Collaboration with digital services provider | |

**Caption:** Selected CEBM pattern; <20% Frequency of combination in cases 50% >80%

**Validation by Experts - Part 2: COMBINATION LOGIC of Circular Economy Business Model patterns**

**Instructions:** provide your feedback to each of the aspects of the pattern by indicating a grade (1 to 4). Provide your comments for improvement in the indicated field below or directly on the template of the pattern.

**1) To what extent is the suggested combinations of patterns coherent?**

1 – Not coherent ◉
2 – Needs improvement ○
3 – Coherent ○
4 – Very coherent ○

*Comments for improvement:*
*Obs.: if you think a recommended pattern does not make sense select 'No - exclude' or '? – in doubt' in the box in front of the pattern (see previous sheet). If you think that the level of recommendation should be altered select 'H- highly recommended'; 'M- moderately recommended'; 'S – sparsely recommended'. If possible, provide your comments here to explain the reasons.*

**2) Would you recommend any other combinations?**

*Obs.: if you think another pattern that is not selected in the previous sheet make sense, select H- highly recommended', 'M- moderately recommended', or 'S – sparsely recommended' in the box in front of the pattern. If possible, provide your comments here to explain the reasons.*

Figure C2 - Evaluation form for CEBM patterns' combination logic.

## Appendix D – Results of the application of the CEBMn process model (R2)

Table D1 presents the results obtained by companies with the application of the CEBMn process model (section 3.2).

Table D1 - Summary of results of the application of the CEBMn process model in companies A-D (v.1 and v.2 of the process model) and E-G (v.final of the process model).

| Company | **Sense**<br>***Diagnosis & roadmaps for CEBM innovations*** | **Seize**<br>***CEBM configurations with demonstrations of resource decoupling and economic potential*** | **Transform (planned during 'Seize')**<br>***Experimentation or pilot project plans*** |
|---|---|---|---|
| **A** | • *15 CE characteristics*– e.g. core offering based on services for use-cycle extension of electronic equipment for navigation systems of vessels. Services include: repair, maintenance, software upgrades, refurbishment/retrofit.<br>• *68 opportunities; 4 BM ideas.* | • *3 prioritised ideas:* (1) navigation electronic equipment as service; (2) sales/retrofit of navigation electronic equipment with extended warranty; (3) multiple maintenance service packages for navigation electronic equipment.<br>• *Economic potential:* different retention periods for service contracts (1), rate of adhesion of customers, expected period for refurbishment (2) and price of packages (3) tested. Delayed breakeven of 8 years, requiring partnership for initial financing.<br>• *Resource decoupling potential:* (1) - 40%; (2) -10-20%; (3) - 50%. Energy/fuel consumption: (3) - 20% for customers; - 25% for company. | *Experiments/pilots:* 1 project and deployment of operational capabilities<br>• Organisational structure/training for services team;<br>• Modularity in navigation electronic equipment design;<br>• Data analytics/artificial intelligence skills for predictive maintenance of navigation systems;<br>• Development of partners for reducing marginal costs and increasing reutilisation of electronic components after refurbishment. |
| **B** | • *34 CE characteristics* - e.g. core offerings based on long-life lifting equipment with provision of high-quality services for use-cycle/life extension enabling equipment to continue in functional state for the double/triple amount of time in respect to design lifetime; emerging access and performance-based models for material handling activities.<br>• *31 opportunities; 10 BM ideas.* | • *3 prioritised ideas:* (1) data-driven service offerings: 1a) energy/resource efficiency management for customers' operations; 1b) predictive maintenance of lifting equipment; (2) expansion of lifting equipment as service with complete life-cycle support in the portfolio; (3) platform to trade used lift equipment and life-extension services.<br>• *Economic and resource decoupling potential:* evaluated internally by the company. | *Experiments/pilots:* 4 projects and deployment of operational capabilities<br>• Platform for trade of used lift equipment;<br>• New technologies to take care of the absolute end-of-life (e.g. oil recycling);<br>• Product design strategies/trade-offs – e.g. easier reuse by different customers versus customisations;<br>• Refurbishment – e.g. expansion of technical centres, quality certification for used lifting equipment;<br>• Data analytics/artificial intelligence skills to generate data-driven value for customers;<br>• Sustainability performance management. |

| | | | |
|---|---|---|---|
| **C** | • *9 CE characteristics* – e.g. core offering based on furniture modularity/upgradability and additional adhoc basic services for use-cycle extension (e.g. repair, reconfiguration of spaces).<br>• *11 opportunities; 8 BM ideas.* | • *2 prioritised ideas:* (1) space dividers platform with temporary service agreements (e.g. subscription); (2) workspaces as service with complete life-cycle support.<br>• *Economic potential:* (1) Different subscription, leasing fees, contract periods. Delayed breakeven of 10 years. Co-financing by investors, potentially reducing breakeven time in 40%.<br>• *Resource decoupling potential:* (1) - 20%-45% - limitations to capture the 'full product circularity potential' imposed by market requirements and time taken for products to be returned. | *Experiments/pilots:* 3 projects and deployment of 19 operational capabilities<br>• Platform for providing offerings;<br>• Services for customers and investors – e.g. pricing and remuneration logic, access to reports and environmental certificates, take back logistics;<br>• Development and sourcing of new recycled materials - e.g. ocean plastics – with the creation of a spin-out company in partnership with company E;<br>• Sustainability performance management. |
| **D** | • *4 CE characteristics*- e.g. pilots of services for use-cycle extension of coffee machines, planning pilot for bar coffee brewing as service contracts.<br>• *19 opportunities; 8 BM ideas.* | • *2 prioritised ideas:* (1) bar coffee brewing as service; (2) long-life coffee machines with buy-back agreements/ next-life sales/reutilisation in bar coffee brewing as service contracts.<br>• *Economic potential:* (1) Different service fees, contract periods, costs for take-back. Delayed breakeven of 7 years, requiring partnership for initial financing.<br>• *Resource decoupling potential:* experiments (cooperation with component suppliers) to increase data reliability. Due to low volume of returning products, partnerships are necessary. | *Experiments/pilots:* 4 key projects and deployment of 12 operational capabilities<br>• Partnerships – e.g. structure refurbishment/remanufacture; co-finance initial implementation of coffee bar brewers as service (i.e. installation of routers on all coffee machines in the field).<br>• Organisational structure and training for services team;<br>• Restructuration of relationship with customers and sales strategy. |
| **E** | • *7 CE characteristics* – e.g. warranty on products' materials (15 years for wood lacquer and 50-80 years against rust); 20% of recycled materials; maintenance service teams; refurbishment services; recovered ocean plastics into furniture.<br>• *4 opportunities; 4 BM ideas.* | • *2 prioritised idea:* (1) Long-life product sales with buyback: "Furniture for social meeting places to last a lifetime/trade-in and pick-up of used furniture for free"; (2) Access model: "Best-fit furniture for social meeting spaces as service".<br>• *Economic potential:*<br>- (1): different buy-back fees (i) and rate of products' substitution by new ones (ii) were tested; acceptable breakeven of around 6 years.<br>- (2): different prices (3) and period of service contracts (4) were tested. Delayed breakeven of 9 years/ company able to self-finance experiments.<br>• *Resource decoupling:* (1) 7-30%; (2)15-30%. | *Experiments/pilots:* 1 project and deployment of 12 operational capabilities<br>• Take back and management of inventory;<br>• Review of product design strategies - e.g. trade-off between durability and modularisation for disassembly;<br>• Refurbishment processes – e.g. facilities, methodology, partners;<br>• Maintenance team – e.g. formalisation of methodology and process procedures; enhancement of hiring/training; development of service level agreements;<br>• Partnerships – e.g. recycling companies, local refurbishment centres, logistics. |

| | | | |
|---|---|---|---|
| **F** | • *7 CE characteristics* – e.g. durable products with classic looks and sizeable folds; repair kits; special detergents to prolong life of wool; sufficiency philosophy with moderate branding and slow-fashion positioning (e.g. 2 collections/year, repeating colour pallets, premium prices, clothes passed along generations lasting 5-10 years); certified wool requires less washing.<br>• *8 opportunities; 3 BM ideas.* | • *1 prioritised idea:* Long-life products sales with buyback for cascaded product sales: "Return baby clothes at the end-of-life, get a discount on new purchases and contribute to the creation of new circular products (e.g. teddy-bear, bags for prams) with re-used wool".<br>• *Economic potential:* different products and prices were tested; acceptable breakeven led to the selection of teddy bears as new product category.<br>• *Resource decoupling potential:* reduction of textile waste and substitution of synthetic fibres used as fillings of comparable teddy bears on the market.<br>• | *Experiments/pilots:* 1 project and deployment of 6 operational capabilities<br>• Collection or take back processes;<br>• Development of new product categories;<br>• Expansion of sales channels and tools – e.g. buy-back valuation and shipping calculators on webstore; development of channels for selling new products made of reused wool;<br>• Receiving and sorting processes – e.g. rules for sorting and potential reuse of parts in repair kits (e.g. buttons);<br>Partnerships – e.g. sorting and production. |
| **G** | • *2 CE characteristics* – e.g. take back systems deployed in specific countries; market acceptance to reused products.<br>• *11 opportunities; 4 BM ideas* – i.e. scope limited to products in early design stage, lower regulatory restrictions for reusing, and high volume of sales. | • *1 prioritised idea and 2 BM configurations detailed*: (1) Immobilisation devices with refurbishment services; (2) Immobilisation treatment as service.<br>• *Economic potential*: solution (1) results could not maintaining margins for provider and partners (e.g. clinics and hospitals) when compared to current traditional sales model.<br>• *Resource decoupling potential:* products' longevity increased by a factor of 4. | *Experiments/pilots:* 1 project and deployment of operational capabilities<br>• Relocation of distribution centres;<br>• Development of refurbishment processes – e.g. sorting, handling and sterilisation instructions;<br>• Take back processes and adaptation of relationship with distributors;<br>• Adaptation of sales channels;<br>Partnerships: cleaning and sterilisation local providers; recycling facilities. |

# Appendix E – Results of evaluation of ‘Transform’ for the CEBMn process model (R2)

Appendix E summarises the results for the evaluation of the stage ‘Transform’ (activities 8, 9 and 10) of the CEBMn process model by manufacturing companies (section 3.2). The complete evaluation can be downloaded from: https://doi.org/10.11583/DTU.12318914.

<u>Activity 8: Plan and execute CEBMn projects to implement CEBMs (Figure E1)</u>

All companies that managed to engage in the *activities* of the stage ‘Transform’ were successful in either planning (B and E in Table 2 of section 3.2) or implementing (C and D Table 2 of section 3.2) at least one *CEBM pilot* (see Appendix D for details). Additionally, two of the companies were able to collaborate to create a spinout to *scale-up a CEBM configuration*. The companies acknowledged that the *outcomes* and *tools* deployed in the stages ‘Sense’ and ‘Seize’ supported the generation of substantial arguments and evidence that encouraged the implementation of CEBM pilots. In particular, companies continued to rely on and refine the outcomes obtained through four tools: (*i) Economic and Resource Decoupling Calculators; (ii) CEBM Framework; (iii) CEBM Configurator (high-fidelity prototype); and (iv) CEBM Innovations Roadmap.* However, they suggested *modifications* to enhance the potential support and applicability of some of the tools in the stage ‘Transform’, such as:

- The Economic and Resource Decoupling Calculators require:
    - Flexibility in the parameters to allow simulations with different CEBM configurations (e.g. pay-per-experience, pay-per-use, pay-per-month), as opposed to the current fixed structure;
    - Flexibility to add a detailed level of information in the calculations of costs (e.g. at the level of bill of materials of products) to allow the identification of trade-offs (e.g. lighter weight and more compact products versus durable components);
    - Overall guidelines to allow the integration of CEBM parameters with investment proposal tools already available in organisations (e.g. company G embedded elements of the CEBM Calculators in their standard global tool);
    - Definition of guidelines or targets to identify the minimum level of resource decoupling benefits necessary to qualify a BM configuration as CEBM.
- The overall CEBMn process model is quite extensive, so a structured overall framework or tool to help the iteration of steps and maybe an automated workflow also envisioning the interfacing of tools (i.e. which output from one tool could serve as input to another) could be beneficial to support the CEBM *reviews and adaptations* applied in the Transform stage.

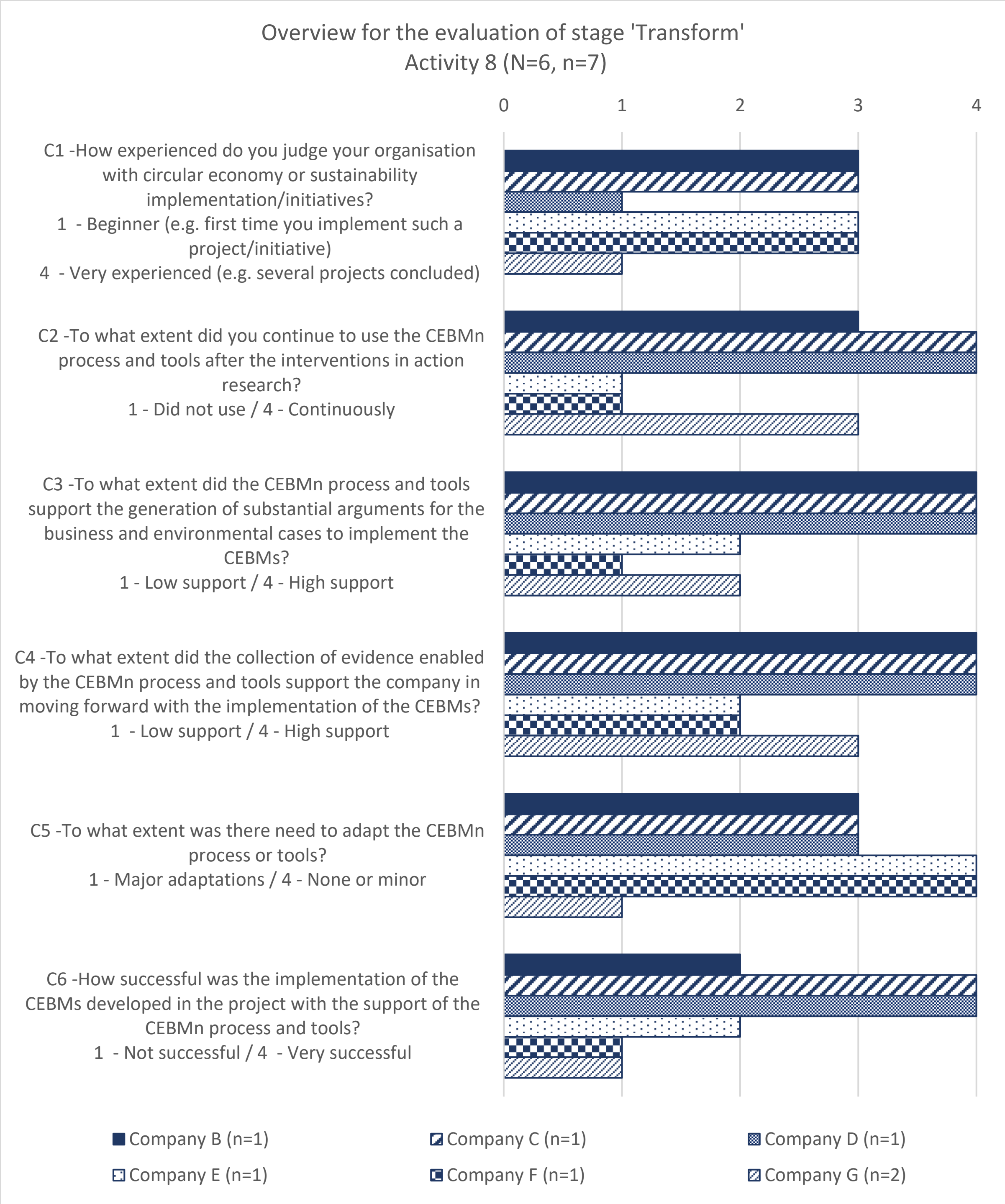


Figure E1 - Overview of results for the evaluation of stage 'Transform' - Activity 8 (Legend: N - number of companies; n - number of respondents within companies).

A9: Plan and manage organisational change towards CEBMs (Figure E2)

The companies that were successful in implementing the pilots (C and D) claimed to have a *high engagement of owners, investors, board members and employees.* Moreover, they explained that *low internal resistance* to change was identified, which they associated with *proactive actions of training employees and treating CE-thinking as part of their culture.* The other two companies (B and E) that were still in the planning stage for their CEBM pilots, associated the slower pace to higher levels of internal or external resistance to change and difficulties in attaining top management buy-in and commitment due to prevailing linear thinking. As action plans to countermeasure the internal resistance, they highlighted *a need for training and engagement of the leadership* and working with the middle management and with customers *to generate success CEBM cases to convince the leadership.*

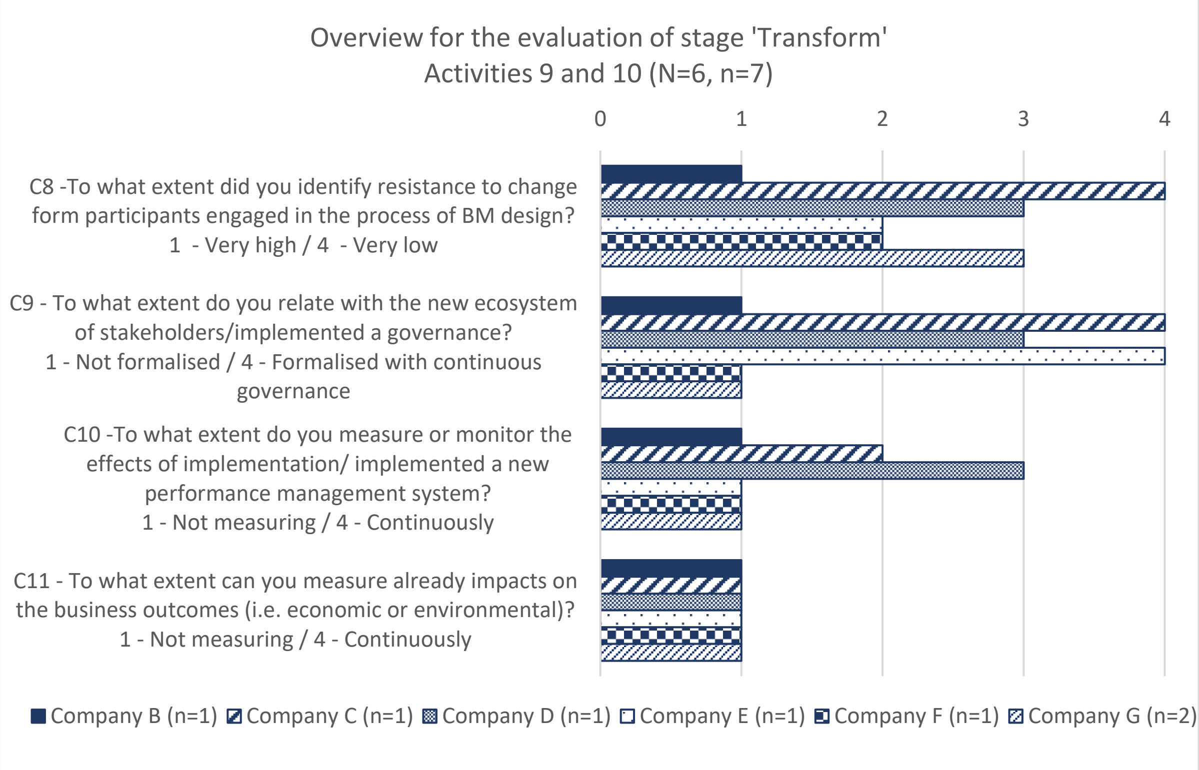


Figure E2 - Overview of results for the evaluation of stage 'Transform' - Activities 9 and 10 (Legend: N - number of companies; n - number of respondents within companies).

A10: Adjust, review and diversify CEBMs (Figure E3)

None of the companies was able to implement *performance management systems or simply monitor selected Key Performance Indicators (KPIs)* to track the outcomes of the CEBMs (i.e. environmental and economic). This was probably related to the short period of the pilots' execution when the case studies were carried. However, some companies (C and D) were monitoring the implementation milestones with intermediate success indicators (e.g. number of machines fully equipped with routers for enabling predictive management and tracking for taking the product back at the end of life or number of customers interested in furniture as service offerings in events).

Moreover, a series of *internal and external actions to overcome barriers for CEBM implementation* were identified by the companies, and recommended to be used as a *CEBM Barrier-Action* Checklist *Tool* to support A10 in the stage ‘Transform’. As an example of the most recurrently reported *barrier-action* by the companies:

- Barrier: CEBMs were only promising to specific customer segments and product types from the entire portfolio.
- Action: Companies that successfully implemented pilots had to adapt the initial CEBM configuration, and expand it to generate different value propositions according to niche segments and customers’ needs. For example, company C created three CEBM configurations with distinct value propositions, services

contract lengths and pricing to fulfil needs from three distinct niche segments – i.e. event spaces as service (short-term contracts), shop interiors as service (medium-term contracts), and workspace dividers as service (long-term contracts).

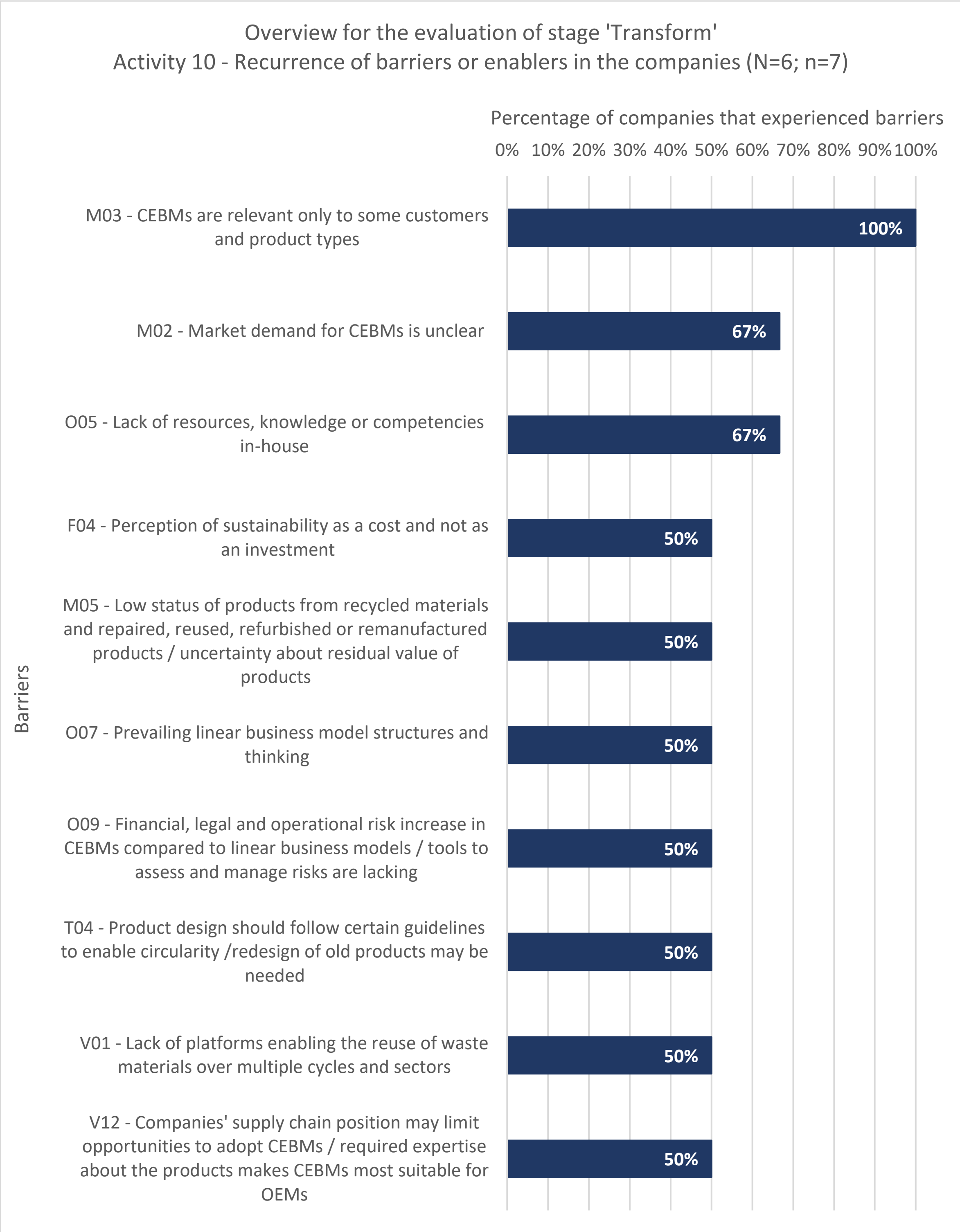


Figure E3 - Overview of results for the evaluation of stage 'Transform' with a summary of the recurrence of top barriers/enablers for the implementation of CEBMs in companies B, C, D, E, F and G. Legend: M -Market; O - Organisational and cultural; F - Financial; T - Technological; V - Value chain / N - number of companies; n - number of respondents within companies. Barriers adapted from Guldmann and Huulgaard (2020); de Jesus and Mendonça (2018); and Kirchherr et al.(2018).

# Appendix F – Results of the evaluation of CEBM patterns by experts (R4)

Figures F1, F2 and F3 summarise the evaluation of CEBM patterns by academic experts. The complete evaluation can be downloaded from: https://doi.org/10.11583/DTU.12318917.

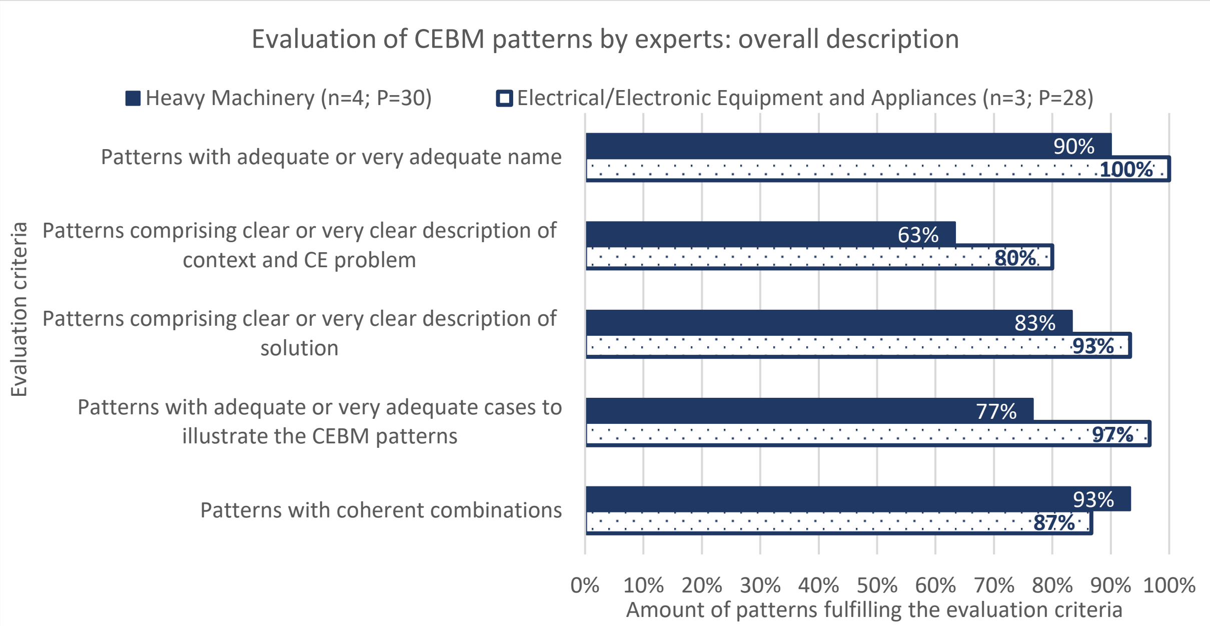


Figure F1 - Results of the evaluation of CEBM patterns by experts – overall description (Legend: n - number of experts; P number of patterns).

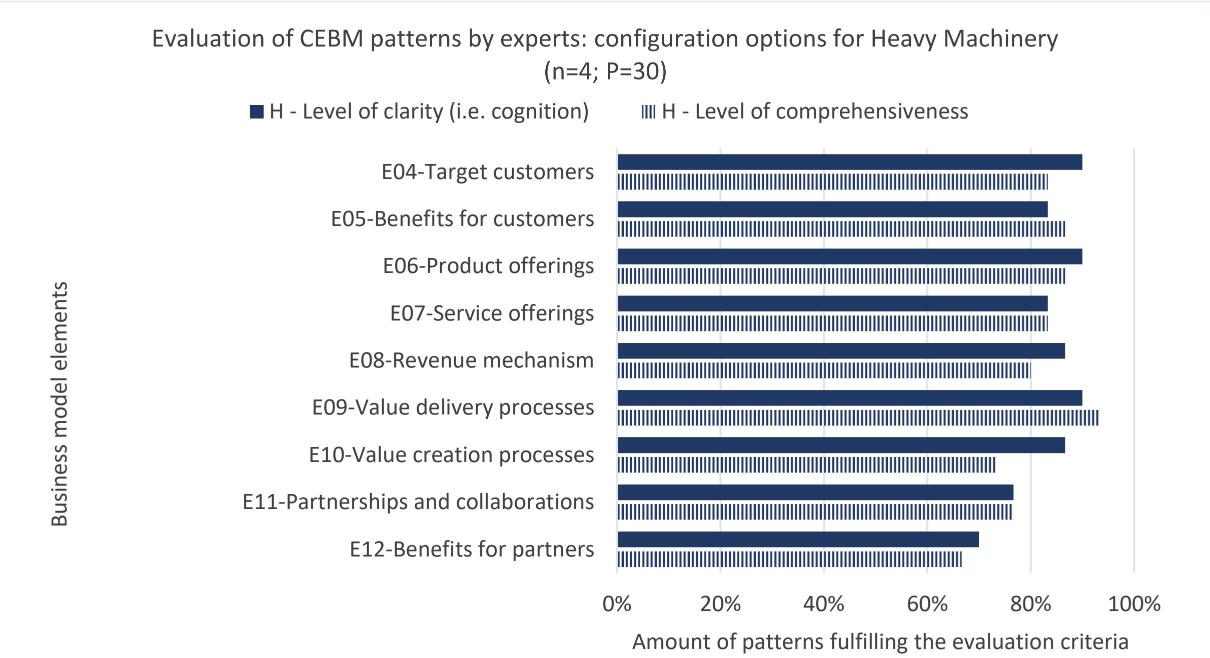


Figure F2 - Results of the evaluation of CEBM patterns by experts – configuration options for heavy machinery (Legend: n - number of experts; P – number of patterns).

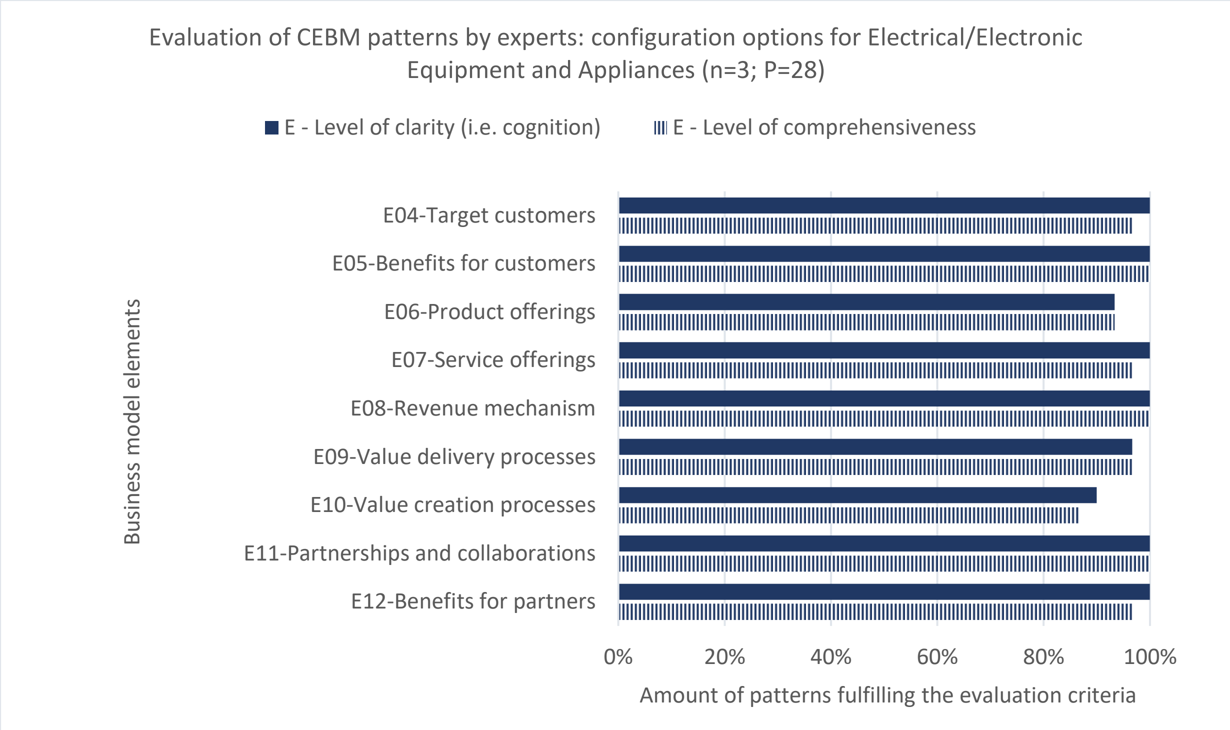


Figure F3 - Results of the evaluation of CEBM patterns by experts – configuration options for electrical/electronic equipment and Appliances (Legend: n - number of experts; P – number of patterns).

# Appended Publications (AP)

The appended publications that support the argumentation of this PhD thesis are presented in the following pages. An **EDGE INDEX** is available to help locating each of the six publications.

They are presented in the following order:

**AP1**

Pieroni, M.P.P., McAloone, T.C. and Pigosso, D.C.A. (2019), "Business model innovation for circular economy and sustainability: A review of approaches", Journal of Cleaner Production, Vol. 215, pp. 198-216. https://doi.org/10.1016/j.jclepro.2019.01.036

**AP2**

Pieroni, M.P.P., McAloone, T.C.and Pigosso, D.C.A. (2020), "Developing a process model for Circular Economy business model innovation within manufacturing companies", (Manuscript under review at Journal of Cleaner Production).

**AP3**

Pieroni, M.P.P., McAloone, T.C. and Pigosso, D.C.A. (2020), "From theory to practice: systematising and testing business model archetypes for Circular Economy", (Manuscript under review at Resources, Conservation & Recycling).

**AP4**

Pieroni, M.P.P., McAloone, T.C. and Pigosso, D.C.A. (2020), "Circular Economy business model innovation: sectorial patterns within manufacturing companies", (Manuscript under review at Journal of Cleaner Production).

**AP5**

Pieroni, M.P.P, C. McAloone, T. and C. A. Pigosso, D. (2019), "Configuring New Business Models for Circular Economy through Product–Service Systems", Sustainability, Vol. 11 No. 13, p. 3727. https://doi.org/10.3390/su11133727

**AP6**

Pieroni, M.P.P., McAloone, T.C., Borgianni, Y., Maccioni, L, Pigosso, D.C.A. (2020), "An expert system for Circular Economy business modelling: advising manufacturing companies in decoupling value creation from resource consumption", (Manuscript under review at Journal of Cleaner Production).

# Appended Publication 1

AP1

Pieroni, M.P.P., McAloone, T.C. and Pigosso, D.C.A. (2019), “Business model innovation for circular economy and sustainability: A review of approaches”, Journal of Cleaner Production, Vol. 215, pp. 198-216. https://doi.org/10.1016/j.jclepro.2019.01.036

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Review

# Business model innovation for circular economy and sustainability: A review of approaches

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ABSTRACT

As circular economy and sustainability gain greater attention of governments, industry and academia, business model innovation for circularity and/or sustainability is becoming fundamental to sustain companies' competitive advantage. A variety of business model innovation approaches have been proposed to suit circular economy or sustainability principles. Although they largely have been addressed independently as two separate knowledge areas, there is an opportunity to seize synergies from the intersection of both streams. This paper provides a review of approaches for business model innovation for circular economy and/or sustainability, based on a systematic review of academic literature and practitioner-based methodologies. The systematic literature review identified 94 publications and 92 approaches (including conceptual models, methods or tools). The different approaches were categorized according to the business model innovation process, following a three stage dynamic capability view. Subsequently they were compared based on five characteristics (nature of data, boundaries of analysis, level of abstraction, time-based view, and representation style), to allow for a better understanding of how to use the approaches in research and practice. Based on the review, key findings outlining trends and a reflection about the interface of the scopes of circular economy-oriented and sustainability-oriented business model innovation are presented. Moreover, a number of gaps are identified and a framework that maps a future research agenda to simultaneously advance both streams is outlined.



**Contents**



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## 1. Introduction

Sustainability and circular economy (CE) are of growing interest for governments, investors, companies and the civil society. Sustainability envisions a balanced integration of economic performance, social inclusiveness, and environmental resilience, to the benefit of current and future generations (Geissdoerfer et al., 2017a). CE emerged as an umbrella concept in the 2010's (Blomsma and Brennan, 2017), and envisions the achievement of a more resource effective and efficient economic system by intentionally narrowing, slowing and closing materials and energy flows (Bocken et al., 2016; EMF, 2015). CE is often seen as a means to achieving sustainability, but with a narrower focus on the economic and environmental dimensions (Geissdoerfer et al., 2017a). Nevertheless, not all systems (e.g. businesses, value chains) incorporating circular principles are intrinsically more sustainable (Geissdoerfer et al., 2018b).

Enhanced sustainability or circularity requires changes in the way companies generate value, understand and do business. Companies are compelled to interact within an ecosystem of actors, moving from a firm-centric to a network-centric operational logic. This transition requires rethinking their incumbent business models (BM), in order to enable a decoupling of value creation and resource consumption (Bocken et al., 2016). Hence, business model innovation (BMI) towards sustainability and circularity is a fundamental capability for companies.

Research related to the BM concept within the boundaries of sustainability and CE is still recent, with just 10 and 5 years of activities, respectively (Diaz Lopez et al., 2019; Foss and Saebi, 2017; Lüdeke-Freund and Dembek, 2017). As expected, these bodies of knowledge or potential 'emerging' research fields are still in a conceptualization stage and literature is fragmented (Lüdeke-Freund and Dembek, 2017; Merli et al., 2018; Nuβholz, 2017). Likewise, the boundaries and synergies between circular and sustainable BMI are not clearly explored (Geissdoerfer et al., 2017a). While researchers are focusing on understanding and describing these fields, practitioners are already being 'pushed' for the transformation of their BMs as a means of embedding circular or sustainability thinking (European Commission, 2018, 2014). Therefore, sustainable and circular BMI approaches have also been proposed in the gray literature by companies, consultancies, governments or NGOs.

Despite the excitement, a shared framework does not yet exist to support researchers/practitioners in need of understanding how to conceptualize, design and implement circular or sustainable BM as a means to solve or avoid environmental or social issues, whilst aiming for economic benefits. In addition, the way in which general BM-related research has evolved might generate confusion in regards to the interpretation of the BM construct (Lüdeke-Freund and Dembek, 2017). Research about conventional BM concepts and BMI has progressed into a more robust body of knowledge over the past 15 years. However, it is still in a consolidation phase, with inconsistencies and conceptual ambiguity associated with multidisciplinary contributions from different research fields and the elusive nature of the BM construct, which allows for interpretative flexibility (Foss and Saebi, 2017; Massa and Tucci, 2014; Wirtz et al., 2016). The BM construct is applied widely and sometimes promiscuously. Many of the proposed approaches for circular or sustainable BMI are inspired by conventional BM theory and consider circular/sustainable BMI as sub-fields of conventional BMI (Lüdeke-Freund and Dembek, 2017), which to a certain extent inherits the aforementioned lack of consistency. Furthermore, many authors proposing approaches for sustainable and circular BMI try to highlight their differentiation from the conventional stream and assume a positioning of individual 'silos', instead of promoting complementarity or integration of approaches for synergistic gains. Additionally, there is a lack of clarification of where existing tools for conventional BM are sufficient and where new tools are required for embedding circularity or sustainability in BMI (Lüdeke-Freund and Dembek, 2017; Nuβholz, 2017). Not only have they assumed a 'silo' positioning regarding conventional stream, but also in relation to each other. Several approaches have been proposed either for circular or sustainable BMI, however few approaches try to address the integrated vision of both concepts (Antikainen and Valkokari, 2016; Geissdoerfer et al., 2018a; Vogtlander et al., 2017). In this dynamic scenario, characterized by an intensive boost of heterogeneous intellectual content in a short period, it is difficult for researchers/practitioners to decide on where to start or which approach to follow.

This paper attempts to address this challenge by providing an overview of the different approaches for circular or sustainable BMI currently available in literature or in use by practitioners. Using the lens of BMI as a transformational process towards circularity or sustainability, we systematize approaches (i.e. conceptual frameworks, methods and tools) supporting circular or sustainable BMI processes based on a dynamic capabilities view. With this, we attempt to provide greater clarity around how each approach is applied, plus their differences and potential synergies, in order to support the selection of appropriate approaches, identify gaps and promote a unified research agenda.

Our research contributes to the intersection of CE, sustainability and BMI literature, envisioning the academic/practitioner perspectives, and responding to several recent calls for research (Geissdoerfer et al., 2017b; Schaltegger et al., 2016a) by providing:

(1) A systematization of a comprehensive collection of approaches currently available to support BMI towards CE or sustainability (Schaltegger et al., 2016a). While some publications analyze some approaches for sustainable (Breuer et al., 2018; Prendeville and Bocken, 2017; Schoormann et al., 2016) or circular (Nuβholz, 2018; Roos and Agarwal, 2015) BMI independently, so far there is no comparative study that takes an in depth look at the approaches for both concepts.
(2) A holistic view of BMI envisioning approaches to support different stages of the process (Foss and Saebi, 2017).
(3) A better understanding of how to use the approaches in research/practice (Foss and Saebi, 2017; Geissdoerfer et al., 2018b, 2017b; Nuβholz, 2017).

(4) An outline of improvements and opportunities for future research in BMI within CE/sustainability.

The paper is structured in six sections. Section 2 introduces foundations of conventional, sustainability-oriented, and CE-oriented BMI. Section 3 presents the research methodology. The remaining sections present the results including descriptive and comparative analyses of approaches (4); provide a discussion and an agenda to address future research needs (5); and conclude with recapping the research contributions and limitations (6).

## 2. Background

### 2.1. Business model innovation (BMI)

The BM construct emerged in the 1970's and was originally associated with system modelling in information technology. Since the 1990's, the concept has been maturing, with contributions from many disciplines, including technology, organizational and strategy theories (Wirtz et al., 2016). In its modern interpretation, BM is understood as the "design or architecture of the value creation, delivery, and capture mechanisms" of a business (Teece, 2010). In other words, it explains how a business work (Magretta, 2002).

Due to its elusive nature and the comprehensiveness of its scope in the modern interpretations, linking two 'conflicting' domains of knowledge (the technical/physical, generally based on hard facts, and the economic, generally based in uncertain assumptions), the BM construct definition is yet imprecise and has been interpreted in different ways (Gassmann et al., 2016). In general, BM frameworks converge around the notion of a *value generation logic of a reference system* (e.g. organization, value chain, industry sector), which can be represented by different elements (Wirtz et al., 2016). One of the most referenced representations, the BM Canvas, considers nine building blocks for value generation, organized in four pillars: 'product/value proposition', 'financial aspects', 'customer interface' and 'infrastructure management' (Osterwalder et al., 2005). These four pillars are further refined by Richardson (2008) in three main forms of managing value: 'value proposition', 'value creation and delivery' and 'value capture'. Such representations are related to the static view of BM.

In parallel to these studies, there is the notion of *BM innovation*, which consists of changing (by creating, diversifying, acquiring or transforming) BM as a response to internal and external incentives (Foss and Saebi, 2017; Geissdoerfer et al., 2018b). In this view, BM can be an (1) enabler of strategic changes in innovation processes (e.g. products/services), or (2) the source of competitive advantage acting as innovation itself (Boons et al., 2013).

The dynamic process of BMI can occur in different *intensities*, related to the degree of novelty introduced (i.e. 'new to the firm' or 'new to the industry') or the scope of changes (i.e. individual components or systemic/architectural structure) (Foss and Saebi, 2017). Moreover, different *triggers* (internal or external), such as changes in the competitive environment or legislations, can stimulate BM changes.

Recently, BMI is receiving increasing attention in *specific areas* (e.g. sustainability, CE, servitization, digitization). Due to the importance of these concepts in their individual investigation fields, different 'sub-streams' emerged (Foss and Saebi, 2017). This article explores two of these 'sub-streams', addressing BMI in the context of sustainability and CE.

### 2.2. Sustainability-oriented BMI

The sustainability-oriented BMI sub-stream has evolved significantly over the past decade, on the basis of seminal works framing the concept (Birkin et al., 2009; Lüdeke-Freund, 2010; Stubbs and Cocklin, 2008); special issues (Boons et al., 2013; Dentchev et al., 2018; Schaltegger et al., 2016a); and reviews of conceptual foundations (Bocken et al., 2014; Boons and Lüdeke-Freund, 2013; Evans et al., 2017b; Geissdoerfer et al., 2018b; Lüdeke-Freund and Dembek, 2017; Schaltegger et al., 2016b; Wells, 2016).

Sustainability-oriented BMI incorporates sustainability principles as guidelines for BM design, adding complexity to the conventional ('business as usual') BMI process. On top of *generating superior customer value* to achieve competitive advantage and capture economic value, it also seeks to *contribute positively to the environment and society*. (Lüdeke-Freund, 2010; Stubbs and Cocklin, 2008).

The extent at which sustainability principles will be embedded on the BMs and generate impactful outcomes from a triple bottom line perspective will depend on the levels of ambition of decision makers. Schaltegger et al. (2012)'s typology suggests *three strategies for embedding sustainability into BMI*: defensive (focus on reducing risks/costs to maintain business as usual), accommodative (focus on ameliorating the BM to reduce impacts) and proactive (focus on completely new designs of the value logic). Proactive strategies usually are more impactful, because they embed sustainability principles in the core logic of businesses, 'rethinking' the value proposition, delivery/creation, and capture systems to maximize societal and environmental benefits, and not only economic profit (Bocken et al., 2014; Wells, 2016).

By addressing value generation logic of businesses for multiple stakeholders beyond the customers, BMI for sustainability intensifies the need for different and more *systemic boundaries of analysis*. Boons and Lüdeke-Freund (2013) propose three levels of analysis:

(1) Organizational: focused on individual firms and its own value adding activities;
(2) Inter-organizational: focused on the interrelationship with other actors that co-create and share values;
(3) Societal: focused on the interrelationship with other organizations to produce a shared societal value.

To cope with the aforementioned complexity added on top of the conventional BMI, specific methodological support for guiding sustainability-oriented BMI have been proposed in literature. Initial manifestations towards comparing different methodological support exist (Breuer et al., 2018; Schoormann et al., 2016; Schoormann and Knackstedt, 2018), but holistic approaches for sustainability-oriented BMI (i.e. from design to implementation) are still in development stage (Geissdoerfer et al., 2017b).

Definitions for 'Sustainable BM' have been proposed, but views still require alignment. After reviewing literature for definitions, Geissdoerfer et al. (2018b) define it broadly as BMs "that incorporate pro-active multi-stakeholder management, the creation of monetary and non-monetary value for a broad range of stakeholders, and hold a long-term perspective". Wells (2016) is more precise in emphasizing the concept of 'sufficiency' and social relevance, as he argues that a 'SBM' is "both sufficiently profitable and that results in a process of comparative absolute or relative reductions in environmental and socioeconomic burdens through the delivery of socially relevant products and services". The 'sustainable business model (SBM)', 'sustainable business model innovation (SBMI)', 'circular business model (CBM)' and 'circular business model innovation (CBMI)' terminologies have been frequently employed, but we understand that there is no such a thing as an absolute SBM or CBM. Instead, principles/practices that enable a fit with the vision of sustainable development or CE can be incorporated in BMs. Using the aforementioned acronyms might mislead understandings and hinder the practical implementation of the concepts. Therefore we recall the views of some previous works (Boons and Lüdeke-Freund, 2013; BSI, 2017; Schaltegger et al., 2016a) and address the concepts in this paper either as '*BMI for sustainability or CE*' or '*sustainability-oriented and CE-oriented BMI*'.

### 2.3. CE-oriented BMI

Research on CE-oriented BMI is even more recent than sustainability-oriented BMI, but has grown rapidly in the last five years (Diaz Lopez et al., 2019). So far, the literature has evolved with seminal works discussing the relevance of the topic (Linder and Williander, 2017) or framing the concept (Lewandowski, 2016; Nuβholz, 2017).

As a response to an increasing pressure on our natural resources, CE aims to create multiple types of value with the ultimate goal of achieving a more resource effective and efficient economic system (EMF, 2015). CE-oriented BMI incorporates principles or practices from CE as guidelines for BM design. It aims at boosting resource efficiency and effectiveness (by narrowing or slowing energy and resource loops) and ultimately closing energy and resource flows by changing the way economic value and the interpretation of products are approached (Bocken et al., 2016; Den Hollander and Bakker, 2016).

The incorporation of circular principles into BMs also occurs at different levels, depending on decision makers' ambitions and adopted strategies. Urbinati et al. (2017)'s taxonomy suggests three available modes of integrating CE principles in BMs: *downstream circular* (altering value capture and delivery, through new revenue schemes and customer interface – e.g. pay-per-use models), *upstream circular* (changing value creation systems, e.g. reverse logistics), or *fully circular* (combining upstream and downstream principles). Similarly to the sustainability proactive strategies, the 'fully circular' business strategies are more impactful for the equilibrium of environmental and economic benefits.

CE-oriented BMI also adds uncertainties and complexity to conventional BMI. New variables have to be considered, for instance, reverse on top of forward logistics; quality, quantity and timing of returns of resources; customers perceptions and preferences for 'as new' (Bocken et al., 2018). This requires a systemic and transdisciplinary view (Sakao and Brambila-Macias, 2018), which has been reflected in recent publications exploring the interfaces of CE-oriented BMI with other innovation perspectives, such as product design, value chain and digital technologies (Bocken et al., 2016; Geissdoerfer et al., 2018a). Methodological support for guiding CE-oriented BMI is already available, including a CE standard (BSI, 2017). However, no systematization of the methodological support developed so far has been proposed. Also, although CE has been recognized as a driver for sustainability, explicit relation of sustainability with CE-oriented BMI is missing.

## 3. Research methodology

The main objective of this paper is to systematize the state-of-the-art of available approaches supporting circular-oriented or sustainability-oriented BMI process. These approaches comprise (Osterwalder et al., 2005; Pigosso et al., 2011):

(1) Conceptual frameworks: theoretical approaches promoting common understanding or conceptual alignment about BMI – e.g. diagrams, requirements, typologies, morphologies, taxonomies, ontologies;
(2) Methods: procedures guiding on how to perform BMI – e.g. process model, guidelines.
(3) Tools: instruments supporting the execution of determined BMI activities – e.g. canvas, software.

Based on the overall objective, three research questions were formulated:

R1 - What are the existing approaches for BMI in the context of sustainability and CE?
R2 - Which stages of the BMI process do they support?
R3 - How do they compare to each other?

A systematic literature review was conducted to tackle the overall objective and answer the aforementioned questions. The review protocol (see supplementary information) was organized in three activities: data collection, analysis and reporting (de Almeida Biolchini et al., 2007).

### 3.1. Data collection

Data collection comprised search and selection of existing sustainability-oriented and CE-oriented BMI approaches. The search, in Scopus and Web of Science (July 2018) (Table 1), resulted in 1078 unique publications. In total, 56 publications were selected according to three criteria:

(1) BMI oriented to sustainability or CE explicitly addressed;
(2) Information about the approaches (including foundations and logic) presented;
(3) Generic and holistic approaches proposed (i.e. not addressing specific sectors/individual strategies of CE, e.g. upgrade).

Due to the recent establishment of CE and to capture the content being generated by practitioners, two additional techniques were applied in a second iteration. A backward snowballing approach (Wohlin, 2014) was performed to capture the established and previous conceptual works (through cross-reference) falling outside of the database searches. The references of the initial selected articles from the academic databases were screened and publications were selected according to their relevance (based on their title, venue of publication or authors' background) for sustainability-oriented and CE-oriented BMI. Subsequently, gray literature was investigated (Adams et al., 2017; Tranfield et al., 2003) and influential non-peer-reviewed publications from non-profits organizations or knowledge platforms on sustainability and CE were included (Table 1). The retrieved publications from snowballing or gray literature searches were subjected to the same screening process (filters and criteria) applied for the academic databases (Fig. 1). The literature review resulted in 94 publications (Fig. 1) selected for analysis (see supplementary information).

### 3.2. Data analysis

From the set of 94 publications, 92 approaches were identified (Research Question 1) and organized according to a three-stages BMI process (Research Question 2) (section 4.2.1) following a dynamic capabilities-based view adapted from Teece (2007):

(1) Sensing: identifying opportunities and generating new BM ideas;
(2) Seizing: systematically designing and testing new BM concepts or configurations;
(3) Transforming: building new competences and implementing organizational renewal.

Teece (2007) proposed this multidisciplinary model to explain how organizations should be prepared to continuously adapt and develop innovations, including BMs. Beyond suggesting processes and tools to support the BMI management, the model opens space

**Table 1**
Search parameters (n/a = not applicable).

| Database | Scopus | Web of Science | Ellen MacArthur Foundation (EMF) | CE Practitioner Guide |
|---|---|---|---|---|
| Fields | (1) title, keywords<br>(2) title, keywords, abstracts | (1) title, keywords, abstracts | n/a | n/a |
| Search string | (1) ("circular economy"OR"circle economy"OR circularity OR circle OR circular OR"closed loops"OR"sustainable"ORsustainab*)AND "business models"AND(method OR tool OR framework OR approach OR methodology OR procedure OR technique OR canvas)<br>(2) ("circular economy" OR"circle economy"OR circularity OR circle OR circular OR"closed loops")AND"business models"AND (method OR tool OR framework OR approach OR methodology OR procedure OR technique OR canvas) | | business models | business models |
| Databases filters | English | English | n/a | resource and tool |
| Type of retrieved publications | articles, book chapters, conference papers, reviews | | articles, book chapters, conference papers, thesis, toolkits, manuals, online tools, reports, white papers | |

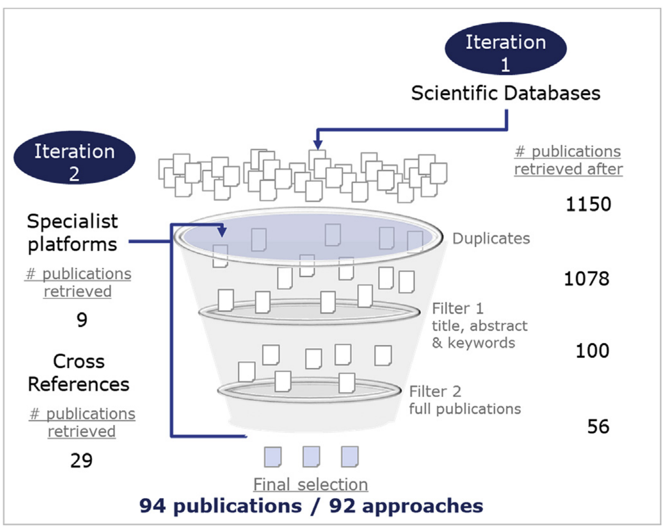


**Fig. 1.** Systematic literature review process and results.

for normative or change management aspects (e.g. values, mindset, behaviors, engagement, leadership), shedding light on how human-behavior (represented by managers or decision makers) plays a role in BMI. In our view, this model represents more adequately the 'real world' phenomena, especially in transformational contexts such as sustainability and CE (Roome and Louche, 2016).

Furthermore, a framework was developed to enable comparison by describing other five characteristics of the approaches (Research Question 3): (a) nature of data (section 4.2.1); (b) BMI characteristics (boundaries of analysis, level of abstraction, and time-related view) (section 4.2.2) and (c) representation style (section 4.2.3). The framework was developed in an iterative process by applying content analysis and coding techniques (Dresch et al., 2015). Initial characteristics were developed upfront (a/b) based on a preliminary literature review. Additional characteristics were added throughout the analysis (c).

## 4. Results

### 4.1. Descriptive findings

Around 34% of the 94 publications (from 2007 to June/2018) are published in the Journal of Cleaner Production (JCLP). The majority is from Europe (85%), with the United Kingdom (26%) leading, followed by the Netherlands (21%), Germany (11%), Sweden (7%) and Finland (7%). The development of CE-oriented BMI approaches lags behind the sustainability-oriented, with the first publication on CE-oriented BMI appearing in 2013, which coincides with a larger effort with dissemination of CE by institutions such as the EMF (EMF, 2012) and the World Economic Forum (WEF, 2014).

Publications show a rising trend after 2015 (Fig. 2, Fig. 3). From the perspective of sustainability-oriented BMI, this might be associated to two special issues focused on BM for sustainability by the journals "Organization and Environment" (Schaltegger et al., 2016a) and JCLP (Dentchev et al., 2018). Likewise, a peak of publications in 2013 coincide with a previous special issue by JCLP (Boons et al., 2013). From the perspective of CE-oriented BMI, the rising trend might be associated to several research projects being funded especially in the European Union since 2014 (European Comission, 2016). Moreover, publications on CE in 2016 have pointed to the lack of appropriate methods and tools for BMI (Bocken et al., 2016; Ghisellini et al., 2016; Lewandowski, 2016), which might have triggered new research lines and contributed to the increasing number of publications in 2017/2018. Still regarding CE-oriented BMI, before 2016 the number of gray literature was larger than the ones retrieved in scientific databases. This is natural considering the very recent dissemination of the concept as a research topic and also due to its appeal to industries and practitioners in general.

The majority of the approaches are either theoretical (45%) or experimental (50%) (Fig. 4). From one perspective, this confirms the necessity of advancing research in these sub-streams and supports studies such as this one that can help shedding light on the critical aspects at this stage and ways forward, but requires parsimony in the interpretations, since the discourse and conceptual foundations might yet suffer modifications. The complete list of 92 approaches is in the Appendix.

### 4.2. Systematic comparison of approaches

Our objective with this comparison is to provide an overview and systematize the state-of-the-art in sustainability-oriented and CE-oriented BMI approaches. We structured it in three blocks.

The first block (section 4.2.1) aims to explore the systemic view of approaches 'composing' the BMI process based on the *dynamic capabilities model*. In relation to the research questions (section 3), it aims to answer what are the available approaches in practice and literature and how they support the BMI process.

The second and third blocks (sections 4.2.2 and 4.2.3) aim to explore the characteristics of single approaches. In relation to research questions (section 3), they aim to answer how the approaches compare to each other.

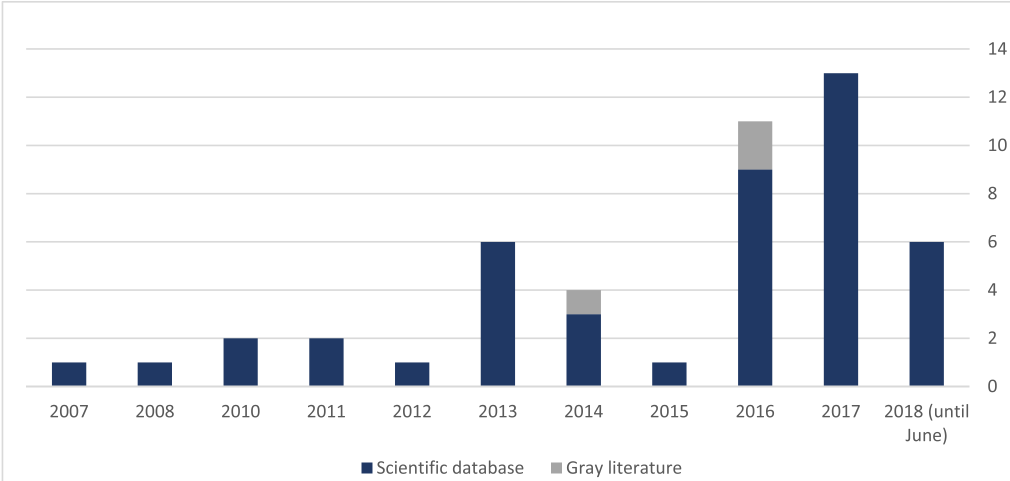


**Fig. 2.** Publications on approaches for sustainability-oriented BMI.

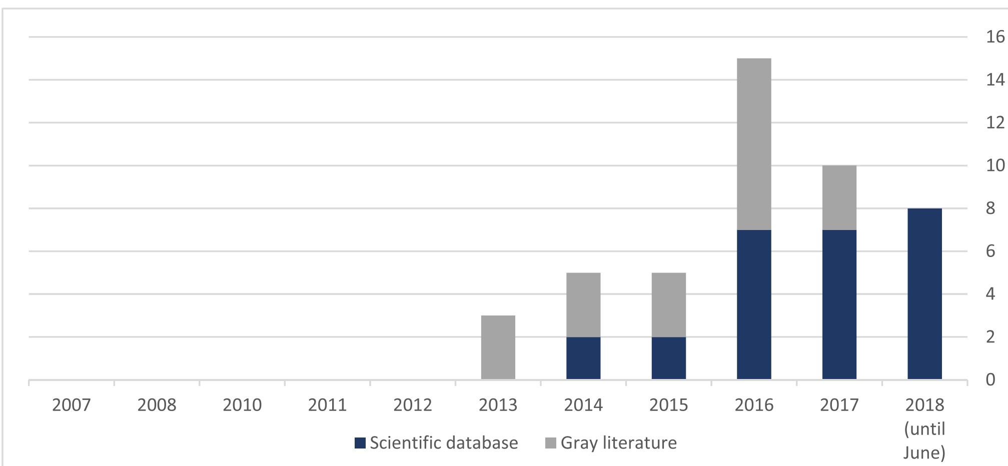


**Fig. 3.** Publications on approaches for CE-oriented BMI.

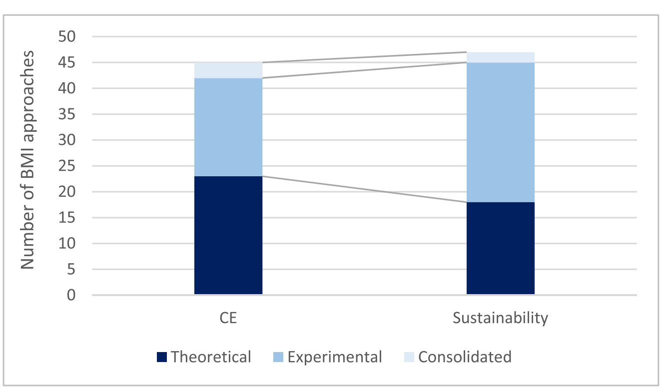


**Fig. 4.** Development level of approaches for sustainability-oriented and CE-oriented BMI. Legend - Theoretical: conceptual studies; Experimental: case studies/pilot projects; Consolidated: applied regularly in companies.

### *4.2.1. Stages of application and data nature*

The distribution of approaches along the BMI process stages are presented in Fig. 5. 80% of the identified approaches support activities related to *sensing* (understanding opportunities) and *seizing* (translating opportunities in BM concepts). Only 20% of the identified approaches address the *transforming* stage, which envisions activities of piloting, preparing the organizational capabilities for change, and implementing the new BM concepts. Although success cases of BMs for sustainability or CE appear in literature (Diaz Lopez et al., 2019) and practice (CircleLab, 2018; EMF, 2018), systematized support with methods/tools that can help the dissemination of more successful implementations are still lacking.

Although the majority of approaches address individual activities of a specific stage, there are some approaches covering the complete BMI process (further discussion in section 4.2.3). Five approaches fall outside of the classification as they are related to conceptual foundations of sustainability-oriented or CE-oriented BMI, transcending the idea of stages [AR48; AR56; AR60; AR86; AR88] (Evans et al., 2017a; Geissdoerfer et al., 2018a; Laasch, 2018; Randles and Laasch, 2016; Schaltegger et al., 2016b).

The majority of approaches (93%) use *qualitative* data for maneuvering decision-making. CE-oriented BMI tend to combine *qualitative* and *quantitative* information. This might be related to a pragmatic CE discourse, oriented to benefit the economic actors of the system and sponsored by practitioners (e.g. businesses, consultancies, government, NGOs) (Geissdoerfer et al., 2017a). It might also explain why approaches originated in gray literature appear

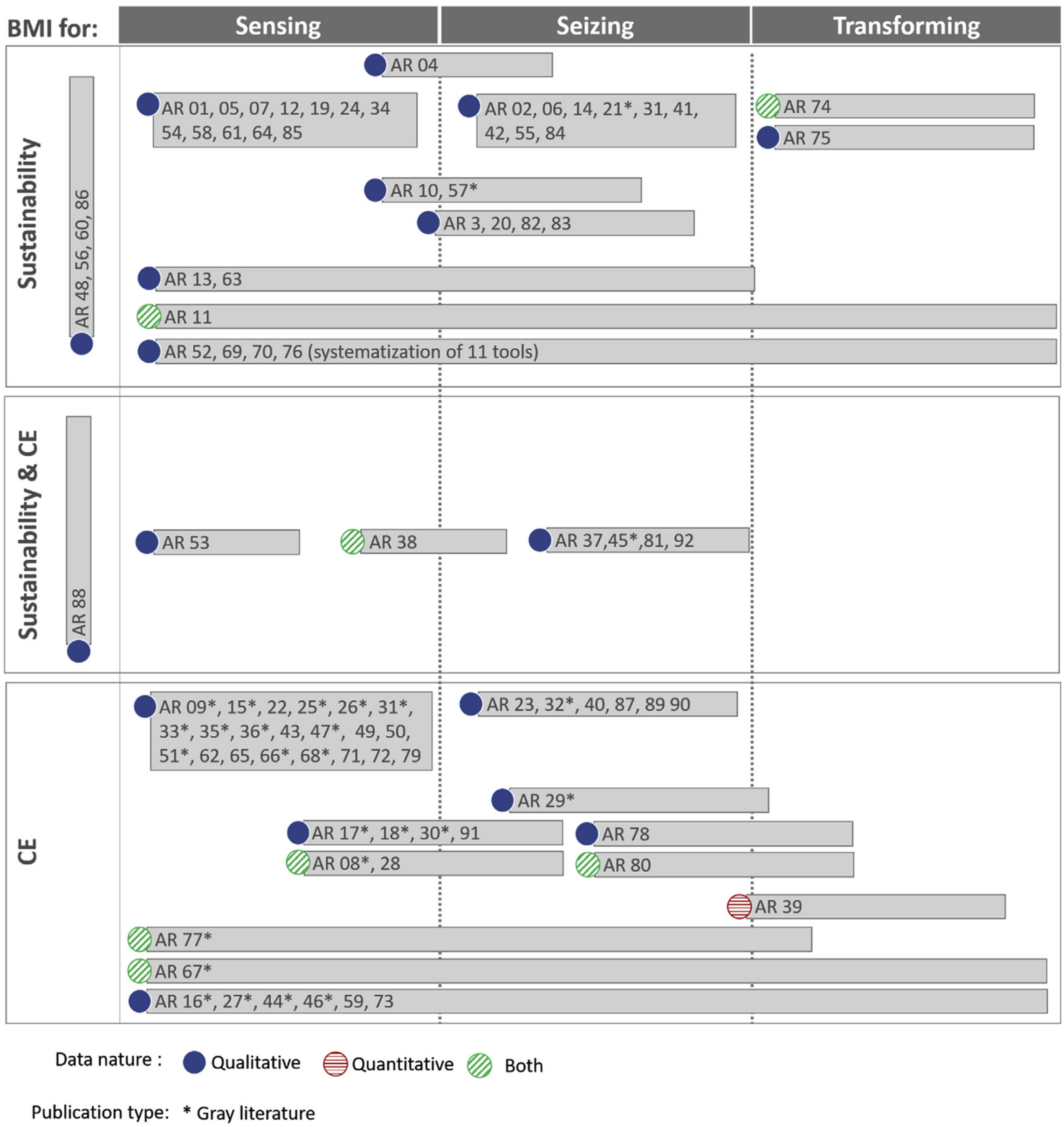


**Fig. 5.** Stages of application and data nature of sustainability-oriented and circular economy (CE)-oriented BMI approaches [AR] (codes at Appendix). Legend for data nature – Qualitative: support subjective analysis providing general guidance; Quantitative: support objective analysis providing quantification; Both: quantitative and qualitative characteristics. Adapted from Inigo et al. (2017) and Teece (2007).

more frequently in CE (check '*' marks on Fig. 5). Examples of methods for quantitative assessments mentioned by these hybrid approaches are business case (with economic indicators such as return on investment, income, net present value, financial and resources savings, margins and splits to suppliers), life cycle assessment, eco-costs, and multi-criteria decision analysis. Although the focus is larger on assessing economic and environmental aspects, Chiu et al. (2015) [AR28] propose a multi-criteria decision analysis for the selection of BM concepts based on product/service system (PSS) envisioning social aspects such as 'interaction among stakeholders', 'diversity' and 'employment opportunities'. The majority of these hybrid approaches are prescriptive in nature, which means that they provide directions for 'what' is required to be performed, but not necessarily guidance on 'how' to do it. Chiu et al. (2015) [AR28] and Scheepens et al. (2016) [AR39] act on that aspect by proposing tools to support the calculations. Asif et al. (2016) and Lieder et al. (2017) also propose a *quantitative* simulation tool based on System Dynamics and Agent Based modelling for assessing economic and environmental performance of different BMs for resource efficiency. Due to the requirement of detailed information, the authors recommend the application in advanced stages of validation or implementation of BM concepts.

Finally, as shown in the middle part of Fig. 5, some approaches explicitly explore synergies of BMI for sustainability and CE. They combine concepts of sufficiency and eco-efficiency with effective solutions (i.e. closed loops) [AR38; AR53] (Bocken and Short, 2016; Scheepens et al., 2016); propose graphical frameworks to represent the BM concepts with elements of sustainability and CE [AR45; AR81] (Bocken et al., 2018; Kraaijenhagen et al., 2016); or suggest assessment approaches to verify the sustainability potential of CE-oriented BMs (as they highlight that circularity might not necessarily lead to enhanced sustainability) [AR37; AR92] (Antikainen and Valkokari, 2016; de Pádua Pieroni et al., 2018).

*4.2.2. BMI characteristics: boundaries of analysis, abstraction level and time-related view*

This section explores the boundaries set by the approaches to analyze the systemic value flows, their level of accuracy, and their view in respect to BM changes over time (Fig. 6; Table 2).

Concerning *boundaries of analysis*, despite the importance of *inter-organizational* collaboration for CE and sustainability, 68% of the identified approaches still adopt *organizational* boundaries. That might be a consequence of their foundations, usually building on approaches from the conventional BM literature that lay more emphasis on value exchanges through the customer interface (i.e. downstream) than on the value creation (i.e. upstream flows) (e.g. BM Canvas (Osterwalder and Pigneur, 2010)). This could also be related to the fact that, in practice, a lot of complexity is added when BMs are explored at the level of inter-organizational boundaries, especially regarding the 'normative organizational aspects' that require new mindset towards alignment of values and establishment of trust among organizations. Only two approaches [AR02; AR86] (Laasch, 2018; Stubbs and Cocklin, 2008) allow for spanning the boundaries of analysis for BMs to a *societal* level. This is consistent with previous findings in literature of sustainability-oriented BMI (Boons and Lüdeke-Freund, 2013).

Concerning *abstraction level*, sustainability-oriented BMI approaches are harmonically distributed into the three categories with the *moderately aggregated* group slightly on the lead (39%). The largest concentration of CE-oriented BMI approaches is at

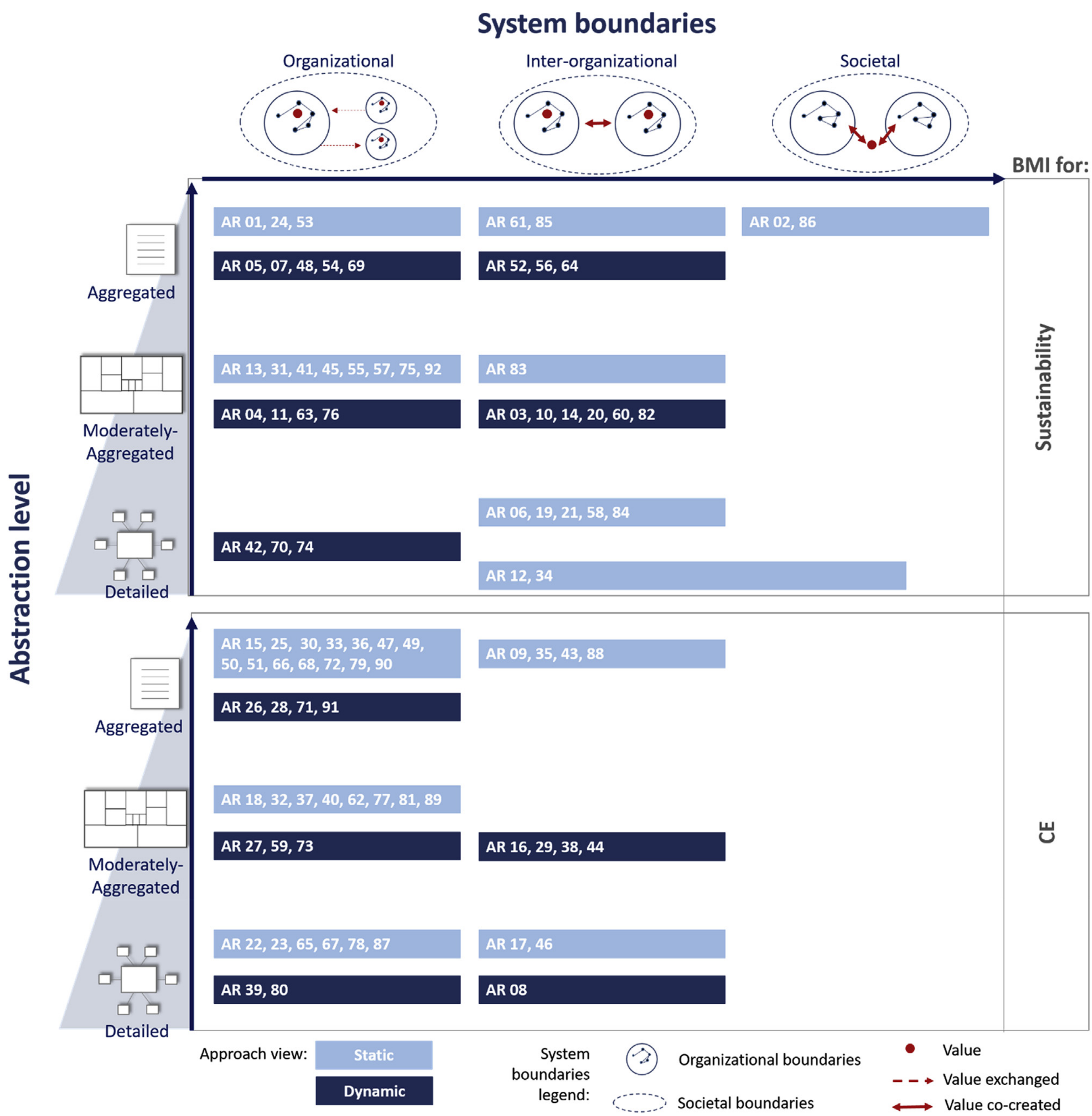


**Fig. 6.** Abstraction level, system boundaries and time-related view of sustainability-oriented and circular economy (CE)-oriented BMI approaches [AR] (characteristics in Table 2; AR codes in Appendix). Adapted from Massa and Tucci (2014).

**Table 2**
Key characteristics of approaches: BMI aspects.

| Characteristics | Alternatives | Meaning | Sources |
|---|---|---|---|
| System boundaries | Organizational | Drivers focused on individual firms and their own value adding activities. | (Boons and Lüdeke-Freund, 2013; Wirtz et al., 2016) |
| | Inter-organizational | Drivers shared by different organizations. Focus on the interrelationship with other actors to co-create shared value. | |
| | Societal | Drivers triggered by societal (or regime) shifts. Focus on interrelationship with other organizations, to produce shared value. | |
| Abstraction level of representation | Highly aggregated | Simple and concise descriptions, i.e. resembles a 'vision' or idea described in low depth (e.g. narrative or archetypes). | Massa and Tucci (2014) |
| | Moderately aggregated | Accurate descriptions, yet with parsimony to keep it simple (e.g. graphics). | |
| | Detailed | Accurate and robust descriptions, adding depth and many details (e.g. flow-charts and relationships). | |
| Variation over time | Static | Describes the BM, focusing on components and their coherence (i.e., a model, blueprint). | (Demil and Lecocq, 2010; Foss and Saebi, 2017) |
| | Dynamic | Focus on transformational perspective and how BMs evolve over time requiring changes in capabilities. | |

*highly aggregated* abstraction level (45%), which envisions concise representations resembling a 'vision' of the BM concept (e.g. narratives or archetypes). This might be a consequence of CE discourse and dissemination outside of academia, which requires simple, concise and 'catchy' messages that allow for the cognition of the concepts by a diverse public, not familiar with CE (e.g. different types of organizations, sectors, skills or functional areas within organizations).

Concerning *perception of changes over time*, the majority of approaches adopt a *static* view, meaning that they interpret the BM concept as 'picture' at a point in time. Only 40% of approaches adopt the *dynamic view*, which triggers the need for continuous activities of *sensing, seizing* and *transforming* within organizations and requires the development and instantiation of BMI processes focused on, for example, sustainability and circularity. Therefore, not only tools (able to perform determined activities at a point in time), but also methods (such as process models or guidelines) are required as supporting approaches. This is further explored in section 4.2.3.

### 4.2.3. Representation styles

This section explores different styles of representation considered in the approaches (Fig. 7; Table 3).

In terms of *conceptual frameworks*, typologies and taxonomies are the most common styles of representation both for sustainability-oriented and CE-oriented BMI (44%). They are used with two purposes to describe:

(1) paths that organizations follow to transform their BMs from profit-oriented ('conventional') to sustainability/CE-oriented [AR54, AR56] (Jabłoński and Jabłoński, 2016; Schaltegger et al., 2016b);
(2) mechanisms or solutions that contribute to designing sustainability/CE-oriented BMs [AR01, AR15, AR24, AR25, AR27, AR33, AR49, AR51, AR53, AR54, AR56, AR68, AR72, AR79, AR85, AR91].

Bocken et al. (2014) [AR24] is the most cited typology, introducing eight archetypes for sustainability-oriented BM (maximize material and energy efficiency; create value from 'waste'; substitute with renewables and natural processes; deliver functionality rather than ownership; adopt a stewardship role; encourage sufficiency; re-purpose the business for society/environment; and develop scale-up solutions). CE-oriented BMI comprises variations of typologies (Accenture, 2014; Bakker et al., 2014; Bocken et al., 2016; Bocken and Short, 2016; Diaz Lopez et al., 2019; Forum for the Future, 2016; Lacy et al., 2013; Weetman, 2016; WRAP, 2018). Some authors attempted to systematize them [AR72, AR79] (Nuβholz, 2017; Planing, 2018), but due to the recent development of the field, it is still early to identify preferences and signs of consensus towards the adoption of one over the others.

Concerning *methods, process models* (considered one type of *method* in our classification) covering the three stages of BMI are the least frequent category of approaches (14%). The ones available differ considerably in the names for the BMI stages and the content presented, which might include required activities [AR16, AR52, AR70, AR73] (Antikainen et al., 2017; Geissdoerfer et al., 2017b; Mentink, 2014; Roome and Louche, 2016), expected deliverables [AR52, AR73] (Antikainen et al., 2017; Roome and Louche, 2016), applied tools [AR11] (Girotra and Netessine, 2013), challenges and enablers [AR52, AR70] (Geissdoerfer et al., 2017b; Mentink, 2014; Roome and Louche, 2016), or organizational change management tasks [AR44, AR52] (Kraaijenhagen et al., 2016; Roome and Louche, 2016)). They also have varied styles of representation ranging from textual documents [AR13, AR46] (Holgado et al., 2013; Weetman, 2016) to visual representations, such as linear process flows [AR52, AR67, AR70, AR73] (Antikainen et al., 2017; Geissdoerfer et al., 2017b; REBus, 2015; Roome and Louche, 2016), circular process flows [AR16, AR27, AR44, AR59] (Kraaijenhagen et al., 2016; Mendoza et al., 2017; Mentink, 2014; van Renswoude et al., 2015), and innovation-like funnels [AR11, AR63] (França et al., 2017; Girotra and Netessine, 2013).

Concerning *tools*, the ones focused on visualization of the BM concepts are the most applied. Different types of visualization tools are available, ranging from component based diagrams in canvas format [AR3, AR10, AR18, AR20, AR21, AR28, AR29, AR31, AR32, AR37, AR40, AR41, AR45, AR57, AR63, AR77, AR81, AR89] (Antikainen and Valkokari, 2016; Bocken et al., 2018; Breuer and Lüdeke-Freund, 2014; Chiu et al., 2015; Dewulf, 2010; EMF, 2016; França et al., 2017; Jones and Upward, 2014; Joyce and Paquin, 2016; Kraaijenhagen et al., 2016; Lewandowski, 2016; Mentink, 2014; Nuβholz, 2018; Rohrbeck et al., 2013; Sempels, 2013; Sustainn, 2017; Tiemann and Fichter, 2016; Wiithaa, 2018), circular format [AR35] (Materials, 2016), or life cycle format [AR19, AR78, AR89] (Manninen et al., 2018; Nuβholz, 2018; Yang et al., 2017a,b); arrow or process diagrams [AR19, AR58, AR63, AR74, AR77] (França et al., 2017; Kurucz et al., 2017; Sustainn, 2017; Yang et al., 2014; Yang et al., 2017a,b); matrices [AR61] (Haanstra et al., 2017); flowcharts or loops [AR17, AR26, AR36, AR84] (Achterberg et al., 2016; Bakker et al., 2014; Brehmer et al., 2018; Mentink, 2014); co-centric geometric forms [AR12, AR38] (Bocken et al., 2013; Scheepens et al., 2016); tables or lists [AR43] (Aminoff et al., 016); and hierarchical representations of circular strategies or of the life cycle [AR36] (Achterberg et al., 2016).

The representation styles are different along the three BMI stages, as they vary in objective and expected deliverables. For instance, the 'seizing' stage is uniformly supported by component-

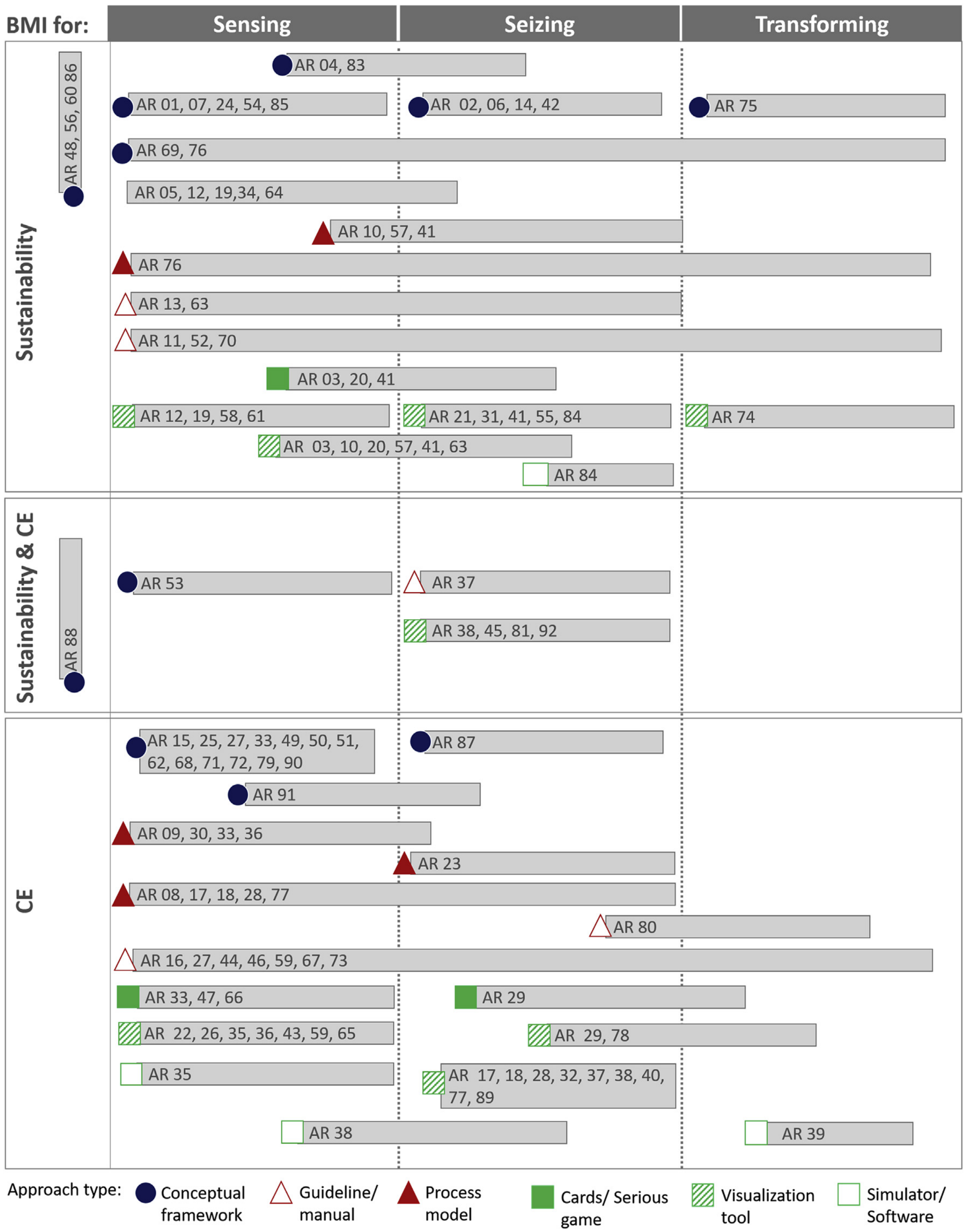


**Fig. 7.** Styles of representation of sustainability-oriented and circular economy (CE)-oriented BMI approaches [AR] (characteristics in Table 3; AR codes in Appendix). Adapted from Inigo et al. (2017) and Teece (2007).

based diagrams tools that represent the BM design options for alternative configurations. On the other hand, tools for 'sensing' opportunities are more diverse in shape, as the activity is abstract and creative.

Visualization tools are especially important and recurrent in the 'seizing' stage, where they provide an easy and collaborative way of defining the composition (in terms of elements) of future BMs. The tools are usually variations of conventional BMI tools. For instance, tools for 'seizing' being proposed until 2017 often ended up with variations of the BM Canvas (Osterwalder and Pigneur, 2010). New approaches from 2018 started to build on the Activity Systems perspective (Zott and Amit, 2010), as they defend that it enables a more adequate fit with collaborative requirements of sustainability or CE, with enhanced visualization and consideration of multiple stakeholders beyond the firm-centric view.

**Table 3**
Key characteristics of approaches: representation styles.

| Alternatives | | Meaning | Sources |
|---|---|---|---|
| Method | Guideline/ manual | General guidelines to be followed during the BMI and design. | (Lüdeke-Freund et al., 2018; Osterwalder et al., 2005; Pigosso et al., 2011) |
| | Process model | A set of activities and steps that represents the complete or parts of the process for BMI. | |
| Tool | Cards | Paper-based tool describing opportunities/design options. | |
| | Serious game | Paper-based/computational tool that simulates a part or the complete BMI process. | |
| | Visualization tool | Paper-based/computational tool using visual techniques to represent the logic of value generation/flow within one/multiple organizations. | |
| | Simulator/ Software | Computational tool supporting the application of BM tools (might include concepts of decision making theory). | |

## 5. Discussion

This section discusses the key findings of the study with respect to the research questions (section 3), identifying the most important trends in approaches for CE-oriented and sustainability-oriented BMI. Moreover, the main gaps are summarized and translated into a future research agenda.

### 5.1. Key research findings

Although recent, research on approaches for sustainability-oriented and CE-oriented BMI is receiving increasing attention. This research identified, compared and categorized 92 approaches. A key finding is that these proposed approaches usually address individual stages of the BMI without considering the continuous activities necessary to adapt the companies' capabilities to the dynamic changes (internally or externally) required by 'CE/sustainability thinking'. Many publications do not contextualize the BMI stage in which they are contributing to, as if they assumed that BMI was only about single stages (e.g. designing BM representations). These results are consistent with recent findings in conventional BMI literature (Wirtz et al., 2016), indicating that these topics are not comprehensively considered by researchers, despite its importance and complexity (Foss and Saebi, 2017). Moreover, it could be contributing to a design-implementation gap in sustainability-oriented BMI (Ceschin, 2013; Geissdoerfer et al., 2017b).

The analyzed approaches seem to be more advanced in helping companies in identifying opportunities (sensing) and designing new business model concepts for CE or sustainability (seizing). However, there is a lack of methods/tools for experimenting, testing, and implementing the BM concepts (transforming). Bocken et al. (2018) emphasize the importance of experimentation and the on-going 'learning by doing' process for sustainability-oriented/CE-oriented BMI. Similar gaps were identified in the innovation processes for products (Brones and Monteiro de Carvalho, 2015) or services (Lee, 2016; Rosa et al., 2017), and might be due to required skills/knowledge from other fields (e.g. project management, organizational change management) transcending the expertise of innovation/design; or needs for longitudinal research approaches, which have a longer-term nature than design and conceptualization. Without envisioning this last stage, we will not truly understand the effectiveness and impact of BMI approaches to leverage sustainability or CE principles.

A second key finding emerging from the comparison indicates that CE/sustainability-oriented BMI approaches are becoming more heterogeneous and relying on multiple theories that deviate from the traditional view disseminated by the BM Canvas (Osterwalder and Pigneur, 2010). Variations lie in the way approaches adopt boundaries to analyze systemic value flows (organizational, inter-organizational, and societal), the level of accuracy enabled in the BM concepts representation, the view in respect to changes in the BM over time, and mainly, in the types and styles of BM representation. Examples of types of representation include checklist, figure/model, visualization tools, guideline/manual, matrix, morphology/morphological box, ontology, process model, requirement, serious games, simulator/configurator, software, taxonomy, typology. Each type of approach presents also multiple styles; for instance, visualization tools present more than ten variations (e.g. canvas format, matrices, life-cycle format). There seems to be a correlation of particular representation styles in different BMI stages, as they vary in objective and expected deliverables. Usually the level of details in the BM representation enabled by the approach increases as it gets closer to the *transforming* stage. Regarding the boundaries set by the approaches to analyze the systemic value flows, there is a trend of approaches moving to an inter-organizational (Biloslavo et al., 2018; Brehmer et al., 2018) or societal levels (Laasch, 2018; Stubbs and Cocklin, 2008), as this aligns better with sustainability/CE principles.

A third key finding regards a limitation of incorporation of human-behavior aspects into the approaches. Randles and Laasch (2016) and Boons and Lüdeke-Freund (2013), discuss the role of normative aspects, such as leadership and organizational culture in enabling the transformation towards sustainability-oriented BMI. Kraaijenhagen et al. (2016) incorporate change management activities in their cyclical process for CE-oriented organizational transformation. Our intention with employing Teece (2007)'s dynamic capabilities model as the backbone for the categorization of approaches was exactly to broaden the lens of innovation management to include normative and change management aspects, which in our view represents the real world phenomena with superior fidelity. The framework worked successfully in the categorization and enabled explaining the complex process more concisely than alternative models identified in this study (e.g., Geissdoerfer et al. (2017b); Girotra and Netessine (2013); Mentink (2014)). Moreover, it helped emphasizing the gap in human-behavior orientation in CE/sustainability-oriented BMI approaches, which might be hindering an impactful application of methods/tools. Lastly, the BMI stages based on a dynamic capabilities view can facilitate the coordination with other innovation processes that focus on different BM elements (e.g. product development, processes innovation) (Mezger, 2014), which is fundamental to guarantee that the sustainable or circular values embedded in a specific BM architecture will be seized after the BM implementation (Pieroni et al., 2018).

Finally, as a fourth key finding, researchers' discourses seem to converge about the notion that CE is 'one way' - and not the only one - towards sustainability, and that CE-oriented BMs are 'a possible archetype' (Bocken et al., 2014) of sustainability-oriented BMs. However, the interface of both concepts is superficially addressed by the approaches, undermining the potential capture of synergies of both research streams, such as for instance, the assessment whether CE BMs are truly contributing to the ultimate target of sustainable development or whether and how approaches can be used interchangeably in both streams. Especially regarding the development of methods/tools, the streams seem to be following 'individual' paths, with few works applying the concepts simultaneously (Antikainen and Valkokari, 2016; Bocken et al., 2018; Bocken and Short, 2016; de Pádua Pieroni et al., 2018; Geissdoerfer et al., 2018a; Kraaijenhagen et al., 2016; Scheepens et al., 2016).

To advance this aspect, we propose a comparative view based on the scope or core drivers for value generation usually adopted by CE/sustainability-oriented BMI approaches (Fig. 8). This aims to suggest an initial reflection to promote future research (complementing the systematic comparison from section 4.2).

The comparative view is built upon approaches that explicitly discuss principles for sustainability-oriented or CE-oriented BMI (Bocken et al., 2016; Breuer et al., 2018; Geissdoerfer et al., 2018a; Wells, 2016), and complemented by examples of other approaches' positioning in regards to the CE-oriented vs. sustainability-oriented BMI scope (top lane of Fig. 8). Moreover, we provide examples (second/third lanes in Fig. 8) of how BMI archetypes or design options are addressed differently by approaches from each scope. Approaches from sustainability-oriented BMI usually suggest additional BM archetypes (e.g. base of pyramid solution) and BM design options (e.g. participatory approaches) when compared to CE-oriented BMI.

Providing customer superior value is a driver both for CE-oriented and sustainability-oriented BMI, as without this, the value capture in monetary terms might not occur, hindering the longevity of the business (de Pádua Pieroni et al., 2018; Geissdoerfer et al., 2018a; Lüdeke-Freund, 2010). On top of that, the main drivers for CE-oriented BMI are resource efficiency, resource longevity/effectiveness, and economic growth (despite natural resource restrictions) (Geissdoerfer et al., 2017a). CE-oriented BMI might also generate value to social relevance or work enrichment, but those are depicted as secondary effects (dotted arrow in Fig. 8), instead of core drivers for value generation. When this happens, CE-oriented BMI (green-ellipse in Fig. 8) contributes positively to the wider scope of sustainability (blue ellipse in Fig. 8). However, negative effects might also occur. According to Urbinati et al. (2017), design options for CE might be partially in place in the BMI. For instance, they can foster solely downstream circularity, seeking for customer superior value (e.g. cheaper access to a product by paying-per-use instead of paying-for-ownership). Not necessarily, appropriate upstream design options (e.g. 'closed-loop reverse logistics') are in place, hence the drivers of resource efficiency/longevity are not deployed. In that case, BMI might generate negative secondary effects that are unsustainable, such as over-consumption, fast obsolesce/replacement (e.g. pay-per-use cell phone schemes allowing customers to get the latest model every year; generation of toxic material during recycling).

Differently from CE-oriented BMI, sustainability-oriented BMI holds social relevance as a key driver for value generation on top of resource efficiency/longevity and superior customer value. Another difference, is the consideration of trade-offs regarding the economic perspective. This means, business longevity and sufficiency (e.g. in consumption/production) can be prioritized over a rapid profit-maximization strategy in order to perpetuate the positive

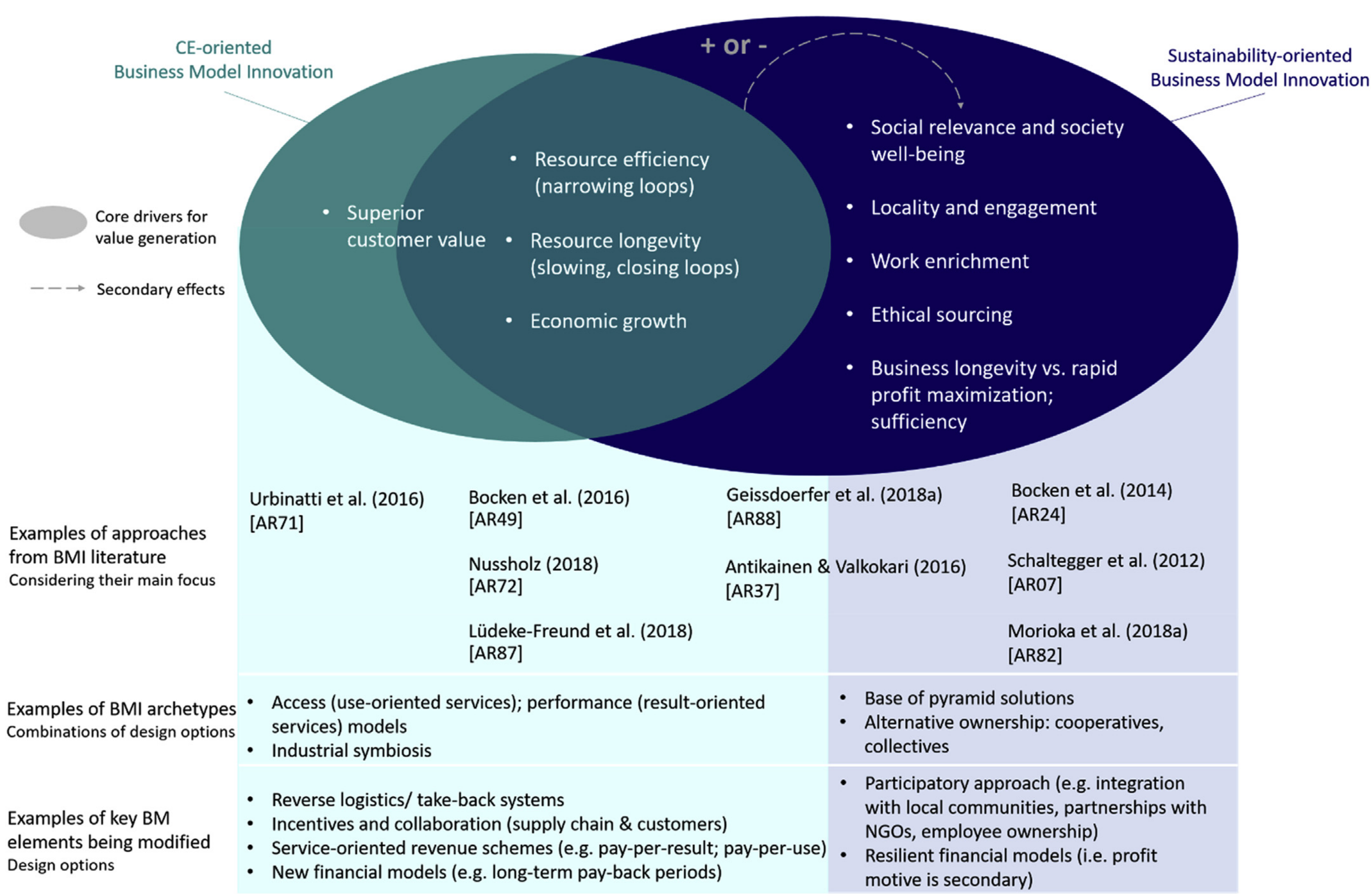


**Fig. 8.** Comparison of scopes of CE-oriented and sustainability-oriented business model innovation approaches.

impacts on social or environmental aspects. To better illustrate the differences, we compare two company-cases: FLOOW2 and Globechain. FLOOW2 is a business-to-business marketplace facilitating rental/sales of used equipment, services, and knowledge of personnel. FLOOW2's main value proposition is CE-oriented: to help customers in reducing costs or increasing revenues with better allocation/use of idle assets. However, they promote secondary benefits related to social relevance and work enrichment as a consequence of the 'sharing' configuration, i.e., a new dynamics and culture of collaboration that stimulates connection and toleration (CircleLab, 2018). Globechain is also a platform to facilitate reuse, connecting businesses and charities. Their value proposition is inserted in the scope of sustainability, since they aim to enable global redistribution of goods to social causes rather than disposal. As part of their value proposition, they support donor companies with waste audits and social impact value assessments (CircleLab, 2018).

In summary, CE-oriented BMI is not always able to capture the full potential of sustainability. Some CE-oriented BM configurations, even when fully circular, might generate negative secondary effects. On the other hand, they might contribute positively to sustainability-oriented BMI principles. Finally, not all CE-oriented BMI approaches accommodate sustainable principles and not all sustainability-oriented BMI approaches accommodate circular principles. These considerations reflect academic discussions presented until now. However, CE is in a development trajectory (Blomsma and Brennan, 2017). Considerations of its scope might change, incorporating potentially even more constructs from the wider space of sustainability.

### *5.2. Advancing research on sustainability-oriented and CE-oriented BMI*

The systematic comparative analysis of the 92 approaches enabled the identification of gaps either pointed as limitations by the authors or inferred with the support of the characteristics employed for analysis. We translated these gaps into future research needs and structured proposals to advance research on approaches for sustainability/CE-oriented BMI divided in four aspects (Fig. 9):

(1) Establishing consensual foundations and taking advantage of synergies:
- Moving beyond the customer interface: publications diverge in their interpretation of BM and some have a reductionist approach, interpreting BM solely as the commercial or revenue model configurations (downstream value generation logic). Especially for CE, decisions regarding the upstream value logic structure are as important as downstream and fundamental to enable closed-loop configurations in value chains. Future research should work for establishing a consensus and emphasizing that sustainability/CE-oriented goes beyond the customer interface.
- Consolidating types of mechanisms/configurations: the existence of different propositions of archetypes for CE-oriented BMs without a consensus might hinder the knowledge consolidation in the field. Establishing common discourse/language to facilitate the dissemination and adoption of circular objectives collaboratively at an inter-organizational or societal level is fundamental. A recently issued British standard (BS 8001:2017) provides guidance on the possible types of BM that can be compatible with CE, including considerations for their selection. They present seven BM groupings: (1) *on demand*, (2) *dematerialization*, (3) *product life cycle extension/reuse*, (4) *recovery secondary raw materials/by-products*, (5) *product as a service/product-service systems (PSS)*, (6) *sharing economy/platforms and (7) collaborative consumption.* Maybe this could be a first step to starting a convergence of terminology.
- Integration of sustainability and CE-oriented BMI: the simultaneous application of CE-oriented and sustainability-oriented BMI approaches is still not fully explored. We have proposed in section 5.1, an initial comparison of BMI scope for both streams in order to initiate a proactive discussion and exploration of synergies. Some BM methods already suggest using sustainability tools into CE contexts. Future research should explore their applicability and appropriate combinations.

(2) Addressing sustainability-oriented and CE-oriented BMI as a continuous/holistic process:
- Holistic view: as indicated in section 5.1, approaches in general could benefit from exploring CE/sustainability BMI with 'process model' lenses. To avoid confusion and contribute to the required longitudinal transformational perspective, where new abstract values and visions need to be disseminated and translated into the operative level, we encourage researchers to contextualize their contributions in regards to the holistic view of BMI in light of principles of CE/sustainability. Process models have been proposed (Fig. 7), so authors could either decide to reference the existing ones (i.e. we adopted the three stages 'sensing', 'seizing', 'transforming') or systematize new proposals. No matter how it will occur, it is important to clarify the dynamic nature of BMI to implement principles (i.e. it is a continuous and long journey instead of a single shot initiative).
- Design-implementation gap: in section 5.1, we pointed out the trend of exploring experimentation approaches for sustainability/CE-oriented BMI (Bocken et al., 2018). Beyond this, future research aiming to contribute to decreasing this gap could engage in integrating knowledge from other theories – e.g. strategic and long-range planning (Phaal et al., 2004), entrepreneurship, project/organizational transformation management (Chapman, 2002), and dynamic capabilities (Teece, 2007). This requires new empirically oriented tools and research methods (check groups 3/4).

(3) Adapting existing methods/tools or exploring new ones to fill in specific gaps:
- Inter-organizational and societal boundaries: the majority of methods and tools still adopt organizational boundaries. Future research should explore how to take the inter-organizational or societal boundaries into account. Some recent tools already incorporated that by adopting different theories from conventional BMI beyond the BM Canvas. We expect that the adoption of Activity Systems (Zott and Amit, 2010) or other new theories might increase in the future.
- Quantitative methods and tools: another future need is the development of quantitative methods and tools to support decision-making. Such tools could propose indicators and measures to assess different concepts of BM economically, environmentally and socially. Attention should be placed on discussions of what types of indicators and assessments to apply for each stage of BMI as a consequence of different levels of detail and intentions. The quantitative assessment could also serve as bridge for the design-implementation gap (Geissdoerfer et al., 2018b), as a way of establishing

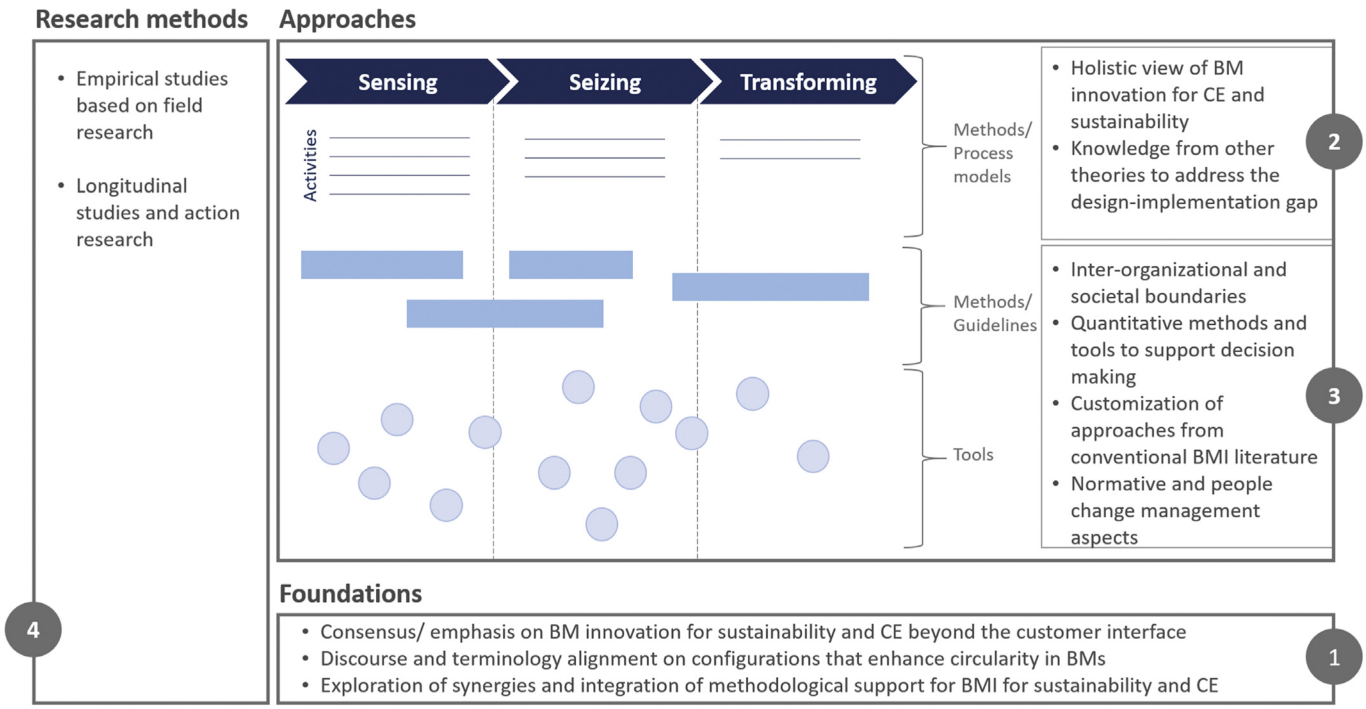


**Fig. 9.** Research framework and guideline for selection of approaches for sustainability-oriented and circular economy (CE)-oriented business model (BM) innovation.

concrete targets for business outcomes that should be monitored longitudinally along the BMs implementation.

- Customization of approaches from conventional BMI literature: It might also be the case that new tools are not necessary, but instead, the customization of existing ones. The notion that BMI for sustainability or CE is a process and not only the outcome, implies that a combination of tools might be required and not only one single visualization tool. In that case, it might be worth exploring how tools from conventional BMI, that are already consolidated, could be adapted or supplemented with other tools for sustainable or resource efficiency innovation in order to instigate circular/sustainable thinking.
- Normative and people change management aspects: values (individual, organizational, societal), organizational culture, mindset, effective communication and leadership are important to be in place, in addition to effective tools or methods (Birkin et al., 2009; Lüdeke-Freund et al., 2018; Randles and Laasch, 2016). These aspects are catalyzers for incorporating sustainability principles into BMI (Randles and Laasch, 2016). The embedment of these considerations in the methodological support development shall be further explored.

(4) Applying different research methods:

- Empirical studies: empirical studies based on field research are required to move the composition of approaches from theoretical/experimental stage and contribute to their maturation.
- Longitudinal studies and action research: the implementation of BM concepts is as important as designing them, as this leads to real transformations in organizations. This should be investigated with practical research methods such as (i) action research, which enables the investigation of the aspects or results of the use of the conceptual frameworks, methods and tools in real-time, instead of only retroactively; and (ii) longitudinal research, which enables the evaluation of the long-term consequences and results of applying the approaches, and consequently their success.

## 6. Conclusion

This research aimed to identify and systematize CE-oriented and sustainability-oriented BMI approaches available in literature and practice, in order to provide a clear overview on this topic for scholars and practitioners.

Applying a three-stage (sensing, seizing, transforming) dynamic capabilities-based view as the backbone to represent the stages of BMI, this article systematically identified and compared 92 approaches – i.e. conceptual frameworks, methods and tools - for sustainability/CE-oriented BMI based on six characteristics: stages supported in the BMI process; nature of data; boundaries of analysis; level of abstraction; time-based view; and representation style.

Based on the analysis, key findings outlining trends of approaches were identified: approaches are becoming more *heterogeneous and relying on multiple theories that deviate from the traditional view disseminated by the BM Canvas*; the *simultaneity of BMI approaches envisioning sustainability and CE principles is emerging timidly* and deserves more exploration to flourish; a *design-implementation gap might be associated to approaches focusing on single stages* of BMI and also a *negligence of human-behavior aspects*. Connected to our first key finding, we proposed an initial comparison for CE/sustainability-oriented BMI based on their scope or drivers for value generation. Moreover, a number of gaps and future research agenda to advance both fields simultaneously were outlined: (1) *establishing consensual foundations and taking advantage of synergies*, (2) *addressing CE/sustainability-oriented BMI as a continuous and holistic process*, (3) *adapting existing methods/tools or exploring new ones to fill in specific gaps*, and (4) *applying different research methods.*

By systematizing a comprehensive collection of approaches currently available to support sustainability/CE-oriented BMI, the research provides contributions for:

- Practitioners: an overview of existing approaches for sustainability-oriented or CE-oriented BMI on the basis of dynamic capabilities;
- Researchers: a starting point for understanding the foundations of approaches, providing guidance on where to focus future research; and,
- Research community: advancing the discussions about the intersection between CE-oriented and sustainability-oriented BMI literature.

Limitations of this research are related to techniques applied for the literature review. The search in academic databases was followed by snowballing and inclusion of non-peer reviewed materials from specialist institutions, which by nature may generate selection bias. Moreover, the fast development of the field has led to many new publications within a short interval. Many analyzed approaches are still being validated/refined, therefore their usefulness has not yet been confirmed in all cases.

As mentioned, challenges identified by this research require future empirical work. This paper documents the first step of a comprehensive research to propose a CE-oriented BMI approach, but with a broader view of sustainability performance, based on best available practices. The proposed approach will be co-developed with industry in action research cycles. Case studies will test the application of the approach and explore what are the specific BM patterns/configurations favoring a sustainable CE in different contexts.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2019.01.036.

## Appendix

**Table 4**
Approaches for sustainability-oriented and CE-oriented BMI. Legend for *Origin*: S= Sustainability; CE= Circular Economy; B = both.

| Code | Origin | Description | References |
|---|---|---|---|
| AR01 | S | Framework for analyzing material efficiency services BMs. | Halme et al. (2007) |
| AR02 | S | Framework with dimensions and characteristics for sustainability-oriented BMs. | Stubbs and Cocklin (2008) |
| AR03 | S | *Play it forward*: game-based tool for designing BMs with sustainability principles. | Dewulf (2010) |
| AR04 | S | BMI process for sustainability, combining transformational sustainability strategies, eco-innovation, and key ideas about value creation. | (Lüdeke-Freund, 2010; Roos and Agarwal, 2015) |
| AR05 | S | *Sustainable innovation workshop*: framework of methods for sustainability driven innovation. | Panarotto and Törlind (2011) |
| AR06 | S | Value cycle framework to embed sustainability in current views of supply chain. | Barber et al. (2012) |
| AR07 | S | Framework of a business case for guiding sustainability-oriented BMI. | Schaltegger et al. (2012) |
| AR08 | CE | Workbook providing guidance on the search for CE-oriented BMs. | (de Jong et al., 2015; Joustra et al., 2013) |
| AR09 | *CE* | *Circular Economy Toolkit*: information on how to find CE benefits in several areas, including BMI. | Evans and Bocken (2013) |
| AR10 | S | Process for 'collaborative business modelling' to foster sustainability innovation. | Rohrbeck et al. (2013) |
| AR11 | S | Systematic stage-gate process of innovation for sustainable firms. | (Girotra and Netessine, 2013; Roos and Agarwal, 2015) |
| AR12 | S | *Value Mapping Tool*: for exploring value opportunities for sustainability-oriented BMs. | (Bocken et al., 2013, 2015; Khripko et al., 2017; Short et al., 2013) |
| AR13 | S | Process for embedding sustainability in BM design by analysing value exchanges and exploring social and environmental values. | Holgado et al. (2013) |
| AR14 | S | Normative requirements of BMs for sustainable innovation. | Boons and Lüdeke-Freund (2013) |
| AR15 | CE | Typology of 5 BMs for CE. | (Accenture, 2014; Lacy et al., 2013) |
| AR16 | CE | *Circular BM Innovation Framework*: process to plan the BMI for CE. | Mentink (2014) |
| AR17 | CE | *Business Cycle Canvas*: tool for designing BMs for CE with focus on the network view. | Mentink (2014) |
| AR18 | CE | Extended version of BM Canvas to support the design of BMs for CE, still with firm-centric view. | Mentink (2014) |
| AR19 | S | *Sustainable Value Analysis Tool*: for identifying opportunities for sustainable value creation during product/service system (PSS) development. | (Yang et al., 2014; Yang et al., 2017a,b) |
| AR20 | S | Business Innovation Kit: game-based tool for designing BMs for sustainable value networks. | Breuer and Lüdeke-Freund (2014) |
| AR21 | S | *Strongly Sustainable BM Canvas*: tool for designing strongly sustainable BMs. | (Jones and Upward, 2014; Kurucz et al., 2017) |
| AR22 | CE | Process for developing BMs for circular value chains. | (Roos, 2014; Roos and Agarwal, 2015) |
| AR23 | CE | Framework showing how companies could integrate CE principles by changing business processes, including BMI. | Laubscher and Marinelli (2014) |
| AR24 | S | Typology of 8 BMs archetypes for sustainability. | Bocken et al. (2014) |
| AR25 | CE | BM archetypes for CE. | Bakker et al. (2014) |
| AR26 | CE | Framework for aligning product design and BM design strategies for CE. | Bakker et al. (2014) |
| AR27 | CE | *Circular BM Scan*: method for CE transition, including insights on what BMs to adopt (typology of 19 BMs) and implementation burdens. | van Renswoude et al. (2015) |
| AR28 | CE | Methodology for developing BMs of PSS based on internal capability and external environment factors. | Chiu et al. (2015) |
| AR29 | CE | *Circulab Game*: 3 game-based tools for 'ecodesigning' BMs, exploring relationships with partners and planning the evolution over time. | Wiithaa (2018) |
| AR30 | CE | *CE Business Toolkit*: to develop a circular strategy by identifying strategic opportunities, analysing value chain, and choosing BM options. | National Zero Waste Council (2016) |
| AR31 | S | *Sustainable BM Canvas Tool*: for designing BMs based on circular and performance economy. | Sempels (2013) |

**Table 4** (*continued* )

| Code | Origin | Description | References |
|---|---|---|---|
| AR32 | CE | Adaptation of BM Canvas for joint application with other tools from a *Circular Design Guide*. | EMF (2016) |
| AR33 | CE | *CE BM Toolkit*: created by Unilever to inspire the development of circular systems based on circular BM archetypes. | (Forum for the Future, 2016) |
| AR34 | S | Framework integrating existing approaches of value mapping and design thinking to support creating value propositions. | Geissdoerfer et al. (2016) |
| AR35 | CE | *Circular BMs Mixer:* web-based tool providing an overview of the most relevant BMs for raw materials industry in the context of CE. | Materials (2016) |
| AR36 | CE | *Value Hill*: tool for identifying gaps and opportunities for the transition to CE, involving new BMs. | Achterberg et al. (2016) |
| AR37 | B | *Framework for Sustainable Circular BMI*: tool for designing and reconfiguring BMs for CE. | Antikainen and Valkokari (2016) |
| AR38 | B | *Circular Transition Framework*: for sustainability-oriented BM design based on analysing potential negative environmental effects of initiatives. | Scheepens et al. (2016) |
| AR39 | CE | Multi-method simulation tool to evaluate economic and environmental performance of circular-oriented BM systems. | (Asif et al., 2016; Lieder et al., 2017) |
| AR40 | CE | *Circular BM Canvas*: conceptual framework to support the transition from linear to more circular-oriented BMs. | Lewandowski (2016) |
| AR41 | S | *Triple Layered BM Canvas*: tool for exploring sustainability-oriented BMI in the creative conceptual phase. | (Joyce, 2017; Joyce and Paquin, 2016) |
| AR42 | S | *Strongly Sustainable BM Ontology*: for modelling sustainability-oriented businesses. | Upward and Jones (2016) |
| AR43 | CE | Framework for mapping multidimensional value(s) for co-creation networks in CE. | Aminoff et al. (2016) |
| AR44 | CE | 10 steps process model for the creation of circular businesses within existing organizations. | Kraaijenhagen et al. (2016) |
| AR45 | B | *Sustainable BM Framework*: tool for designing sustainability-oriented BMs. | Kraaijenhagen et al. (2016) |
| AR46 | CE | Strategic process for implementation of BMs for CE inspired by whole-system design. | Weetman (2016) |
| AR47 | CE | Game-based tool for whole systems design and identification of BMs for CE. | Weetman (2016) |
| AR48 | S | Theoretical model to guide the organizational transformation required for implementing BMs for sustainability. | Randles and Laasch (2016) |
| AR49 | CE | Framework of strategies for BM and product design for CE. | Bocken et al. (2016) |
| AR50 | CE | Systematization of BM archetypes and framework to link BM and design strategies for CE. | Moreno et al. (2016) |
| AR51 | CE | *CE Framework*: overview of commercial models for CE. | Weetman (2016) |
| AR52 | S | Process model of BM development and organizational transformation for sustainability. | Roome and Louche (2016) |
| AR53 | B | *Sustainable BM Framework*: tool to support the design of BMs for sustainability or CE. | Bocken and Short (2016) |
| AR54 | S | Typology for three levels and key changes towards BM for sustainability. | (Jabłoński and Jabłoński, 2016) |
| AR55 | S | 5 main factors and respective subfactors that lead to sustainability in BM design of PSS. | Barquet et al. (2016) |
| AR56 | S | Analytical framework to describe the sustainable entrepreneurship process from BMI to diffusion of sustainability-oriented BM in the mass market. | Schaltegger et al. (2016b) |
| AR57 | S | *Sustainable Business Canvas*: tool and manual for designing sustainability-oriented BMs based on workshops. | Tiemann and Fichter (2016) |
| AR58 | S | Framework to guide manufacturing companies in identifying value uncaptured to trigger the discovery of new sustainable value opportunities. | (Yang et al., 2017a,b) |
| AR59 | CE | *Backcasting and Eco-design for CE (BECE):* framework for aiding business in implementing CE requirements in BMs. | Mendoza et al. (2017) |
| AR60 | S | Requirements and characteristics for the development of sustainability-oriented BM tools. | Evans et al. (2017b) |
| AR61 | S | *Morphological matrix for circular development:* framework providing guidelines for implementation of circular and sustainable principles in BM development. | Haanstra et al. (2017) |
| AR62 | CE | Framework for shaping industrial systems towards CE ecosystems. | Aminoff et al. (2017) |
| AR63 | S | *Framework for Strategic Sustainable Development (FSSD):* for BM innovation and design based on backasting and sustainable principles. | (França et al., 2017; Kurucz et al., 2017) |
| AR64 | S | Process model for sustainable value proposition design. | Baldassarre et al. (2017) |
| AR65 | CE | Questions/criteria for risk assessment and checking in the BM design. | Linder and Williander (2017) |
| AR66 | CE | *Lease or buy*: game-based tool for exploring the implications of choosing ownership-based or access-based BMs. | ResCoM (2017) |
| AR67 | CE | Guide for suppliers Resource Efficient BMs (REBMs): process model to guide the implementation of resource efficient BMs. | REBus (2015) |
| AR68 | CE | Innovative BMs Map: typology of BMs for CE with accompanying case studies. | WRAP (2018) |
| AR69 | S | Framework of sensing, seizing and reconfiguring capabilities in categories (evolutionary and radical) of BMI for sustainability. | Inigo et al. (2017) |
| AR70 | S | *Cambridge BMI Process*: framework for sustainability-oriented BM generation from early conceptualization to implementation. | Geissdoerfer et al. (2017b) |
| AR71 | CE | Taxonomy of CE BMs based on the degree of adoption of circular principles along the customer value proposition/interface and value network. | Urbinati et al. (2017) |
| AR72 | CE | Systematization of definitions of circular BMs, BM types, and potential differences from linear BMs. | Nuβholz (2017) |
| AR73 | CE | Circular BMI process including detailed information about steps, tools, perspectives and participants. | Antikainen et al. (2017) |
| AR74 | S | *Future-Fit Business Benchmark (F2B2):* framework for performance assessment of BMI for sustainability with 21 key performance goals. | Kurucz et al. (2017) |
| AR75 | S | Framework to support sustainability-oriented BM implementation of organizations aligned with sustainability performance goals. | Morioka et al. (2017) |
| AR76 | S | Systematization of 11 service design tools to support sustainability-oriented BMI. | Prendeville and Bocken (2017) |
| AR77 | CE | *Circularity Canvas Methodology*: method for designing BMs for CE, including the design of initial BM Canvas and identification of additional value propositions to close loops. | Sustainn (2017) |
| AR78 | CE | Framework for evaluating the environmental value propositions of BMs for CE. | Manninen et al. (2018) |
| AR79 | CE | Conceptual model for the transition towards CE by introducing a hierarchical structure of new BMs. | Planing (2018) |
| AR80 | CE | *Circular Business Experiment Cycle*: process for experimentation with circular BMs. | Bocken et al. (2018) |
| AR81 | CE | Adapted BM Canvas for sustainability innovation. | Bocken et al. (2018) |
| AR82 | S | *Sustainable Value Exchange Matrix*: tool to help designing sustainability-oriented BMs. | Morioka et al. (2018) |
| AR83 | S | *Value Triangle Canvas:* tool to help designing sustainability-oriented BMs. | Biloslavo et al. (2018) |
| AR84 | S | *BM Connect methodology*: to map and represent sustainable 'BM structures' with the focus on the 'value flow' among actors. | Brehmer et al. (2018) |
| AR85 | S | Conceptual view of hybrid businesses from the perspective of BM design including four clusters of design themes and elements. | Hahn et al. (2018) |
| AR86 | S | | Laasch (2018) |

(*continued on next page*)

**Table 4** (*continued* )

| Code | Origin | Description | References |
|---|---|---|---|
| | | Framework of homogeneous and heterogeneous organizational value logics shaped by a variety of institutional logics. | |
| AR87 | CE | Morphological box of design options for circular BMs and six BM combinations for CE. | Lüdeke-Freund et al. (2018) |
| AR88 | CE | Framework to integrate circular BMs and supply chain management towards sustainable development. | Geissdoerfer et al. (2018a) |
| AR89 | CE | *Circular BM mapping tool*: for mapping circular BMs and standardising the representation of elements and the cycles to prolong the useful life of products and close material loops. | Nuβholz (2018) |
| AR90 | CE | Research framework of PSS BMs for circular supply chains. | Yang et al. (2018) |
| AR91 | CE | Categorizations of resource efficiency measures, BM changes and implementation barriers for CE based on 143 case studies. | Diaz Lopez et al. (2019) |
| AR92 | B | *Sustainable Qualifying Criteria for Designing Circular BMs:* checklist of 24 characteristics that lead to enhanced sustainability potential of circular BMs. | (de Pádua Pieroni et al., 2018) |

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## Appended Publication 2

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# Developing a process model for Circular Economy business model innovation within manufacturing companies

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## Abstract

Circular Economy business model innovation is challenging, as it requires the consideration of new variables, adding complexity to decision-making. Despite the range of existing approaches for Circular Economy business model innovation, they are limited in providing adequate advice to practitioners. Key limitations are related to: lack of a holistic structure with systematisation of practices; focus on single innovation stages; lack of analytical and decision-support structures and; marginal consideration of institutional and strategic aspects, as well as interdependencies with other business processes. This paper addresses these limitations by developing a systematic process model for Circular Economy business model innovation, in close collaboration with seven manufacturing companies. The process model contains four stages (prepare, sense, seize and transform) with recommendations of institutional, strategic and operational practices (including activities, tools, interdependencies, decision gates, and recommended mindset and attitudes). The process model brings unique contributions to manufacturing companies by providing: (i) *a systematic structure to strengthen and mature existing Circular Economy business model ideas into viable and implementable concepts*, and *(ii) a source of inspiration for best practice Circular Economy business models in specific sectors.* Furthermore, the paper contributes to the body of knowledge that develops Circular Economy methodology by (i) *consolidating a holistic and systematic view of practices for Circular Economy business model innovation within manufacturing companies*, and; (ii) *providing an example of approach to develop methodological support that is able to offer proactive advice to practitioners*.

**Key-words:** Circular Economy**,** business model, innovation, manufacturing companies, method, process model

## 1. Introduction

Circular Economy (CE) is an approach that focuses on the economic and environmental sustainability dimensions (Geissdoerfer et al., 2017a; Schroeder et al., 2019). It aims at establishing a resource-effective economic system by intentionally narrowing, slowing, and closing materials and energy flows (Bocken et al., 2016; Kirchherr et al., 2017). Manufacturing companies play a critical role in CE due to their relevance concerning usage of materials/energy, generation of by-products, contribution to employment and gross domestic product, and potential influence to define the products' life cycle, by creating value that is decoupled from linear resource consumption (Lieder and Rashid, 2016; McAloone and Bey, 2009).

CE implementation in manufacturing companies requires a shift that exceeds technological or product innovation and involves the overall creation of value and redefinition of business success (Blomsma et al., 2019; Lieder and Rashid, 2016). It is therefore needed to develop capabilities in CE Business Model Innovation (CEBMI) to adapt existing business models (BM) or create new ones (Khan et al., 2020; Schulte, 2013). Despite its relevance, manufacturing companies still face a number of challenges to recognise the potential benefits, conceptualise and implement feasible CEBMs (Lieder and Rashid, 2016; Ünal et al., 2019). Consequently, CEBMs' market penetration is limited in many sectors (OECD, 2018). Manufacturing companies require guidance on how to apply efforts systematically, to reinvent the logic of how their businesses work and achieve economic and resource efficiency simultaneously (Lieder and Rashid, 2016; Ünal et al., 2019).

Many approaches (i.e. frameworks, models, methods, tools) to CEBMI are available (Bocken et al., 2019; Pieroni et al., 2019a; Rosa et al., 2019). However, they are mainly descriptive in nature and therefore also limited in providing adequate advice to practitioners (Kirchherr and van Santen, 2019; Lieder and Rashid, 2016). In particular, they lack systematisation of managerial practices[1] for CEBMI in a holistic structure (Khan et al., 2020; Pieroni et al., 2019a) and have a granular discussion level with focus on the early development stages in detriment of holistic processes that cover all innovation stages (Bocken et al., 2019; Pieroni et al., 2019a). Additionally, institutional/strategic aspects (e.g. rules, norms, beliefs, targets for growth) for CEBMI, and analytical and decision-support activities are not explicitly considered (Lopes de Sousa Jabbour et al., 2019; Ünal et al., 2019). Lastly, the integration of CEBMI with other business processes and the broader scope of sustainability are limited (Bocken et al., 2019; Chiappetta Jabbour et al., 2019; Pieroni et al., 2019a).

The main objective of this research is to address the above-named limitations by developing a systematic process model to guide manufacturing companies in CEBMI, providing a structure for systematization of CEBMI practices. Process models are often used to deal with complexities of business processes, instructing how work should be performed (Smirnov et al., 2012). The main research question is: *How can a systematic process model be developed for CEBMI within manufacturing companies?* By answering this question, we address the aforementioned limitations and contribute to the body of work that develops CE methodology, while engaging practitioners in a transdisciplinary approach that promotes interaction between academic and non-academic actors (i.e. Transdisciplinary 2 in Sakao and Brambila-Macias (2018)).

The following sections clarify the research gap and shortfalls of CEBMI approaches (section 2) and explain the research methodology (section 3). Then, results of the development approach of the CEBMI process model are described (section 4). Lastly, a discussion of contributions (section 5) and conclusions are presented (section 6).

## 2. Literature review

### *2.1. The additional complexity of CEBMI process*

A BM explains how a business works (Magretta, 2002) by describing its "design or architecture of value creation, delivery, and capture mechanisms" (Teece, 2010). Business model innovation (BMI) deals with the change process of BMs as a consequence of triggers inside or outside the organisational boundaries (Foss and Saebi, 2017). Calls for CE implementation (European Commission, 2018, 2014) are examples of triggers orienting change in BMs. It requires a new way of thinking and doing business (Bocken et al., 2016; Schulte, 2013). CEBMI is a new research stream that emerged to investigate BMI in the specific context of CE (Nußholz, 2017).

[1] A specific type of management activity to support the execution of a process (Pigosso et al., 2013).

CEBMI aims to boost resource efficiency and effectiveness by exploring new ways of generating value throughout the product life cycle (Bocken et al., 2016; Den Hollander and Bakker, 2016). It adds complexity to conventional BMI process because new variables have to be considered (e.g. reverse on top of forward logistics; quality, quantity, and timing for the return of resources; customers' perceptions and preferences for 'as new' products; service-based revenues (Bocken et al., 2018; Urbinati et al., 2017)). Moreover, decision-making becomes more complex due to the consideration of three simultaneous business outcomes*:* (i) superior customer value and (ii) economic growth, (iii) decoupled from new resource consumption (Pieroni et al., 2019b). The rationale behind simultaneous outcomes is to provide value for customers and fulfil growth targets ('i' and 'ii') with revenues originated from new offerings or reduced costs enabled by the systemic approach to manage product life cycles ('iii'). In this context, the decision-makers need to consciously plan future growth in a convergent way for CE (Ünal et al., 2019). This involves discussions of values judgement (Bocken and Geradts, 2019), requires new capabilities (Khan et al., 2020; Lopes de Sousa Jabbour et al., 2019) and methodological support for CEBMI (Pieroni et al., 2019a).

### *2.2. CEBMI process models and shortcomings*

Several approaches for CEBMI are available in literature (Bocken et al., 2019; Pieroni et al., 2019a; Rosa et al., 2019), but they lack systematisation to support the strategic management of CEBMI (Bocken et al., 2019; Pieroni et al., 2019a).

Eleven approaches for CEBMI, identified in previous studies (Bocken et al., 2019; Pieroni et al., 2019a) contain characteristics of process models (

Table 1), which are often used to provide a collection of organised practices and supporting aspects that represent and guide the execution of the complete BMI process (Adrodegari et al., 2018; Pieroni et al., 2019a; Smirnov et al., 2012). However, a number of gaps in their completeness and systematic support to strategic/institutional aspects can be identified:

- Current process models are either conceptual or experimental, hence not yet thoroughly tested. Moreover, they are granular and few of them provide adequate support to all stages of the BMI process (P01, P08, P11, P12, P14, P16). Notably, the implementation of CEBMs is marginally addressed (Bocken et al., 2019; Pieroni et al., 2019a).
- Considerable variations in their elements (i.e. stages, processes/activities/steps, deliverables, challenges, tools, and change enablers) and format (i.e. textual documents, linear or circular process flows, innovation-like funnels). Few process models suggest a formal structure for strategic decision-support (P05, P11, P113, P15). Even when they do so, this is not sufficiently informed by CE objectives (e.g. balancing shareholder and stakeholder value, embracing uncertainty) (Bocken and Geradts, 2019; Ünal et al., 2019).
- Lack of a *transdisciplinary* perspective required for environmental sustainability (Sakao and Brambila-Macias, 2018). From now on in the article, transdisciplinary means: using a systemic view and insights from multiple disciplines in new ways (i.e. Transdisciplinary 1 in Sakao and Brambila-Macias (2018)). Process models provide only limited view on interdependencies of CEBMI with other business processes (e.g. product design) (Lopes de Sousa Jabbour et al., 2019) and the broader scope of sustainability (Bocken et al., 2019; Pieroni et al., 2019a).
- Institutional/strategic aspects (e.g. rules, norms, beliefs, mindset, targets for

growth and organisational objectives) are not satisfactorily addressed by CEBMI process models (Lopes de Sousa Jabbour et al., 2019; Ünal et al., 2019).

A systematic structure that addresses the aforementioned gaps and enables the appropriate representation of practices at the institutional/strategic level (i.e. formalised procedures for decision-support, favourable CEBMI behaviours/mindset/attitudes) and operational level (i.e. activities and tools, link among business processes, link with sustainability) simultaneously and for all stages of the CEBMI process is required.

Table 1 - CEBMI process models in literature.

| References | *Code* - Description |
|---|---|
| **Mentink (2014)** | *P01 - Circular BMI Framework*: five-stage process addressing eighteen CEBMI challenges with demonstration of tools. |
| **Joustra et al. (2013); Jong et al. (2015)** | *P02/P03 - Workbook 'Guided Choices towards a Circular BM'*: five-step process with demonstration of tools to guide organisations in raising awareness, learning about the circularity of the company/partners, designing products/services, testing CEBMs with economic simulations. |
| **Van Renswoude et al. (2015)** | *P04 - Circular BM Scan:* six-step process with suggested tools for identification of gaps/opportunities to improve BMs' circularity. |
| **REBus (2015)** | *P05 - Guide for Suppliers Resource Efficient BMs*: six-stage process guiding the conceptualisation and implementation of CEBMs. Description of activities, steps, deliverables and tools. |
| **National Zero Waste Council (2016)** | *P06 - CE Business Toolkit*: three-step process with suggested tools to define CE strategy by identifying strategic risks/opportunities, analysing the value chain, and choosing BMs. |
| **Achterberg et al. (2016)** | *P07 - 4 Steps Towards a Circular Business Strategy with the Value Hill: f*our-step process for understanding the value chain and identifying CEBMs with the tool 'Value Hill'. |
| **Kraaijenhagen et al. (2016)** | *P08 - 10 Steps Towards a Circular Business:* ten-step process for creating CEBMs in existing organisations. Introduces tools and challenges/change management for collaboration. |
| **Weetman (2016)** | *P09 - Strategic Process for Implementation of Circular BMs:* three-stage and ten-step strategic process for implementation of CEBMs inspired by permaculture whole-system design. Tools are suggested. |
| **Mendoza et al. (2017)** | *P10 - BECE Framework*: ten-step process combining eco-design and backcasting for aiding businesses in implementing CEBMs. Tools are demonstrated. |
| **Antikainen et al. (2017)** | *P11 - BMI process in AARRE-project*: five-step process with detailed information about tools, participants, and challenges for CEBMI. |
| **Girotra and Netessine (2013)** | *P12 - Systematic Stage-Gate Process:* four-stage process for generating, selecting and refining sustainable BMs. Description of activities, tools, and decision gates. |
| **Holgado et al. (2013)** | *P13 - BM Process*: four-step process for embedding sustainability in BM design by analysing value exchanges and exploring social/environmental values. Description of activities and deliverables. |
| **Roome and Louche (2016)** | *P14* - Five-stage SBMI process describing activities and focusing on institutional aspects (i.e. change enablers). |
| **França et al. (2017)** | *P15 - Framework for Strategic Sustainable Development (FSSD):* four-step SBMI process based on backcasting. Description of activities, deliverables, and demonstration of tools. |

| | |
|---|---|
| **Geissdoerfer et al. (2017b)** | *P16 - The Cambridge BMI Process:* three-stage and eight-step SBMI process from early conceptualisation to implementation. Description of activities, deliverables and challenges. |

### *2.3. Systematic structure for the CEBMI process*

Dynamic Capabilities (DC) are recognised in literature as fundamental for CEBMI (Khan et al., 2020; Pieroni et al., 2019a) due to its potential to address institutional, strategic and operational aspects of CEBMI (Bocken and Geradts, 2019). DC are essential aspects to allow transformations of organisations by governing how a company's ordinary capabilities (e.g. other business processes different than innovation such as sales, manufacturing) are developed, augmented and combined (Teece, 2007). Although initially investigated and relevant in large multinational companies (Bocken and Geradts, 2019; Teece, 2007), DC are also applicable for the context of small and medium enterprises (SMEs) (Alves et al., 2016; Arend, 2014).

According to Teece's (2007) framework, DC include capabilities to: (I) *sense* opportunities and threats for changing the existing ordinary capabilities; (II) s*eize* opportunities by designing and testing new ordinary capabilities and BMs able to capture value; and (III) *reconfigure* the existing ordinary capabilities to realise organisational and BM transformation. These competences affect both the operational level (e.g. functional excellence, standardised innovation processes and procedures) and the institutional/strategic levels (e.g. rules, norms, beliefs that guide organisational behaviour or core organisational objectives) of organisations (Bocken and Geradts, 2019). Moreover, they cover all stages of the BMI process – i.e. from conceptualisation to implementation. Hence, a framing based on the view of sense, seize and reconfigure (Teece, 2007) could be useful to guide the consolidation of a structure for a CEBMI process model.

## 3. Research Methodology

A hypothetic-deductive approach (Gill and Johnson, 2002) was adopted as methodological framework. It comprised three phases: 1) theoretical development; 2) empirical development; and 3) testing (Fig.1).

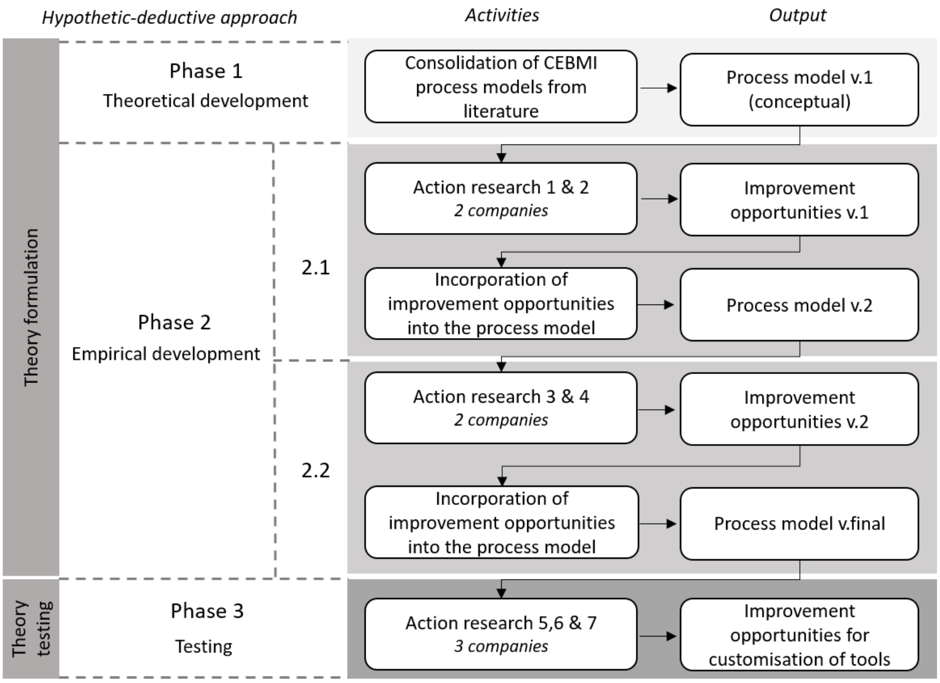

Fig.1 - Research approach.

### *3.1. Phase 1 - Theoretical development*

The process model (v.1) was consolidated from applicable approaches to CEBMI available in literature, based on four steps (details in Supplementary Materials):

- Step 1: 16 process models (see Table 1 in section 2), 115 tools and 12 requirements recommended for development of CEBMI approaches (Supplementary Materials) were identified from systematic literature reviews (Bocken et al., 2019; Pieroni et al., 2019a).
- Step 2: the process models were compared and unified in terms of the terminology of stages, representation style, and unique elements (i.e. activities, deliverables, tools, decision gates, and change enablers).
- Step 3: the view of sense, seize and transform was adopted as the reference framework to structure the process model to ensure the ability to trigger business change, which involves the combination of institutional/strategic and operational practices (section 2.3).
- Step 4: prioritisation of the 115 tools identified to minimise overlap. For each activity of the integrated process model, the potential tools were analysed and scored on their ability to fulfil the 12 requirements (e.g., 0=not fulfilled, 1=partially fulfilled, and 2=fulfilled). The tools with the highest scores were selected for each stage of the process model.

### *3.2. Phase 2 – Empirical development*

Action research (AR) was applied for the further empirical development of the conceptual process model (v.1) in close collaboration with manufacturing companies, with the aim to propose solutions to organisational problems while building theory from observing and interacting with practice (Mathiassen, 2017). The AR guidelines proposed by Mathiassen (2017) were applied, following a cyclical process (Coughlan and Coghlan, 2002) for data collection and analysis comprising three steps: (i) *diagnosing;(ii) planning and taking action; and (iii) evaluating action.*

*Diagnosing* involved identifying the scientific and organisational problems. For that, a number of companies (Table 2) were selected based on three criteria: (i) manufacturing companies; (ii) with intention to start their transformation towards CE from a BMI perspective; and (iii) availability/willingness to provide access to people, access to information and feedback. Different sectors and company sizes were considered to test and explore the application boundaries of the process model in different CE contexts as recommended by Ünal et al. (2019). Only Nordic (i.e. Denmark, Finland, Iceland, Norway, and Sweden) companies were selected to control geographical aspects.

*Planning* and *taking action* consisted in preparing and tackling the problem by applying the conceptual process model (v.1) in two companies (A and B) with a series of workshops (Table 2). The participants, critical decision-makers from multiple functions, were actively involved in applying the process model, activities and tools; providing data; validating results; and providing feedback. A company facilitator was assigned to help in preparing the workshops, coordinating communication with other participants, and confirming the findings and interpretations of researchers.

*Evaluating action* consisted of collecting and analysing data after the application of the process model to identify improvement opportunities. Triangulation was used to enhance the validity of data collection (Yin, 2011). Four data sources were considered: research journal with observations and post-reflection; recordings of the workshops with verbal feedback; results of the application of the process model; and standardised structured questionnaires answered by the participants (one for each stage of the process). The questionnaires, composed of a combination of multiple-choice and open ended questions, aimed to measure the satisfaction level of users with the: (i) structure and activities, (ii) tools, and (iii) results of the process model. A 4-point Likert scale varying from “Unsatisfactory” to “Very satisfactory” was used. The improvement opportunities were catalogued following a coding process (Yin, 2011) indicating the specific stage or activity affected, the company/participant suggesting it, and scope of the suggested change.

After the first two AR cycles (Phase 2.1), critical improvement opportunities could already be incorporated as a means to test whether the proposed modifications would be effective in subsequent AR cycles/companies. Hence, in Phase 2.2, the improvement opportunities (v.1) were assessed and incorporated when/whether they were (1) aligned with the scope of the process model; and (2) feasible/implementable by the researchers. This generated a revised version of the process model (v.2). This version was applied in new AR cycles (following the same steps indicated above) with two additional companies (C and D). This resulted in the identification of additional improvement opportunities (v.2), which were assessed following the aforementioned criteria and incorporated into a new version of the process model (v.final).

### *3.3. Phase 3 - Testing*

In Phase 3, three companies (E, F and G) applied the process model (v.final) following AR cycles with the objective of testing it. No significant improvements were required for the structure and activities of the process model, which indicated that no more testing or AR cycles would be necessary. Improvements for tools were compiled to drive future research.

Table 2 – Sample of companies.

| **Company** | **Sector** | **Size** | **Organisational problem/intention** | **Number of workshops (6h-8h)** | **Duration** | **Number of participants: <u>facilitators</u> and *profiles*** |
|---|---|---|---|---|---|---|
| **A** | Electronic equipment | SME (i.e.< 249 employees) | Exploring benefits of service-oriented BMs. | 4 | February-June 2018 | 4: *<u>Chief Executive Officer</u>; Financial, Supply Chain, and Technical Directors.* |
| **B** | Heavy machinery | Large (i.e.>250 employees) | Understanding and disseminating how they are already contributing and benefiting from CEBMs; exploring different CEBMs. | 5 | February-October 2018 | 12: *<u>Environmental Manager and Specialists;</u> Business Designer; Product and Data Analytics Engineers; Directors for Sales, Services. Product, Support/Quality, Procurement, and Corporate Responsibility.* |
| **C** | Furniture | SME | Exploring different CEBMs. | 5 | July 2018 | 6: *<u>Sales & Operations Manager; External consultant;</u> Marketing & Sales Coordinators; Product Design Manager; a Board Member.* |
| **D** | Electronic equipment | SME | Exploring different CEBMs. | 5 | September 2018 | 3: *<u>Marketing & Sales Manager;</u> Product Design & Operations, and Electronic Design & Software Managers.* |
| **E** | Furniture | SME | Exploring different CEBMs. | 3 | January 2019 | *3: <u>Strategy & Sustainability Manager;</u> Marketing and Product Managers.* |
| **F** | Clothing | SME | Mapping the impacts of a specific CEBM. | 3 | April 2019 | *3: <u>Chief Executive Officer;</u> Financial, and Marketing & Sales Managers.* |
| **G** | Medical devices | Large | Exploring different CEBMs. | 3 | April-June 2019 | *12: <u>Environmental Manager; Quality</u>/Regulatory Vice-President and Director; Patent and Technology Managers; Product Designers, Manager & Director; Research & Development, Strategy & Operations Vice-President; External consultant.* |

## 4. Results

This section explains the results including: an overview of how the first version of the process model was conceptualised (section 4.1); an overview of improvements after applying it in companies (section 4.2); and the final version of the process model, with examples from its application in a case (section 4.3).

### *4.1. Phase 1 - Theoretical development*

The overall structure of the conceptual process model (v.1) is outlined in Fig.2, with an indication of the contribution of the existing process models (conceptualisation and description of elements available as Supplementary Materials).

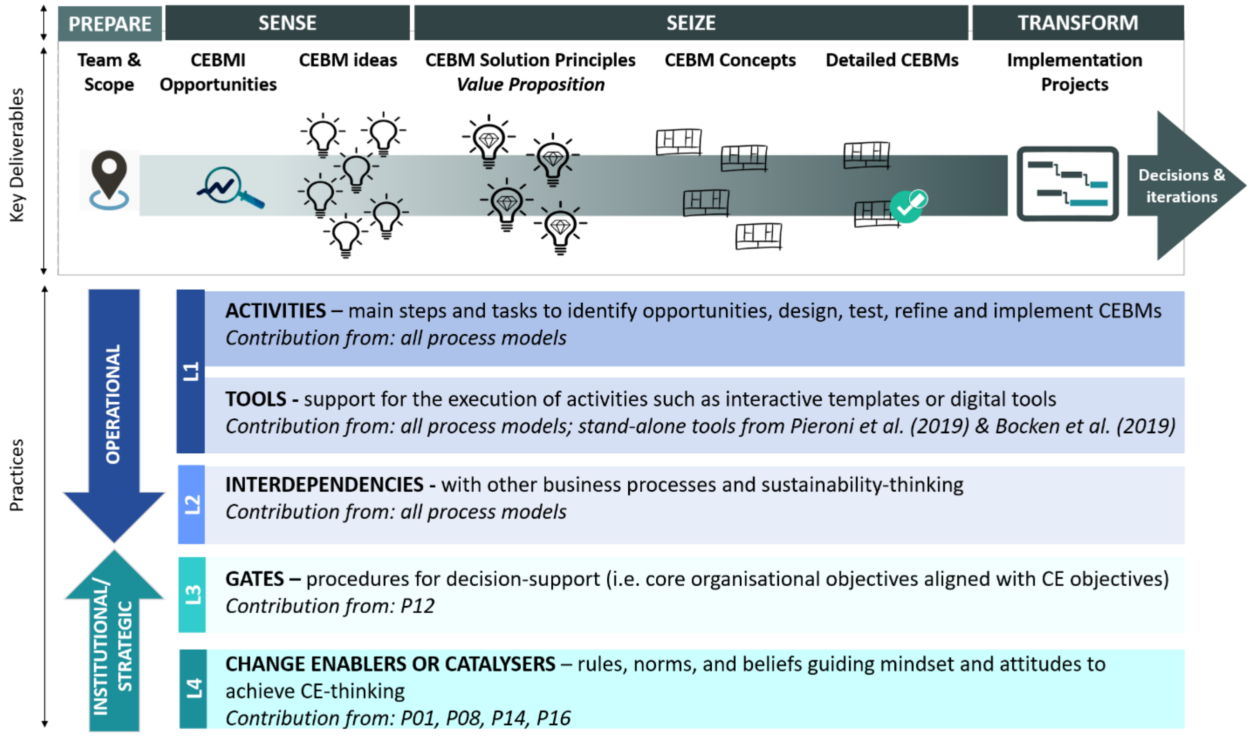


Fig.2 – Structure of process model (v.1).

The conceptual process model (v.1) contains four stages – e.g. prepare, sense, seize, transform - with recommendations of practices for CEBMI at the operational and institutional/strategic levels. At the operational level, 29 activities supported by 30 tools (L1) should be integrated with other business processes and sustainability-thinking (L2). At the institutional/strategic level, 5 decision gates (L3) and 13 change enablers/catalysers should be considered (L4). In total, 21 deliverables should be achieved (see Supplementary Materials), but Fig.2 exemplifies the most critical ones (top layer). For example, *prepare* results in the definition of *team and scope*. *Sense* identifies *CEBMI opportunities*, which are then converted in *CEBM ideas*. *Seize* defines CEBM *value propositions, initial and specified concepts. Transform* ends the process with the definition of *CEBM implementation projects.*

The most comprehensive process model contributing to activities in all stages was P01 (Fig.3). Nevertheless, for each stage, there was at least one process model contributing with at least the same amount of activities as P01 (e.g. P14 to Prepare; P02/P08/P09 to Sense; P05/P08 to Seize; P05/P10/P11/P14/P16 to Transform).

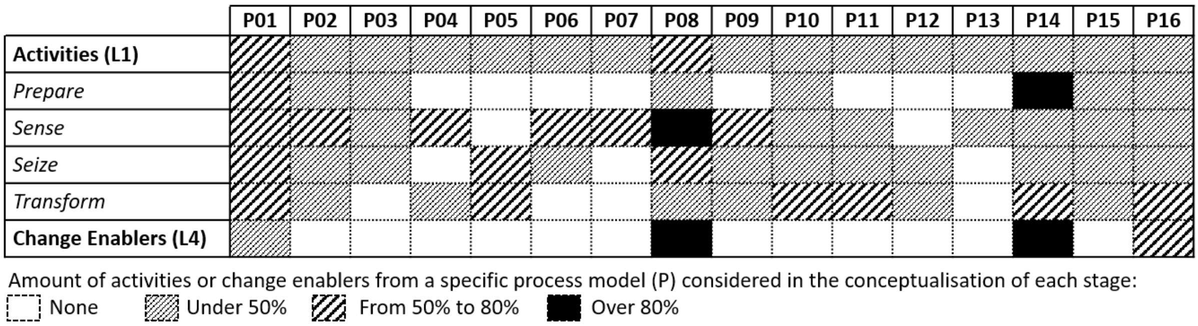


Fig.3 - Contribution of literature to the conceptualisation of process model (v.1).

### *4.2. Phase 2 - Empirical development*

Based on the identified improvement opportunities in phases 2.1 and 2.2, the conceptual process model (v.1) was improved throughout the AR cycles of Phase 2. This section summarises the major improvements in *structure and activities*, and modifications in *tools* (Appendix A presents a complete list of improvements).

Four major improvements (I) were applied to the *structure and activities*:

- I1: The activities in the stage *Sense* were reorganised and simplified (Fig.4). This included changes in sequence, detailing of tasks, and unification of activities.
- I2: 'Design of value propositions for CEBMs' became an independent activity in stage *Seize* and tasks for its execution were recommended (see A5 in Fig.5).
- I3: The procedures for decision gates were clarified (Fig.7) to address companies' hesitation about whether they were achieving the expected results and making the best choices about CE.
- I4: Detailed visual representations were developed for each stage (Fig.4-6) to provide clear instructions during the process and aid to the understanding of the information flow through sequential activities/tools. In particular, facilitators were concerned with not being able to iterate or repeat the process when rolling it out to other products or business units.

Furthermore, four major modifications (M) were applied to tools (T):

- M1: Tools for diagnosing CE characteristics in existing BMs in the stage *Sense* (TC07, TC22, TC34 and TC40 in Supplementary Materials) were substituted by the Circular Strategies Scanner (Blomsma et al., 2019) (Fig.4).
- M2: The CEBM Configurator (Pieroni et al., 2019b) was introduced to support the elaboration of CEBM ideas in stage *Sense* (Fig.4).
- M3: Tools for prioritisation and visioning (see TC43, TC34, TC22 in Supplementary Materials) in the stage *Sense* were substituted by a BMI Roadmap (Phaal, 2017) (Fig.4).
- M4: Tools for calculating the economic and resource decoupling potential of CEBMs in the stage *Seize* were developed (Fig.5).

We elaborate further on these improvements and modifications in section 4.3 to explain how they fit in the overall process model (v.final) and to show how they affected the satisfaction level of companies.

### *4.3. Phase 3 - Testing the final CEBMI process model*

The incorporation of improvements resulted in a new version for the process model (v.final) (Fig.4-7) that was tested in three companies during Phase 3. The following sub-sections introduce the activities and tools for the stages of the process model (v.final), explain how it differs from the conceptual process model (v.1), and exemplify its application in Company E.

#### *4.3.1. Prepare*

A *preparation stage is recommended* to start with the application of the process model (see Fig.7) to make the organisation ready for the development of new CEBMs (especially if it is the first event of the kind within the company).

**Activities and tools:** engaging the leadership with a CE-thinking/mindset, defining an interdisciplinary team, levelling the knowledge of CE among the team, and defining a scope for the CBMI exercise.

**Examples of outcomes:** Company E assembled a team with Strategy & Sustainability Manager; Marketing and Product Managers, and scoped the project to products with high volume of sales in their portfolio of outdoor furniture.

#### *4.3.2. Sense*

Sense aims to identify opportunities for CE and translate them into realistic BM ideas, and is composed of four activities. Fig. 4 provides detailed instructions for each activity, indicating aim, input, tasks, decision gates and output. Moreover, five tools are recommended.

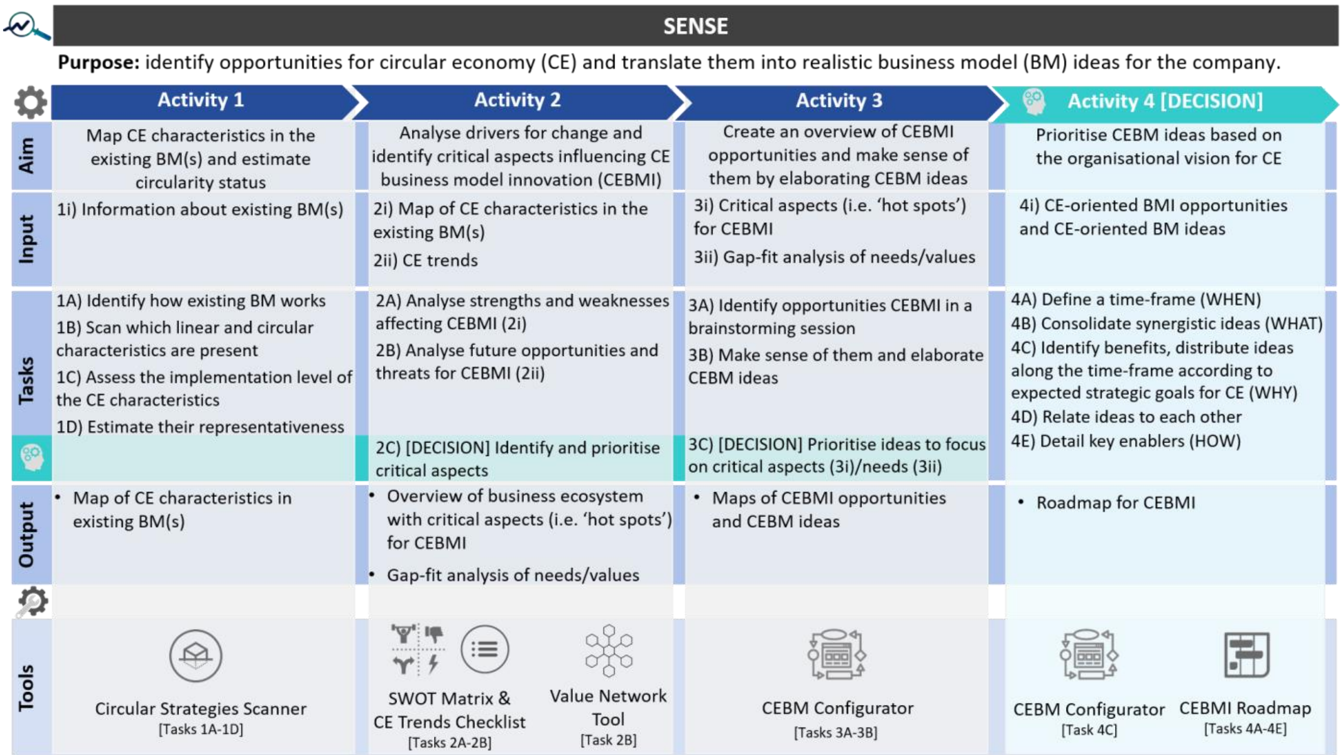

Fig.4 - Detailed view on Sense.

**Activities and tools:** the Circular Strategies Scanner tool (Blomsma et al., 2019) provides a framework for mapping current CE strategies and improvement opportunities for existing BMs (A1). Then, a SWOT Matrix adapted with a checklist of topics based on CE trends (Mentink, 2014), and a Value Network tool (França et al., 2017) can be applied for analysing drivers for change and identifying critical aspects for CEBMI (A2). Lastly, the CEBM Configurator (Pieroni et al., 2019b) can inspire the elaboration of CEBM ideas (A3), which are then prioritised (A4) using a BMI Roadmap (Phaal, 2017).

**Differences from process model (v.1):** the *definition of a vision/purpose for CEBMI* was defined as the first activity in v.1. However, Phase 2.1 companies were not acquainted with the concept of CE/CEBMI when they started. They recommended that the formulation of a CEBMI vision should be the final result of this stage. Therefore, the activity was merged with another activity at the end of stage Sense and became *Prioritise CEBM ideas based on the organisational vision for CE (I1 in section 4.2).* Additionally, tools for visioning and prioritisation were modified (M1, M2 and M3 in section 4.2):

- M1: Phase 2 companies struggled in identifying the CE challenges in existing BMs. The Circular Strategies Scanner helped to tackle this because it was specifically developed for supporting manufacturing companies in finding why to change and which changes are required (i.e. business processes). Companies in Phase 3 confirmed the positive effects of this substitution.
- M2: The CEBM Configurator (i) enabled simpler representation of CEBMs into three elements (value proposition, upstream and downstream architectures); and (ii) provided recommended CEBM configurations based on the combination of patterns and inspirational cases for specific sectors. This was required by Phase 2.1 companies to complement generic CEBM patterns or archetypes suggested in literature (TC06, TC41, TC79, TC96, TC97, TC98 in Supplementary Materials). This was highlighted as one of the main contributions of the process model by Phases 2.2 and 3 companies.
- M3: The CEBMI Roadmap enabled prioritisation of CEBM ideas using more than two criteria (e.g. economic, environmental, time/effort). Moreover, it inherently considered time as a criteria in the prioritisation, which was requested by all Phase 2 companies.

**Examples of outcomes:** Company E completed this stage in a one-day workshop. A1 revealed the strengths (e.g. provision of guarantees on materials' durability; and use of recycled materials (e.g. steel)) and weaknesses (e.g. lack of products' take back, end-of-use strategies, and existing BMs, which were based on pure sales). A2 revealed opportunities for extending the products' use, offering refurbishment services and establishing new purchasing schemes (i.e. leasing or renting). In A3 and A4, eight CEBM ideas were elaborated and three prioritised:

(I) Sales of long-life outdoor furniture with buy-back schemes and refurbishment services;
(II) Sales of long-life outdoor furniture with buy-back schemes and services for predictive maintenance & efficiency management of urban spaces;
(III) Access to best-fit urban space solutions based on leasing contracts (i.e. including furniture, predictive maintenance, and refurbishment).

### *4.3.3. Seize*

Seize aims to configure and optimise the BM concepts for CE. Three activities (A5-A7) and six tools are recommended (Fig.5).

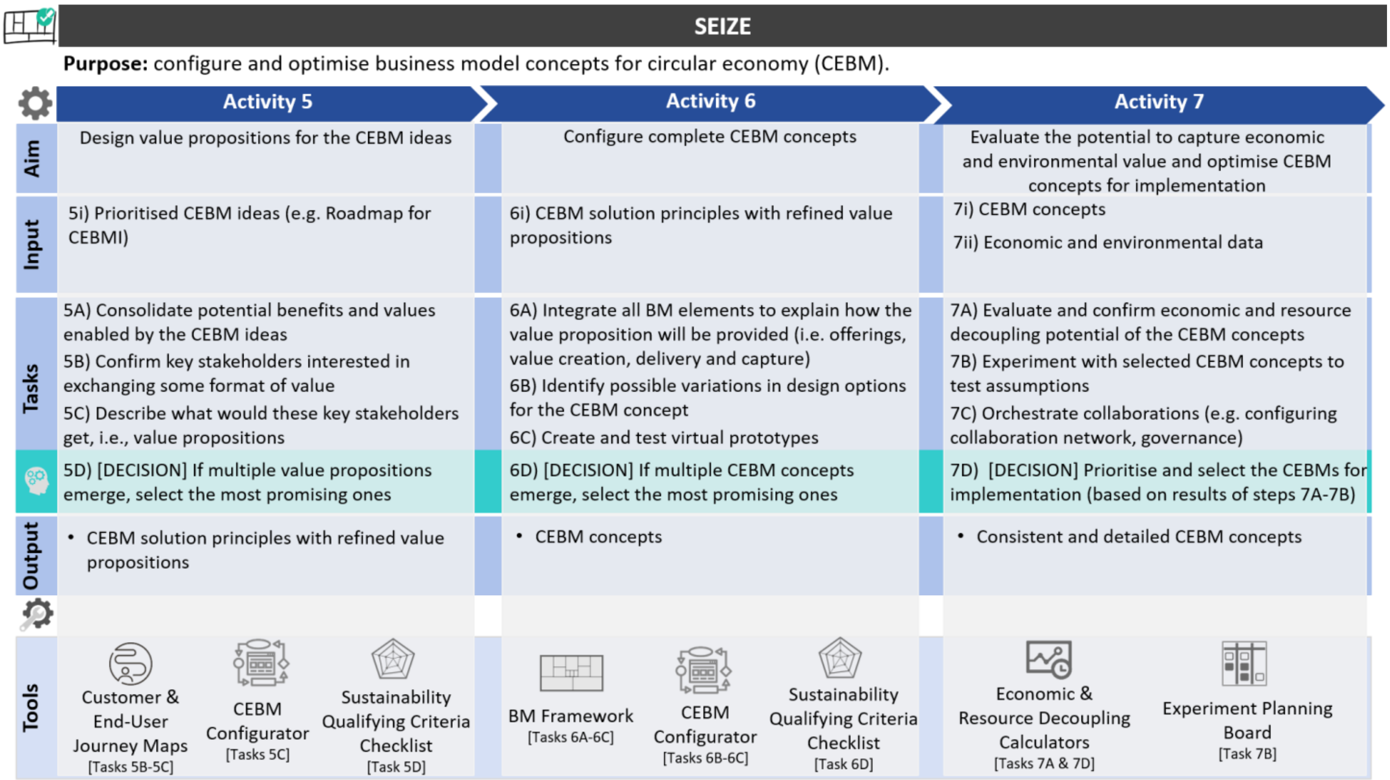


Fig.5 - Detailed view on Seize.

**Activities and tools:** Journey Maps (Antikainen et al., 2017) support refining perceived values (i.e. trade-off between benefits and hurdles), and detailing product-service offerings for each CEBM idea. Based on these, value propositions can be consolidated in the CEBM Configurator (A5). The BM Framework (Kraaijenhagen et al., 2016) can be used to model all elements of the CEBM concepts, with potential recommendations from the CEBM Configurator (A6). If many configurations of value proposition and CEBM concepts are identified, a qualitative scoring model based on a Sustainability Qualifying Criteria Checklist (Pieroni et al., 2018) can guide the selection of promising value propositions or concepts (i.e. based on environmental, economic, and social potentials) during A5 and A6. After that, Economic and Resource Decoupling Calculators are used to verify the potential to monetise the CEBMs and capture value while promoting positive effects in resource efficiency (A7). Lastly, an Experiment Planning Board (Antikainen et al., 2017; Bocken et al., 2018) helps to create a concrete plan for confirming assumptions and refining the CEBM concepts before implementation (A7).

**Differences from process model (v.1):** Phase 2 companies struggled in understanding what a value proposition was and how to define it for CEBMs. A series of tasks to guide value proposition design were added as an independent activity (5A-5C, Fig.5). Furthermore, the CEBM Configurator was adapted to visually guide companies in iterating and consolidating the value proposition. Other relevant enhancements were the Calculators (A7), due to a lack of quantitative tools fitting these purposes in literature (the ones available (TC57, TC94 - Supplementary Materials) were missing instructions, too complex, and time-consuming). The *Economic Potential Calculator* was developed based on cost-benefit analysis with quantitative and qualitative measures (obtained from Kravchenko et al., 2019). The *Resource Decoupling Potential Calculator* was developed based on guidelines provided in Kjær et al. (2019) and

Kravchenko et al. (2019).

**Examples of outcomes:** Company E completed A5 and A6 in a one-day workshop. Two weeks and a final workshop were necessary for A7. The potential of the CEBM concepts concerning resource efficiency (i.e. 10-30% improvements in relation to current BMs) and profitability (comparable to current BMs' profitability in long-term) were confirmed. Moreover, iterations in the configuration of certain key variables were discussed (e.g. minimum service contract period and pricing; service level expected by customers; and choices whether to invest in new facilities or establish partnerships for refurbishment). A joint experiment with existing and new value chain actors was proposed to test: (i) the governance structure for the new collaboration; and (ii) the service level agreement established with a specific customer.

### *4.3.4. Transform*

Transform aims to plan the implementation and build the capabilities required for CEBM. It is composed of three activities (A8-A10) and supported by 4 tools (Fig.6). Due to the longer time-frame required for the transform stage, the empirical development and testing were out of the scope of this research (see section 5). Therefore, this sub-section focuses on the conceptual description.

**Activities and tools:** project (A8) and organisational change management (A9) for the CEBM concepts implementation could be supported by available frameworks (e.g. roadmaps with milestones, project/change management plans). When applicable, it is recommended that the company adopts its usual practices. Then, a periodic governance for revision of the milestones of the roadmaps based on key performance indicators (KPIs) is recommended for adjusting/reviewing CEBMs (A10) (Kraaijenhagen et al., 2016; Mendoza et al., 2017).

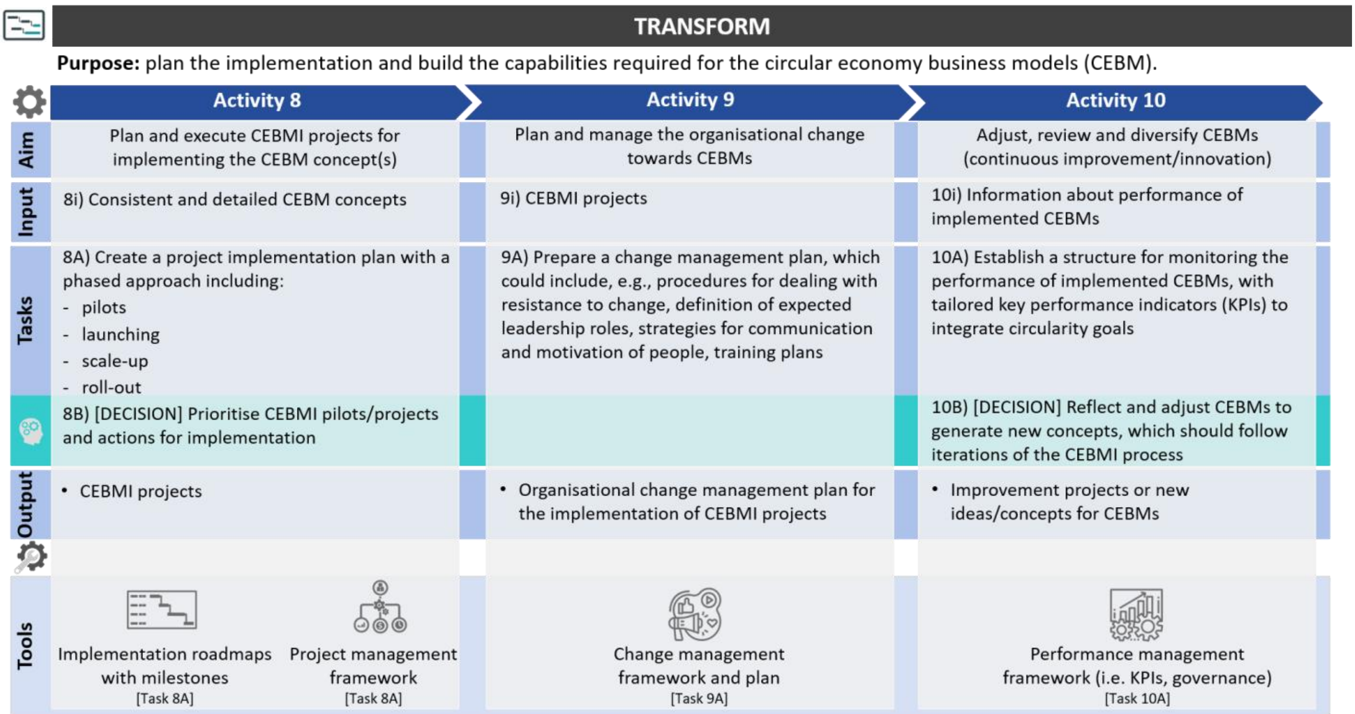


Fig.6 – Detailed view of Transform.

### *4.3.5. The complete structure of process model (v.final)*

The complete structure of process model (v.final) is presented in Fig.7. In addition to the enhancements to the *activities and tools (L1)*, the level of *gates (L3)* was considerably improved. For example, decision gates were included to support prioritisation of critical drivers & opportunities and CEBM ideas (A3 in Sense). Additionally, clear deliverables were defined for each decision gate to clarify the level of information expected (Fig.7) (e.g. 1st gate of Sense: companies should elaborate *CEBMI opportunities)*. Lastly, *change enablers (L4)* were rephrased to point out favourable mindset and attitudes for different actors involved along the process (e.g. key decision-makers should be actively engaged in Sense, and prepared/willing/empowered to question the linear status-quo and values in the organisation).

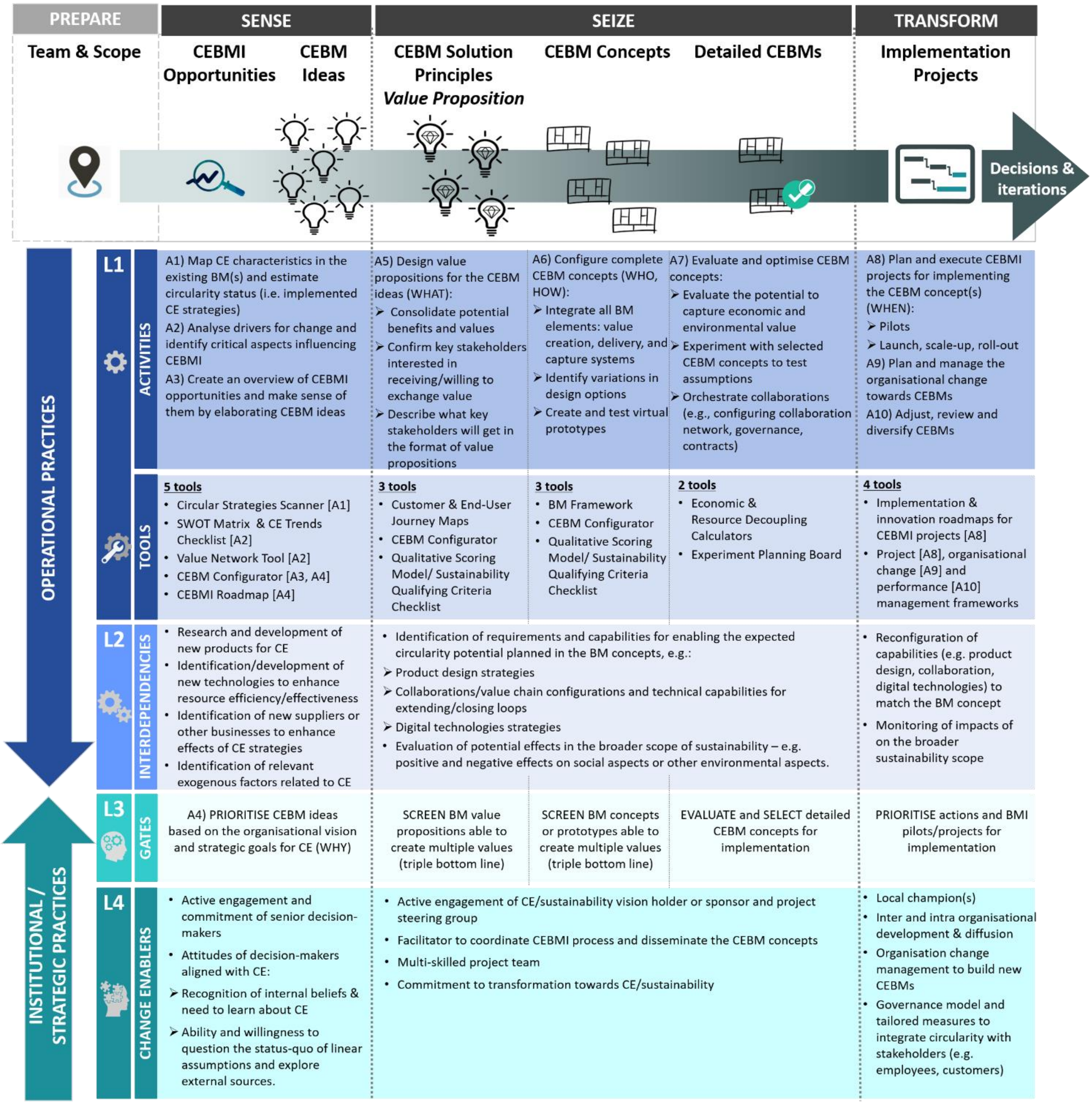


Fig.7 – Process model for CEBMI within manufacturing companies (v.final).

Fig.8 illustrates how Phase 2 and 3 companies evaluated the *structure and activities*, *tools* and *results* of the stages Sense and Seize of the process model (see different patterns in the bars). Most participants considered the process model at least satisfactory, commenting that it was “useful”, “simple to understand”, and "with adequate activities and overall structure". The increasing scores in the satisfaction level of companies from Phase 2.1 to Phase 3 indicate that the modifications applied to the process model were effective, especially concerning *structure and activities*. Moreover, as in Phase 3, only minor improvements in terminology of *activities* were required, the version of the process model presented on Fig.7 was considered final in its *structure and activities*. However, major and medium improvements were still required for *tools* (see Appendix A) *and results*. These are discussed in section 5.

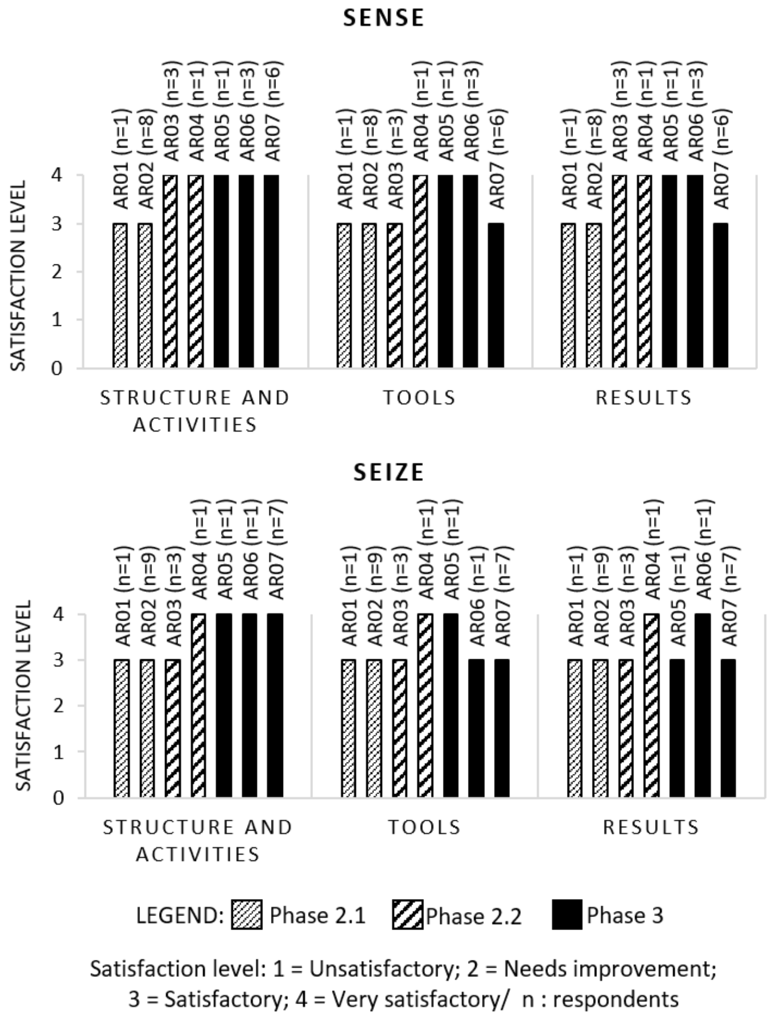


Fig.8 - Feedback from companies.

## 5. Discussion

### *5.1. Insights from the theoretical and empirical development*

To answer the research question, this paper focused on the development, improvement and test of a process model with a systematic perspective and structure for CEBMI within manufacturing companies. The consolidation of existing process models allowed synergy of knowledge otherwise scattered in literature. These synergistic gains were expected and align with the results of studies that proposed unification of practices for SBMI and eco-design (Brones and Monteiro de Carvalho, 2015; França et al., 2017).

The empirical development with action research (AR) further improved the process model by revealing 'real-life' nuances which were not anticipated by literature. This answered to calls to develop CE transformation methodology that promotes useful advice for practitioners (Kirchherr and van Santen, 2019; Sakao and Brambila-Macias, 2018). Three examples highlight the contributions of the empirical development:

- AR cycles in multiple companies stressed the relevance of decision-support for CEBMI, which was marginally addressed by literature (Table 3). Improvements to support decision-making incorporated to the process model in Phase 2 enhanced the efficiency of the process in Phase 3 (see reduction of workshops, Table 2). The modifications helped companies to focus on fewer better CEBM ideas, with more significant potential for implementation.
- As suggested by literature (Lüdeke-Freund et al., 2019; Rosa et al., 2019), we expected that tools using generic CEBM archetypes (Bocken et al., 2016) would be enough to help companies from different sectors with the ideation of their own concepts. However, companies struggled in assimilating the generic CEBM archetypes, especially when they were exemplified by cases from a distinct sector. For instance, in the clothing and furniture sectors, products were substituted prematurely to fulfil aesthetic preferences from customers (e.g. fast fashion, modernization of buildings). In heavy machinery or electronic equipment, aesthetics preferences were not as relevant. Instead, seasonality and variations in functional performance of products were common reasons for premature substitution or overcapacity of products (e.g. increased coffee brewing during festivities in specific regions, increased downtime of operations due to maintenance of machines). Although an access-based BM (Bocken et al., 2016) could tackle the aforementioned problems in the four sectors, the level of details provided in the available generic archetype-based tools were not enough for the level of discussions expected by companies to target their different challenges with resource efficiency. The modification in one of the tools to add sectorial specificity to CEBM archetypes enhanced applicability across sectors in Phases 2.2 and 3.
- Although some companies agreed with the *structure and activities* of the process model, they were not completely satisfied with the *results* (Fig.8). According to their feedback, this was caused by inadequate *tools*. They expected tools to be proactive and precise in suggesting *solutions, i.e. what CEBMs for their specific case should look like*. This is opposed to available tools in literature (and incorporated by the conceptual process model), which offered generic steps/structures about *what companies should do to identify solutions, e.g., which elements required revision when designing CEBMs*. Results from Phase 3 indicate that modifications applied in tools after Phase 2.2 tackled the aforementioned shortcoming, especially for SMEs (see increasing scores in Fig. 8).

In the last example, perhaps a lack of readiness from companies to cope with the *institutional aspects recommended for CEBMI* (L4 in Fig. 7) also influenced their satisfaction with the *results*. For example, some participants/companies lacked the *ability or motivation to question the linear status-quo of their BMs*. In large organisations, this was related to a mindset towards short-term business results (e.g. profitability and market penetration) that could not be fulfilled by the proposed CEBMs. In SMEs, this was related to a noted scepticism about disrupting linear BMs due to their limited influence over established suppliers (e.g. clothing and electronics). Moreover, even though the process model recommended the *engagement of multiple functional areas*, some companies only realised this along the process. Lastly, *large* *companies faced additional challenges* for the application of the process model. Examples are: additional time and support were required during the preparation stage for scoping the CEBMI problem and during decision gates; certainty and fact-based decision-making were fundamental, even in early stages of ideation; and teamwork was impaired by the lack of time or urgency from participants in attending workshops. These observations align with results from Bocken and Geradts (2019) that identified the purpose of corporations to maximise shareholder value and uncertainty avoidance as institutional barriers for SBMI. In addition, the observations point to shortcomings of the process model to deal with institutional aspects in CEBMI. Further investigation about how to support companies to obtain adequate dynamic capabilities and organisational design (Bocken and Geradts, 2019; Khan et al., 2020) for CEBMI is required to strengthen this perspective.

### *5.2. Key contributions to literature*

This paper provides a systematic process model for CEBMI within manufacturing companies. The process model goes beyond previous available process models in several aspects (Table 3). First, it comprises practices for all stages of the CEBMI process, i.e. from sensing opportunities, seizing viable CEBMs, and transforming the organisation to implement the CEBMs. Second, it considers links of the CEBMI with other business processes and provides activities/tools that prompt considerations for improving the sustainability performance of CEBMs. Third, it formalises procedures for decision-support, thereby prompting and guiding companies in balancing core organisational objectives with CE objectives. Lastly, it recommends which behaviours, mindset and attitudes can act as catalysers for CEBMI. With this, we contribute to reducing the gaps identified in section 2 and answer to calls for holistic approaches and views for the strategic management of CEBMI and CE implementation (Khan et al., 2020; Ünal et al., 2019).

Table 3 - Comparison of CEBMI process models.

| Process models | All stages | Link with business processes & sustainability | Formalised decision-support | Institutional aspects |
|---|---|---|---|---|
| **P01 (Mentink, 2014)** | ✓ | ✓ | | ✓ |
| **P02/P03 (Joustra et al., 2013; van Renswoude et al., 2015)** | | | | ✓ |
| **P04 (van Renswoude et al., 2015)** | | ✓ | | |
| **P05 (REBus, 2015)** | | ✓ | ✓ | ✓ |
| **P06 (National Zero Waste Council, 2016)** | | ✓ | | ✓ |
| **P07 (Achterberg et al., 2016)** | ✓ | | | |
| **P08 (Kraaijenhagen et al., 2016)** | ✓ | ✓ | | ✓ |
| **P09 (Weetman, 2016)** | ✓ | | ✓ | |
| **P10 (Mendoza et al., 2017)** | ✓ | ✓ | | ✓ |
| **P11 (Antikainen et al., 2017)** | ✓ | ✓ | | |
| **CEBMI Process Model for manufacturing companies** | ✓ | ✓ | ✓ | ✓ |

### *5.3. Key contributions to practice*

This paper demonstrated that the systematic process model for CEBMI can effectively support CE transformation within manufacturing companies. According to companies' testimonies, the process model "enabled aligning people from different functional units/departments" (Company B), "triggered a shift in organisational mindset" (Company F), and "was important to start building internal buy-in" (Company G). This contributed to the achievement of promising results such as: a roadmap summarizing opportunities and effort for CEBMI, viable CEBM concepts, and concrete plans for experiments or pilot projects (exemplified in section 4.3).

Two main contributions of the process model to manufacturing companies are promising. Primarily, it offers a *structure to strengthen and mature existing CEBM ideas into viable and implementable concepts.* For most companies, the process model was useful to justify thoughts, decisions, and argumentations about CEBM ideas that they already had considered but were uncertain about implementing. In particular, the process model allowed companies to: (i) deal with the complexity of CEBMI/CEBMs by pondering economic and resource efficiency gains; (ii) embrace ambiguities by pushing participants to come to decisions even though they did not have certainty about all facts; and (iii) organise results to help dissemination and implementation (e.g. education of employees, communication with suppliers and investors). Moreover, the process model provides *a source of inspiration for best practice CEBMs in specific sectors.* For some companies, this triggered awareness and insights about entirely new configurations of CEBMs in their sector.

### *5.4. Applicability, limitations and opportunities for future research*

The variety of organisations in the empirical development (Table 2) points to the broad applicability of the process model for manufacturing companies from different sectors and sizes. Action research as a research methodology allowed a deep understanding of the CEBMI process in a number of manufacturing companies (Bocken et al., 2019; Linder and Williander, 2017), which enabled its further development to overcome specific organisational barriers and support the identification of fitting CEBMs (Bocken et al., 2019; Linder and Williander, 2017). The amount of companies involved in this research is superior (Baldassarre et al., 2017; França et al., 2017; Linder and Williander, 2017; Wells, 2016) or comparable (Bocken et al., 2018) to the majority of similar studies that applied action research to build processes or tools within sustainability/CE fields. Moreover, the approach involved quantitative evaluation of the process model, which is strongly recommended and narrowly presented in CEBMI tools/methods (Bocken et al., 2019). However, the process model could be further strengthened with additional action research and evaluation in large companies and other sectors within and beyond manufacturing. In the hypothetic-deductive approach, this is a way of falsifying the hypothesis (i.e. that the process model is applicable to that given context) (Gill and Johnson, 2002).

Furthermore, three improvements recommended by companies and not incorporated due to limitations in the scope of this research deserve further exploration:

- Tools for assessing resource decoupling and economic potentials require simplification in the number of variables and flexibility for different CEBM configurations;
- The process model could be digitised and designed for iterations, enabling simulation and comparison of alternative CEBM configurations;
- Clear instructions, definitions, and more straightforward terminology are required in tools to enable independent application by companies.

Lastly, the empirical development of this research was limited to the stages *Sense* and *Seize*. Future longitudinal research could explore the usefulness of the process model in supporting manufacturing companies in the stage *Transform*. The engagement of external actors, which was limited to some of the cases, could also be further explored.

## 6. Conclusions

This article provides a systematic process model for CEBMI within manufacturing companies, structured in four stages (i.e. prepare, sense, seize and transform) and with a number of operational and institutional/strategic practices to innovate their BMs for CE. It includes aspects such as activities and tools, interdependence with other business processes and sustainability performance, decision-support procedures, and institutional change enablers/catalysers (i.e. behaviours, mindset and attitudes).

For manufacturing companies, the process model offers: (i) *a systematic structure to strengthen and mature existing CEBM ideas into viable and implementable concepts*; and *(ii) a source of inspiration for best practice CEBMs in specific sectors*. With this, we help companies in improving their practices to deal with the complexity of CEBMI by pondering economic and resource efficiency gains, embracing ambiguities and experimentation, and organizing results to help dissemination and implementation.

For literature, this article contributes with: (i) consolidating a holistic and systematic view of practices for CEBMI within manufacturing companies; and (ii) providing an example of approach to develop methodological support that is able to offer proactive advice to practitioners. Such an approach could be employed by scholars to develop further CE methodologies.

The development of the process model presented in this paper showed the importance of approaching CEBMI with a holistic process (i.e. from sensing opportunities to transforming the organisation to implement the CEBMs) and linking CEBMI with other business processes and sustainability performance measurement. Moreover, it highlighted the importance of formalising procedures for decision-support while considering favourable behaviours, mindset and attitudes for CEBMI in order to prompt companies to balance core organisational objectives with CE objectives for designing more impactful CEBMs.

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# Appendix A

Table A1 - Evaluation of opportunities for improvement (I) after research phases. Legend: ‘F’ – participants’ feedback; ‘O’ – researchers’ observations/ Criteria for not treating improvement requirements: S - alignment with the scope of the process model, E- effort to accomplish the improvement or limitations of researchers’ role.

| Code | Stage | Need for improvement | Source | Phase | Treated | Criteria |
|---|---|---|---|---|---|---|
| **OVERALL PROCESS - activities, decision gates, and integration with business processes (L1, L2, L3)** | | | | | | |
| **Major** - changes to the structure and format, such as modifications in the sequence of activities or additions of elements | | | | | | |
| I01 | Sense | It was difficult to do some of the activities on the same day that the frameworks and concepts were introduced. For example, companies were not acquainted with the concept of CE/CEBMI when they started and they were asked to define a vision for it as a first activity. | F | 2.1 | Yes | |
| I02 | Sense | Problem-oriented focus was required, i.e., clarity about the relevance of problems and challenges in the existing business models. | F | 2.1, 2.2 | Yes | |
| I03 | Seize | It was difficult to understand what a value proposition is and how to define it. The design of value propositions should be instructed by a dedicated and clear procedure. | F/O | 2.1, 2.2 | Yes | |
| I04 | Sense | Too many drivers for change and opportunities were identified during the brainstorming activity and companies it was difficult to prioritise them. | F/O | 2.1 | Yes | |
| I05 | Sense, Seize | It was difficult to understand what are the expected deliverables were expected along the stages- The process model and tools should support organizing and making explicit the level of information and evolution of content in the outputs along the decision gates. | F/O | 2.1, 2.2 | Yes | |
| I06 | Sense, Seize | It was difficult to follow the flow from one activity to the next and do iterations. | F | 2.1, 2.2 | Yes | |
| **Medium or minor** - enhancements to existing elements or refinement in labels, definitions and instructions | | | | | | |
| I07 | Sense, Seize | Need for enhancing the procedures for iterations, i.e., action plans with frequency for revisiting the prioritisation of CEBMI opportunities. | F | 2.2 | Yes | |
| I08 | Seize, Transform | It was difficult to understand the difference between short-term experimentation and long-term implementation. | F/O | 2.2 | Yes | |
| I09 | Sense, Seize, Transform | The terminology needs to be straight-forward, i.e., too many technical or academic expressions raised questions and misunderstandings. | F | 2, 3 | Partially | |
| **TOOLS (L1)** | | | | | | |
| **Major** - substitution or creation of new tools | | | | | | |
| I10 | Sense | The identification of CEBMI opportunities and elaboration of CEBM ideas need to be focused on business values. Additional information and knowledge is required for decision-making, i.e., “is there a realistic business opportunity from the company and customers’ point of view?" | F | 2.1 | Partially | S, E |
| I11 | Sense | The identification of CEBMI opportunities and elaboration of CEBM ideas need to be supported by case examples focused on specific sectors of application. | F/O | 2.1 | Yes | |
| I12 | Sense | Some CEBM ideas generated were fragmented, meaning that they were not at the level of a complete CEBM concept, e.g., ideas for single elements of the BM. | F/O | 2.1, 2.2 | Yes | |
| I13 | Sense, Seize | CEBM concepts need to be assimilated before the detailing. Companies should be able to pitch CEBMs shortly with awareness about the generated values for key stakeholders. | F/O | 2.1, 2.2 | Yes | |
| I14 | Sense | The prioritisation of CEBMI ideas should be consensual and take into account different values (e.g. economic, environmental, time/effort) in the impact axis. The Feasibility Matrix tool should be reconsidered. | F/O | 2.1, 2.2 | Yes | |
| I15 | Seize | Resource decoupling and economic assessments need flexibility to adapt to different CEBM types and simplification regarding the number of variables. | F/O | 2, 3 | Partially | E |
| I16 | Sense, Seize | Simple frameworks, implementing fast, and testing early are preferable than complex tools. The ideal is to have time and flexibility to compare and test alternative CEBM configurations. The process model could be digitised and designed for iterations (i.e. repeating process), meaning that previous answers become new defaults so that it is easy to make changes and see the effects. | F | 2, 3 | No | E |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Medium or minor -** changes in existing tools' structure and terminology or instructions for application | | | | | | |
| I17 | Seize | The tool/framework to model the CEBMs need to consider environmental and social results on the bottom line (value capture) and for target customers. Moreover, it would be nice to have the activities in the elements value creation and value delivery as process flows. | F | 2.2 | Partially | S |
| I18 | Seize | Need to push participants for defining a plan for experiments with concrete actions. | F | 2.2 | Yes | |
| I19 | Seize | The tool Sustainability Qualifying Criteria Checklist needs to be improved with: a scale with extra options for scores; normalization of the graph of sustainable qualifying criteria; simplification of the number and meaning of criteria; instruction about how to apply it iteratively with the CEBM Framework. | F | 2.1, 2.2 | Yes | |
| I20 | Sense | Clarify definitions and instructions to use case examples to support identifying CEBM opportunities and elaborating CEBM ideas. | F/O | 3 | Partially | E |
| I21 | Seize | The tool/framework to model the CEBMs requires simplified terminology, clear definitions and instructions (e.g. order to fill it in), and examples to allow independent use of the tool by participants. | F/O | 3 | No | E |
| I22 | Seize | Resource decoupling and economic assessments need clear instructions in definitions and interpretations of results. | F | 2.2, 3 | No | E |

Table A2 - Modifications to the process model to fulfil improvement opportunities [I] (see Table A1). Legend: # - number of modification mentioned in section 4.2.

| |
|---|
| **OVERALL PROCESS -** activities, decision gates, and integration with business processes |
| **Major modifications -** changes to the structure and format, such as modifications in the sequence of activities or additions of elements |
| After Phase 2.1<br>#1 - [I01, I02] Unification and repositioning of activities and detailing of tasks for stage Sense. The activity 'definition of a vision/purpose for CEBMI' was repositioned and merged with another activity at the end of stage Sense and became 'Prioritise CEBM ideas based on the organisational vision for CE'. Moreover, there was an inclusion of a step for pre-inventory of CE challenges and trends by the company, to enable more focused discussions with problem-solving orientation and reliable assumptions. |
| #2 - [I03] Inclusion of a separate activity for definition of value proposition before proceeding with modelling the CEBM concepts. |
| #3 - [I02, I04, I05] Inclusion of a gate for identification of ‘hot-spots’/most critical aspects (e.g. lower hanging-fruits; urgency in addressing) during the definition of drivers and before proceeding to the identification of opportunities for CEBMs. |
| After Phase 2.2<br>#2 - [I03] Inclusion/refinement of recommended steps for the definition of value propositions: 'stakeholder analysis with focus on customers and users', and 'creation of a statement for the value proposition (i.e. intent/promise to stakeholders)'. |
| #3 - [I05] The procedures for decision gates were clarified and the expected outputs were detailed for each activity: A01/A02 - CEBMI opportunities; A03/A04 - CEBM ideas; A05 - CEBM solution principles with value propositions; A06 - CEBM concepts; A07 - CEBM detailed concepts; A08 - CEBM projects |
| #4 - [I06] Detailed visual representations with inputs, tasks, outputs, decision gates, and tools for each activity were developed for each stage. |
| **Medium or minor modifications -** enhancements to existing elements or refinement in labels, definitions and instructions |
| [I07] Reminders for iterations were introduced along the process. |
| [I09] The terminology was reviewed to fit practical application. |
| **TOOLS** |
| **Major modifications -** substitution or creation of new tools |
| After Phase 2.1<br>#5 [I10] Substitution of tools for diagnosing CE characteristics in existing BMs (TC07, TC22, TC34 and TC40 in Supplementary Materials) by a new tool called Circular Strategies Scanner (Blomsma et al., 2019). In respect to the previous tools, the Strategies Scanner is an improvement, since it is oriented to problem-solving for manufacturing companies, trying to help them in finding why (corporate strategy) and where (in terms of business processes) changes are required in existing CEBMs. |
| #6 [I11, I20] Refinements to tools for supporting sensing CEBM opportunities and ideas (see TC06, TC41, TC79, TC96, TC97, and TC98 in Supplementary Materials), resulting in a new too called CEBM Pattern Cards. In respect to previous tools, this tool expands the possibilities of CEBM configurations and it is based on sectorial-oriented patterns and cases. |
| After Phase 2.2<br>#6 [I12, I13] Inclusion/development of a new tool called CEBM Configurator. This tool enables simple representation of key characteristics required in CEBMs at the level of three elements: value proposition, upstream (i.e. value creation) and downstream (i.e. value delivery and capture) architectures. Moreover, it recommends potential configurations for the aforementioned CEBM structure based on the combination of patterns and inspirational cases for specific sectors. |
| #7- [I14]: Tools for prioritisation and visioning (see TC43, TC34, TC22 in Supplementary Materials) in the stage Sense were substituted by a BMI Roadmap (Phaal, 2017). This tool enabled prioritisation of CEBM ideas using more than two criteria (e.g. economic, environmental, time/effort). Moreover, it considered the criteria time in the prioritisation. |
| #8 [I15] Economic Potential Calculator based on cost-benefit analysis with quantitative and qualitative measures (obtained from Kravchenko et al., 2019) and the Resource Decoupling Potential Calculator based on guidelines provided in Kjær et al. (2019) and Kravchenko et al. (2019) were created and iteratively developed. |
| **Medium or minor modifications -** changes in existing tools' structure and terminology or instructions for application |
| [I17] A framework to model CEBMs was adapted from TC13 and TC85 (see Supplementary Materials). |
| [I19] Refinement the tool Sustainability Qualifying Criteria Checklist (see TC115 in Supplementary Materials) by adding a scale with extra scores, normalization of the graph of results and simplification of the number and meaning of criteria. |
| [I08, I18] Refinement of tool TC108 (see Supplementary Materials) to arrive at an Experiments Planning Board, which is able to provide a more concrete structure and frames for defining experimentation plans. |

# Appended Publication 3

Pieroni, M.P.P., McAloone, T.C. and Pigosso, D.C.A. (2020), “From theory to practice: systematising and testing business model archetypes for Circular Economy”, (Manuscript under review at Resources, Conservation & Recycling).

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AP3

# From theory to practice: systematising and testing business model archetypes for Circular Economy

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## Abstract

A number of archetypes exist to describe potential business models for Circular Economy, but the majority of them lack validation in practice. Although diversity is natural for an emerging field such as Circular Economy, building consensus of terminology and archetypes is important to achieve a shared discourse, which is fundamental for the implementation of business models. By reviewing academic and practical literature, this article systematises twenty archetypes of business models for Circular Economy, according to a framework focused on downstream and upstream architecture, and the type of value delivered, created or captured. Additionally, it proposes a way to evaluate the application of the archetypes in practice, through a deck of cards to support companies in identifying opportunities, generating ideas, and prioritising business models for Circular Economy. The application of the archetype cards in six manufacturing companies resulted in four key findings: (i) existing archetypes hold a reductionist approach with limited attention to the downstream value logic; (ii) the archetypes' application in practice requires sectorial contextualisation, harmonisation of the abstraction level and standardisation of archetypes' structure; (iii) there was a lack of detailed guidelines for archetype selection and combination; and (iv) the action research approach enables the exploration of radical innovation for Circular Economy business models.

**Keywords:** Circular Economy; business model; archetypes; typology

## 1. Introduction

As a response to increasing pressure on natural resources, pollution and waste generation, Circular Economy (CE) has been disseminated to propose a shift in existing industrial and consumption foundations (Blomsma and Brennan, 2017; Ghisellini et al., 2016). Although primarily concerned with economic prosperity and environmental aims (Kirchherr et al., 2017), CE can contribute to achieving a number of sustainable development targets (Geissdoerfer et al., 2017; Schroeder et al., 2019). At the industrial level, the adoption of CE as a business strategy entails a new business logic away from the 'take-make-use-dispose' (Lieder and Rashid, 2016). This new logic envisions providing and maintaining materials and products with the highest value and for as long as possible, while consuming as few resources as possible (EMF, 2015). The configuration of new business models (BM) fit for CE is fundamental to enable such a transformation by delivering higher value creation with minimised resource consumption (Bocken et al., 2016; BSI, 2017; Lieder and Rashid, 2016; Schulte, 2013).

A BM for CE or CEBM describes how an organisation or an ecosystem of organisations create, deliver, and capture value by slowing, closing or narrowing flows of energy and materials (Nußholz, 2017; Oghazi and Mostaghel, 2018). Designing and implementing new CEBMs is challenging for organisations. Limited progress in CEBM implementation by companies has been associated to various barriers ranging from cultural, regulatory, market and technological aspects (de Jesus and Mendonça, 2018; Kirchherr et al., 2018). Although technological barriers are dominant in literature, Kirchherr et al. (2018) show that cultural barriers are the most pressing type of barriers according to companies and policy-makers. In particular, a hesitant organisational culture and limited awareness, information, and in-house competencies are considered core barriers for the implementation of CEBMs by companies (de Jesus and Mendonça, 2018; Guldmann and

Huulgaard, 2020; Kirchherr et al., 2018). Especially manufacturers, which have been operating close to the linear industrial model, face difficulties in understanding how and why to change (i.e., what are the economic or other benefits) (Blomsma et al., 2019; Lieder and Rashid, 2016). Companies require support to reinvent the way they innovate, with a more holistic and business-oriented perspective (de Jesus and Mendonça, 2018).

Academic literature has focused on the development of appropriate methods and tools to support companies in changing their innovation practices to enable the transition towards new CEBMs; however, they remain conceptual (Bocken et al., 2019; Pieroni et al., 2019; Rosa et al., 2019). Some authors focus on further understanding the *static view* of a CEBM, with the development of representation frameworks that describe or model the discrete elements that compose the BM architecture (Rosa et al., 2019). However, there is an increased focus on the *dynamic view*, which proposes conceptual frameworks or tools to support the identification of how the BMs and their elements should be *configured or changed* over time to accommodate CE principles (Bocken et al., 2016; Bocken and Short, 2016; De los Rios and Charnley, 2017; Diaz Lopez et al., 2019; Geissdoerfer et al., 2018; Lüdeke-Freund et al., 2019b; Moreno et al., 2016; Planing, 2018; Rosa et al., 2019; Tukker, 2004a; Urbinati et al., 2017; Yang et al., 2018).

Taxonomies or archetypes are examples of such dynamic-oriented conceptual frameworks or tools for CEBM innovation (Pieroni et al., 2019). They describe solutions or configuration of CEBM elements with varying degrees of rigour in the representation of relationships and complexities. Taxonomies are "classification systems that categorise phenomena into mutually exclusive and exhaustive sets with a series of discrete decision rules" (Doty and Glick, 1994). In literature, taxonomies are used to classify CEBMs in discrete categories (e.g. claims of 'it is or it is not'), as illustrated in Urbinati et al. (2017). Archetypes describe how to configure groupings of mechanisms or solutions (i.e. elements) to design or transform BMs according to a specific purpose (e.g. circular economy, sustainability) (Bocken et al., 2014). They can be compared to 'theoretical prototypes' (Helkkula et al., 2018). To complement archetypes, the concept of typologies is often used, providing a structure by which to organise a collection of archetypes, describing (high-level) links or synergies among the archetypes (Helkkula et al., 2018; Pieroni et al., 2019).

The most popular conceptual tools for CEBM innovation are archetypes (Pieroni et al., 2019). One reason for the popularity of archetypes might be associated to their ability to provide elegant solutions, 'simplifying' complex processes that determine the focal organisational outcomes, i.e., innovating BMs to solve CE challenges (Doty and Glick, 1994). In a context where companies are still learning about CEBM innovation, archetypes and accompanying typologies are important tools, due to their potential to stimulate empirical research and trigger ideation with different users (e.g. scholars, business managers, students) (Doty and Glick, 1994).

A number of archetypes have already been proposed by academics and practitioners over recent years (Bocken et al., 2016; Diaz Lopez et al., 2019; Lüdeke-Freund et al., 2019b; Moreno et al., 2016; Planing, 2018; Yang et al., 2018). Although diversity is natural for a maturing research field, the lack of consolidation of the archetypes could present a challenge to the evolution of CE, both in practice and theory. A consensus of terminologies could benefit both practice and academia by establishing a common language and discourse, facilitating the dissemination and adoption of CE objectives collaboratively (Blomsma and Brennan, 2017; Kirchherr et al., 2017; Merli et al., 2018; Pieroni et al., 2019; Planing, 2018; Reike et al., 2017). Furthermore, the archetypes (and accompanying typologies) present limitations in how they were developed, sometimes failing to follow good practices and guidelines for theory building (Doty and Glick, 1994; McKelvey, 1975). Three main limitations can be highlighted. Firstly, the archetypes are proposed mainly based on inductive and retrospective approaches (i.e. of companies that had already changed their BMs), and therefore risk being inherently restricted by the analysed sample. Moreover, archetypes are frequently discussed independently (i.e. one archetype per time in focus) rather than complementarily, although in practice they may not appear in isolation (Helkkula et al., 2018). Lastly, there is a lack of practical demonstration on how they can be applied to foster change with companies in need to design CEBMs (Bocken et al., 2019; Kirchherr and van Santen, 2019; Pieroni et al., 2019; Rosa et al., 2019).

In this context, two research questions emerge:

(i) *What are the existing archetypes of BMs fit for CE, according to academic and practical literature?*

(ii) *How to enable the application of archetypes in practice to support CEBM innovation/design?*

To answer the research questions, this paper systematises archetypes for CEBMs and proposes a way to enable their practical evaluation within BM innovation, showing initial insights and improvement opportunities. By doing so, the research contributes to *advising* and creating *knowledge for action, 'with' and 'to' businesses* (Andreasen, 2011; Lüdeke-Freund et al., 2019a), advancing the academic and practical fields simultaneously.

The paper is structured in five sections. Section 2 describes the research methodology. Section 3 presents the results of the systematisation of archetypes and their evaluation after application with six manufacturing companies. The remaining sections discuss the results in relation to literature, summarising how the research questions were addressed (section 4) and concludes by recapping the research contributions and limitations (section 5).

## 2. Research Methodology

A hypothetic-deductive approach (Gill and Johnson, 2002) was adopted as the methodological framework to answer the two research questions presented in section 1. The methodological framework, including two cycles of theory development followed by empirical testing and evaluation, is described in the following sub-sections (schematics available in Appendix A).

### *2.1. Cycle 1*

#### 2.1.1. Theory development

Research Question I

CEBM archetypes were identified in recent systematic literature reviews about approaches (i.e. conceptual frameworks, methods and tools) for CEBM innovation (Pieroni et al., 2019; Rosa et al., 2019). The identified archetypes were codified and classified in a framework following four characteristics:

(a) Archetype label: a short tag for the archetype;
(b) Description: explanation of their meaning in regards to how they affect the BM elements;
(c) Case examples: demonstration of application by companies;
(d) Source of resource decoupling: key sub-model of the BMs contributing to principles of CE, i.e. (i) upstream (i.e. new revenue schemes and customer interface) or (ii) downstream (i.e. value creation systems, such as product design, reverse logistics) elements (Urbinati et al., 2017).

The archetypes were compared through content analysis (Dresch et al., 2015), and a first version (v.1) of a consolidated set of archetypes (i.e. typology) was developed based on semantic similarities. Only archetypes being referenced by more than one publication were considered in the final typology.

Research Question II

Based on the findings from the literature review, two hypotheses were formulated regarding the second research question:

- Hypothesis 01: archetypes for CEBM innovation can support companies during the CEBMs design (i.e., identification of opportunities and ideas).

- Hypothesis 02: generic archetypes accompanied by generic case examples are enough to support ideation during the CEBMs design.

To test the validity of such hypotheses, the set of archetypes was transformed into a deck of cards to support CEBM innovation (*deck of cards of CEBM archetypes* (v.1)). The cards were developed by following guidelines on how to create tools for CE (Bocken et al., 2019) and Design Heuristics theory. Design Heuristics can contribute to effective idea generation (Christian et al., 2012; DALY et al., 2012), i.e. increasing practicality and elaboration of ideas (Leahy et al., 2018). Instructions on how to apply the card deck during the initial stage of generating ideas of CEBMs were provided.

#### 2.1.2. Theory testing and evaluation

The first version of the card deck and accompanying guidelines (v.1) was applied and tested with three companies, following an action research (AR) approach (Coughlan and Coghlan, 2002; Mathiassen, 2017). AR enables collaboration of researchers and company members to explore and prescribe solutions to real organisational problems while building *theory for action,* from observing and interacting with practice (Mathiassen, 2017).

Participating companies were recruited within the context of a broader research project[1], on the basis of a number of workshops. Interested companies were selected based on three criteria: (i) manufacturers; (ii) with intention to explore or develop CEBMs; (iii) and availability and willingness to provide access to people, information and feedback. The manufacturing companies participating in Cycle 1 covered the sectors of capital goods, electronic equipment and furniture (companies A, B and C in Table 1).

Each AR was planned and executed in one workshop (3-4 hours). Triangulation was considered in the AR protocol to minimise bias from researchers (Yin, 2011). Hence, a combination of methods was employed for data collection: (i) research journal with observations and post-reflection; (ii) recordings to enable compilation of verbal feedback; and (iii) evaluation questionnaire. Whenever possible, observations from different researchers were collected and more than one participant in the companies replied to the questionnaire. The evaluation questionnaire was composed of a combination of multiple-choice and open questions, focused on measuring the ‘satisfaction’ level of the companies in regards to: (i) usefulness of results obtained by the application of the card deck; and (ii) usability of the card deck. A four-point Likert scale varying from “Unsatisfactory” to “Very satisfactory” was employed.

The collected data set was analysed to enable the evaluation of the application of the card deck by the companies. Improvement opportunities (v.1) were catalogued following a coding process (Yin, 2011) (i.e., indicating a code, the suggested change, and the company/participant suggesting it). A level of saturation in the identification of new improvement opportunities was reached after the application with the third company, which triggered the need for improving the card deck and starting a new cycle of tests.

### *2.2. Cycle 2*

Improvement suggestions (v.1) from Cycle 1 were assessed in order to decide how to treat conflicting suggestions and which ones to incorporate for refining the card deck (v.1). Improvements were incorporated when or whether they were: (1) aligned with the scope of the tool and (2) feasible. A revised version of the card deck (v.2) was developed and applied within three different manufacturing companies, following the same action research approach, as mentioned above. The companies covered the sectors of furniture,

[1] http://circitnord.com/

textiles/clothing, and medical devices (D, E, and F in Table 1). This cycle resulted in the identification of additional improvement opportunities (v.2) and key insights to the research questions and hypotheses.

Table 1 - Manufacturing companies participating in the AR cycles.

| **Company** | ***Country*** | **Sector** | **Size** | **Number of Participants**<br>***Profiles*** |
|---|---|---|---|---|
| **A** | Finland | Capital goods | Large (>250 employees) | 12<br>• *Corporate Social Responsibility Director*<br>• *Environmental Manager and Specialists*<br>• *Business Designer*<br>• *IoT/ Data Analytics Engineer*<br>• *Procurement Director*<br>• *Product Engineers*<br>• *Sales Director*<br>• *Services/Product Director*<br>• *Support/Quality Director* |
| **B** | Norway | Furniture | Small (< 50 employees) | 3<br>• *Marketing and Sales Coordinator*<br>• *Sales & Operations Manager*<br>• *External Consultant in Business Development* |
| **C** | Sweden | Electronic equipment | Small | 2<br>• *Marketing & Sales Manager*<br>• *Product Design & Operations Manager* |
| **D** | Norway | Furniture | Small | 3<br>• *Marketing Manager*<br>• *Product Manager*<br>• *Strategy & Sustainability Manger* |
| **E** | Norway | Textile & clothing | Small | 3<br>• *Chief Executive Officer and Designer*<br>• *Financial Manager*<br>• *Marketing & Sales Manager* |
| **F** | Iceland | Medical devices | Large | 12<br>• *Environmental and Safety Manager*<br>• *Quality and Regulatory Vice-President and Director*<br>• *Patent Manager*<br>• *Product Designers*<br>• *Product Manager and Director*<br>• *Research & Development, Strategy & Operations Vice-President*<br>• *Technolog*y Manager<br>• *External consultant in Environmental Management* |

## 3. Results: a systematisation of archetypes for CEBM innovation

This section presents the results. Section 3.1 presents an overview of the systematisation of archetypes. Section 3.2 explains how the archetypes were transformed into the card deck and applied in the manufacturing companies, followed by an example of its application. Section 3.3 concludes with insights that emerged from the evaluation with the manufacturing companies.

### *3.1. Systematising CEBM archetypes*

In total, sixteen publications with specific focus on CEBM archetypes were identified. Eight publications are academic literature. The seminal work of Tukker (2004b) introduces eight archetypes for sustainability-oriented BMs based on product-service systems (PSS). Although they were developed prior to the emergence of CE in its modern notion, the archetypes are acknowledged within the field. The archetypes are organised into three categories: (i) “product-oriented PSS” (comprising “product-oriented” and “advice and consultancy”); (ii) “use-oriented PSS” (including “product lease”, “product renting/ sharing”, and “product pooling”); and (iii) “result-oriented PSS (containing “activity management”, “pay per service unit”, and “functional result”).

Publications focusing on BM archetypes for CE with its modern notion emerged in 2016. Bocken et al. (2016) propose six archetypes according to different strategies: (i) “access and performance models” for “extending product value”; (ii) “classic long-life model” and “encourage sufficiency” to “slow loops”; (iii) “extend resource value” and “industrial symbiosis” to “close loops”. Moreno et al. (2016) systematise five archetypes from literature and identify their contribution to value flows: (i) “sharing platforms” and “extending product value” to “slow resource flows”; (ii) “product life extension” to “cycle resources for longer”; and (iii) “resource value” and “circular supplies” to “cascade or narrow resources flows”. De los Rios and Charnley (2017) build on the archetypes proposed by Accenture (2014) (explained below) to analyse how companies use archetypes in practice.

Planing (2018) systematises nine archetypes from literature: (i) “access model/collaborative consumption”; (ii) “performance model/products as services/result-based models”; (iii) “reuse/refurbish/ maintain/redistribute/next-life sales”; (iv) “hybrid model/gap exploiter model”; (v) “remanufacturing next-life sales”; (vi) “upgrading”; (vii) “product transformation”; (viii) “product recycling/recycling 2.0”; and (iv) “energy recovery”. Rosa et al. (2019) propose thirteen archetypes adapted from OECD (2018): (i) “renewable energies”; (ii) “bio-/secondary materials”; (iii) “co-ownership”; (iv) “co-access”; (v) “use-oriented PSS”; (vi) “reuse”; (vii) “repair”; (viii) “industrial symbiosis”; (iv) “product-oriented PSS”; (v) “refurbish/remanufacture”; (vi) “recycling”; (vii) “result-oriented PSS”; (viii) “de-materialise”.

Two academic works expand the boundaries and build on other concepts from the broader field of sustainability (e.g., sufficiency and product life-cycle management) to create archetypes that can advance CEBM innovation. Bocken and Short (2016) propose six archetypes of sufficiency-based BMs observed from cases: (i) “sharing or no ownership”; (ii) “demand reduction services”; (iii) “moderating sales and promotion”; (iv) “extending product life”; (v) “direct reuse”; and (vi) “full life cycle sufficiency”. Diaz Lopez et al. (2019) review over a hundred case studies and propose archetypes based on resource efficiency measures, comprising: (i) “cradle-to-cradle”; (ii) “take-back management”; (iii) “circular economy”; (iv) "green products”; (v) “green services "; (vi) “services instead of products”; (vii) “functional sales”; (viii) “take-back management"; (ix) “industrial symbiosis”; (x) “cleaner production and eco-efficiency”; (xi) “green supply chain management”; and (xii) “waste management”.

The grey literature contributes to eight publications. Lacy et al. (2013) deliberate about five BM archetypes that are driving CE: (i) “product as services”; (ii) “next life sales”; (iii) “product transformation”; (iv) “recycling 2.0”; and (v) “collaborative consumption”. Later, the same authors on behalf of Accenture (2014) launched a report with a new version of the archetypes, which has been broadly disseminated among industry practitioners and researchers: (i) “product as service”; (ii) “sharing platforms”; (iii) “product life-extension”; (iv) “resource recovery”; and (v) “circular supplies”. Bakker et al. (2014) propose five BM archetypes to enable “products that last”: (i) “classic long life model”; (ii) “hybrid model”; (iii) “access model”; (iv) “performance model”; (v) “gap exploiter”. These archetypes were later reviewed in a publication with updated case examples (Den Hollander and Bakker, 2016).

After 2015, the authors started to systematise previous archetypes proposing different categorisations. Van Renswoude et al. (2015) systematise nineteen CEBM archetypes, which were categorised in six groups according to the value creation source: (i) “short cycle”; (ii) “long cycle”; (iii) “cascades”; (iv) “pure circles”; (v)“dematerialised services”; and (vi) “produce on demand”. The research project REBus (2015) proposes an interactive map containing ten innovative archetypes of resource-efficient BMs currently in use by different companies: (i) “incentivised return & reuse”; (ii) “long life”; (iii) "hire & leasing”; (iv) “collaborative consumption”; (v) “Product Service System”; (vi) “dematerialised services”; (vii) “bring your own device”; (viii) “collection of used products”; (ix) “asset management”; (x) “made to order”.

Weetman (2016) compiles eight archetypes: (i) “exchange or redistribution”; (ii) “rent or lease”; (iii) “share”; (iv) “service or results”; (v) “refill and maintain”; (vi) “resell and reuse”; (vii) “remanufacture”; (viii) “recovery and recycling”. Lastly, a first attempt to establish shared discourse and language emerged with a British Standard (BS 8001:2017) (BSI, 2017). It provides guidance on which BMs are compatible with CE, including reflections for their selection. The proposed archetypes are: (i) “on demand”; (ii) “dematerialisation”; (iii) “product life cycle extension/reuse”; (iv) “recovery secondary raw materials/by-products”; (v) “product as a service/product-service systems (PSS)”; (vi) “sharing economy/platforms”; and (vii) “collaborative consumption”.

Based on the comparison of the works and after treating them to find semantic similarities (see Supplementary file), a consolidated version of twenty archetypes was generated (Figure 1 and Table 2). The archetypes are organised in eight categories, which are distributed in downstream and upstream architecture (i.e. sub-models of the BM). Six categories focus on changes related to the downstream architecture of a business and two categories on the upstream.

Figure 1 shows how different archetypes were organised according to the source (i.e. downstream or upstream the value system) and type of value generation for CE regarding key elements of a BM (i.e., economic and environmental value captured, value delivered to market, or value exchanged with the network/collaborators).

Table 2 describes the meaning of each archetype, providing case examples of how they are applied in practice. It also shows a correlation of how different archetypes change different elements of a BM to embed CE principles, and the recurrence of archetypes, as mentioned by the analysed literature. The most recurring archetypes are *access models* and *sharing or pooling systems/platform*, appearing in more than 90% of publications. The least recurring archetypes are the *demand reduction*, *encourage sufficiency*, *sharing economy*, *asset management*, and *cleaner production/eco-efficiency*, appearing in 10% of publications.

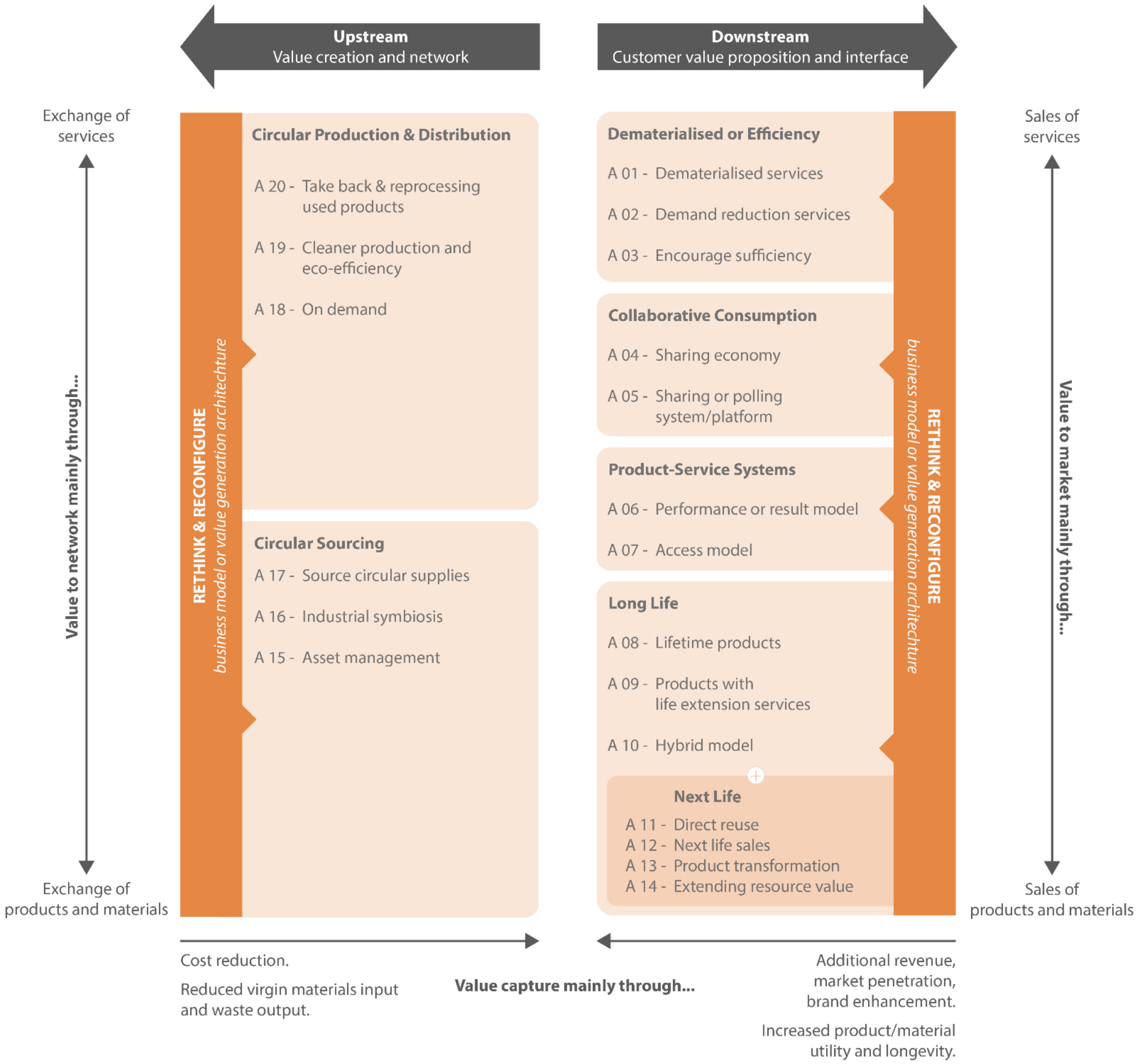


Figure 1 – Consolidated typology of CEBM archetypes (Legend - A: archetype).

Table 2 – Description, examples, and recurrence of consolidated CEBM archetypes (Legend - Cat: categories / #: recurrence / BM elem.: key affected elements to embed CE principles in the BM - VP: value propositions, CH: channels, CS: customer segments; CR: customer relationships; RE: revenue streams; KA: key activities; KR: key resources; KP: key partners; CO: cost structure (Osterwalder and Pigneur, 2010)).

| **Cat** | **Code** | **BM archetypes for CE**<br>***Alternative names*** | **Description** | **Case examples** | **BM Elem.** | **#** | **References** |
|---|---|---|---|---|---|---|---|
| | | | DOWNSTREAM | | | | |
| Dematerialised or efficiency | A01 | Dematerialised services<br>- *Physical to virtual*<br>- *Digitalisation* | Value delivered by replacing physical infrastructure/assets with digital/virtual services. Collaboration, sharing, and grouping of product needs change consumption patterns to achieve potential material saving through not producing a physical good. This must be balanced against the materials & energy used in the service infrastructure (e.g., data centres). Value is captured with recurrent income from service contracts/ subscriptions. | • On-demand delivery of music and film via internet or mail, using outsourced / public infrastructure with minimal overheads - e.g., Spotify, Netflix, Amazon<br>• Cloud computing, email and document management services on virtual software platforms running on out-of-house hardware - e.g., Xerox | VP<br>CH<br>CR<br>RE | 4 | van Renswoude et al (2015); REBus (2017); BSI (2017); Rosa et al. (2019) |
| | A02 | Demand reduction services | Value delivered by solutions that moderate the use of energy and resources by individuals and companies. Customers benefit from savings that are greater than the service fees. Value is captured through recurrent income from service contracts. | • Add-on services to educate or assist customers in reducing consumption - e.g., Energy Service Companies (ESCOs), Kyocera, Riversimple | VP<br>CR<br>RE | 2 | Bakker et al. (2014); Bocken and Short (2016) |
| | A03 | Encourage sufficiency<br>- *Moderating sales and promotion* | Value delivered by conscious actions to moderate sales activities, such as eliminating manipulative marketing campaigns and reducing sales incentives. Value is captured with potential reduction in the need to produce physical goods, which could leverage the companies' brand image. | • Campaign 'don't buy this jacket' & repair stores – Patagonia | CR | 2 | Bakker et al. (2014); Bocken and Short (2016) |
| Collaborative consumption (continues) | A04 | Sharing economy<br>- *Access economy*<br>- *Share* | Value is delivered/created by products, assets or services, owned by individual or non-commercial organisations (e.g. government) and shared without a charge. Socially driven rather than commercial, access might strengthen community and relationship. | • Tool libraries - e.g., electric drills, lawnmower<br>• Sharing overcapacity in communities - e.g., cars/ houses | VP<br>CS<br>CH<br>CR<br>KP | 2 | BSI (2017); Weetman (2017) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Collaborative consumption (continuation) | A05 | Sharing or pooling systems/platforms<br>*- Collaborative consumption*<br>*- Share*<br>*- Co-access or co-ownership* | Value is delivered/created by products, assets or services, owned by individual/commercial organisations and shared/lent with some form of transactional arrangement for commercial purposes (i.e., value capture). Value can also be created with an integrator platform amongst multiple customers or users. | • Sharing mobility (car) - e.g., Riversimple, Zipcar, Audi Unite<br>• Ride sharing/car-pooling -e.g.,Lyft, BlaBlaCar<br>• Photo equipment rental - e.g., Share Grid.<br>• Shared logistics infrastructure- e.g., containers, storage, shipping<br>• Shared ownership of products - e.g. laundries in apartments | VP<br>CS<br>CH<br>CR<br>KP<br>RE | 15 | Tukker (2004); Lacy et al. (2013); Accenture (2014); Bakker et al. (2014); Den Hollander and Bakker (2016); van Renswoude et al (2015); Bocken et al. (2016); Moreno et al. (2016); Weetman (2016); Planing (2018) ; REBus (2017); Rosa et al. (2019); De los Rios and Charnley (2017); Bocken and Short (2016) |
| Product-service systems (continues) | A06 | Access model<br>*- Availability- or usage-based services*<br>*- Product as services*<br>*- Hire & leasing*<br>*- Rent or lease*<br>*- Extending Product Value*<br>*- Use-oriented products/PSS*<br>*- Pay per use*<br>*- Product-service systems (PSS)*<br>*- Services instead of products*<br>*- Functional sales*<br>*- Take-back management* | Value is delivery by temporary access to products rather than ownership. Companies capture value and profit with continuous revenues. | • 'Tires as a service', in a pay per miles scheme - e.g., Michelin<br>• Modular headphones for a monthly fee - e.g., Gerrard Street<br>• Rental of electric tools - e.g., Kingfisher drills<br>• Fashion rental/leasing service - e.g. Girl meet dress; jeans leasing<br>• Rental of ICT equipment on long-term lease -e.g., Dell<br>• Leasing of industrial solvents<br>• Leasing of flow/wall coverings | VP<br>CR<br>RE | 15 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Product-service systems (continuation) | A07 | Performance or result model<br>*- Result-oriented Product Service System*<br>*- Performance based contracting*<br>*- Service and function-based models*<br>*- Functional sales and management services models*<br>*- Deliver functionality, rather than ownership* | Value is delivered by product's performance or certain agreed result based on functionality rather than the product. Companies capture value and profit with continuous revenues. | • Pay-per-molecule services of endangered elements (e.g., Ruthenium) - e.g., Umicore<br>• 'Pay-per-Lux' - e.g., Philips<br>• Pay-per-print - e.g., Xerox's document management system<br>• 'Power-by-the-Hour' jet engine - e.g., Rolls-Royce<br>• Integration/management grid-connected renewables - e.g., RWE | VP<br>CR<br>RE | 10 | Tukker (2004); Bakker et al. (2014); Den Hollander and Bakker (2016); van Renswoude et al (2015); Weetman (2016); Planing (2018) ; REBus (2017); DiazLopez et al (2018); BSI (2017); Rosa et al. (2019) |
| Long life | A08 | Lifetime products<br>*- Classic long- life model*<br>*- Long life products*<br>*- Green Products and Services*<br>*- Extending product life (designed to last a lifetime)*<br>*- Product life extension* | Value is delivered by high-end products claiming to last beyond a lifetime, and supported by design for durability and repair (value creation). Companies capture value and profit from premium high-end prices. | •Phantom car - e.g., Rolls Royce<br>• Model trains - e.g., Marklin<br>• Washing machines - e.g., Miele<br>• Luxury watches - e.g., Rolex or Patek Philippe | KA<br>RE | 7 | Diaz Lopez et al. (2019); Bakker et al. (2014); Den Hollander and Bakker (2016); Bocken et al. (2016); REBus (2017); BSI (2017); Bocken and Short (2018) |
| | A09 | Premium products with life extension services<br>*- Product-oriented services or PSS*<br>*- Extending product life*<br>*- Product modular design*<br>*- Refill and Maintain*<br>*- Upgrading/Ownership-based BMs*<br>*- Repair services* | Value delivered by products accompanied with additional high-quality services for life extension. Companies create and capture value from through-life/recurrent support services, e.g., repair, upgrade. It may include procurement and stock-holding services for a 'full service' offer. | •Life cycle care program for heavy machinery - e.g., Konecranes<br>• Specialists that calibrate and maintain high-value medical equipment, industrial fans and extraction systems, or production equipment. | KA<br>RE | 7 | BSI (2017); Bocken and Short (2018); van Renswoude et al (2015); Rosa et al. (2019); eetman (2016); Planing (2018) ; Tukker (2004) |
| | A10 | Hybrid model<br>*- Gap exploiter model* | Value delivered through a combination of durable product and short-lived consumables. Companies capture value and profit from the gap in lifetime of components. | • Printer and print ink cartridges - e.g., Océ Canon<br>• Coffee machines and branded capsules - e.g., Nespresso | KA<br>RE | 3 | Bakker et al. (2014); Den Hollander and Bakker (2016); Planing (2018) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Next life (continues) | A11 | Direct reuse<br>*- Facilitated reuse*<br>*- Exchange/Redistribution*<br>*- Trash-to-cash* | Value is created /delivered with second-hand markets for used goods to reduce waste to landfill or idle assets. Reuse can occur with or without repair or upgrade and supplied either free of charge or resold. | • Patagonia in partnership eBay<br>• Skill- and time-exchange platforms - e.g., Echo<br>• Product exchange after use - e.g.; Freecycle, Preloved, eBay, Gumtree | CH<br>KA | 3 | Weetman (2016); Bocken and Short (2016); BSI (2017) |
| | A12 | Next life sales<br>*- Product Life-Extension*<br>*- Product Life Cycle Extension*<br>*- Extending product value*<br>*- Incentivised return & reuse*<br>*- Exchange/Redistribution*<br>*- Take back management*<br>*- Refurbish & resell*<br>*- Cradle-to-Cradle*<br>*- Trash-to-cash*<br>*- Gap-exploiter*<br>*- Refurbishment/ remanufacturing* | Value is delivered by incentivising customers to return used/unwanted items to the producer via a convenient system. Value is then created by enabling products to have a next life, either through refurbishment or remanufacturing. Value is captured by putting products back to the market to earn a second or subsequent income, from a second or subsequent user. | • Cash for electronics and selling refurbished electronics - e.g., Gazelle<br>• Second hand car dealership - e.g., Tata Motors Assured<br>• Automotive parts remanufacturing - e.g., Bosch; BMW<br>• Repair and renovation service prior to replacing furniture - e.g., Steelcase | CR<br>KA<br>KR | 12 | Lacy et al. (2013); Accenture (2014); van Renswoude et al (2015); Moreno et al. (2016); Bocken et al. (2016); Weetman (2016); REBus (2017); Planing (2018) ; BSI (2017); Diaz Lopez et al. (2019); Rosa et al. (2019); De los Rios and Charnley (2017) |
| | A13 | Product transformation<br>*- Cascades and repurpose*<br>*- Extending product value*<br>*- Upcycle*<br>*- Incentivised return & reuse* | Value is delivered by incentivising customers to return used/unwanted items to the producer via a convenient system. Producer creates value by using parts of the product or reprocessing it for application in another purpose. Value is captured via potential savings with supplies. | • Clothing return initiatives for use in damping components of automotive or building industries- e.g., H&M, M&S' Shwopping | CR<br>KA<br>KR | 6 | Lacy et al. (2013); Planing (2018); Bocken et al. (2016); Accenture (2014); van Renswoude et al (2015); REBus (2017) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Next life (continuation) | A14 | Extending resource value<br>*- Cascades or upcycle recycling*<br>*- Recovery of secondary materials/ by-products (including recycling)*<br>*- Circular economy (CE)*<br>*- Product recycling/ Recycling 2.0*<br>*- Resource Recovery*<br>*-Recycling and waste management*<br>*- Incentivised return & reuse* | Value is delivered by incentivising customers to return used/unwanted items via a convenient system. Original equipment manufacturers or specialist actors in the value chain (e.g. recyclers) create value by recycling the materials. Value is captured via potential savings with supplies. | • Carpet take-back programme - e.g., Desso<br>• Providing customers with reward points for recycling and other environmentally benign activities - e.g., RecycleBank | CR<br>KA<br>KR | 12 | Lacy et al. (2013); Accenture (2014); van Renswoude et al (2015); Moreno et al. (2016); Bocken et al. (2016); Weetman (2016); Planing (2018) ; BSI (2017); Diaz Lopez et al. (2019); Rosa et al. (2019); De los Rios and Charnley (2017); REBus (2017) |
| UPSTREAM | | | | | | | |
| Circular sourcing (continues) | A15 | Asset management<br>*- Exchange and Reuse*<br>*- Redistribution/Resell and Reuse* | Value is created by optimising companies' own assets (i.e. products such as ICT equipment, car or equipment fleet) by pooling, sharing, lending, re-using, refurbishing, or re-selling. Value is captured via potential operational savings. | • Business-to-business sharing marketplace where companies and institutions can share equipment, skills and knowledge of personnel internally or externally- e.g., FLOOW2 | KA<br>CO | 2 | REBus (2015); Weetman (2016) |
| | A16 | Industrial Symbiosis<br>*- Multiple cash flows / revenues*<br>*- Create value from waste*<br>*- Co-product generation*<br>*- Secondary/by-products recovery*<br>*- Waste reduction (production)*<br>*- Waste exchange (external/internal)* | Value is created with a process-oriented solution to use residual outputs from a process as input for another process, benefiting from geographical proximity. Value is captured via potential savings with supplies. | • *Kalundborg* Eco-Industrial Park (http://www.symbiosis.dk/en)<br>• Sugar refiners treating internal "waste = value" - e.g., AB sugar | KR<br>KP<br>CO | 5 | Bocken et al. (2016a); van Renswoude et al. (2015); Diaz Lopez et al. (2019); BSI (2017); Rosa et al. (2019) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Circular sourcing (continuation) | A17 | Circular supplies<br>- *Closed-loop production*<br>- *Waste regeneration systems*<br>- *Cradle to cradle*<br>- *Renewable energy. & bio/secondary material* | Value is created by sourcing circular products or materials, e.g., recycled, renewable, waste, or pollution. Value is captured via potential savings with supplies. | • *Interface* collects and supplies fishing nets as a raw material for carpets.<br>• Circular Supplies for Packaging - e.g., Ecovative® | KA<br>KR<br>KP | 5 | Moreno et al. (2016); Accenture (2014) ; van Renswoude et al. (2015); Rosa et al. (2019); De los Rios and Charnley (2017) |
| Circular production and distribution | A18 | On demand<br>- *Make to order*<br>- *Produce on order*<br>- *Customer vote (design)* | Value is created by producing a product or providing a service only when customer's demand has been quantified and confirmed. Customers can vote which product to make, avoiding over-stocks and unwanted products, and contributed to capture of savings | • Furniture designs to order - e.g., Made | CR<br>KA | 3 | Van Renswoude et al. (2015); REBus (2015); BSI (2017) |
| | A19 | Cleaner production (CP, inc. EMS) and eco-efficiency (EE, inc. energy efficiency)<br>- *Waste reduction ( production)* | Value is created with waste, pollution and energy consumption reduction in production process. Value is captured with potential savings from compliance or reduction of waste management fees. | N/A | KA | 2 | Van Renswoude et al. (2015); Diaz Lopez et al. (2019)) |
| | A20 | Collection, take back, and reprocessing of used products<br>- *Collaborative production*<br>- *Resell and reuse*<br>- *Product transformation*<br>- *Online waste exchange platform*<br>- *Gap Exploiters* | Value is created by cooperation in the production value chain leading to closing material loops. Value is captured via potential new revenues or savings. | • Online platform connecting corporates to charities, individuals and SMEs allowing them to help each other by donating and re-using unwanted items - e.g., Globechain | KA<br>KP | 5 | Bakker et al. (2014); Weetman (2016); van Renswoude et al. (2015); Den Hollander and Bakker (2016); Rebus (2017) |

*3.2. Testing the use of archetypes to support BM innovation for CE in manufacturing companies*

Each card in the deck correlates with one archetype presented in Figure 1 and Table 1. The cards contain distinct information on their front and back (example in Appendix B). The foreside includes: number/name of the archetype, icon for abstract depiction, and questions to provoke CE thinking. The reverse of each card presents a case example and describes affected BM elements.

The card deck was applied during a three-hour workshop with the purpose of mapping opportunities and ideas for new CEBMs, for each company.

In addition to the card deck, the group of companies in Cycle 1 (A-C) received a simplified template adapted from Figure 1, which was embedded as part of another template for mapping CE-oriented innovation (previously developed and documented in Blomsma et al. (2019)). As a first step, participants of each company brainstormed freely about how they could change the incumbent CEBMs, documenting ideas on adhesive notes. Thereafter, they distributed the cards among the group, screened them for inspiration, and ideated individually, underway documenting ideas on adhesive notes. Lastly, the participants shared, discussed and consolidated final ideas before transferring them to the template adapted from Figure 1.

The group of companies in Cycle 2 (D-F) received a different template (Figure 2) for placing and combining the different BM archetypes that could make sense for their case. This template was introduced as a result of improvement opportunities identified by companies A, B and C. The *combination framework* (Figure 2) replaced the template adapted from Figure 1 used with companies A-C. An example of the application of the card deck based on the BM archetypes for CE is presented in Figure 2 for a case in the furniture sector. To offer "furniture for social meetings places to last a lifetime" for municipalities or private companies (S1 in Figure 2), company D relied on two archetypes downstream – i.e. A09 and A12 (S2 in Figure 2) – and two archetypes upstream – i.e. A20 and A17 (S3 in Figure 2).

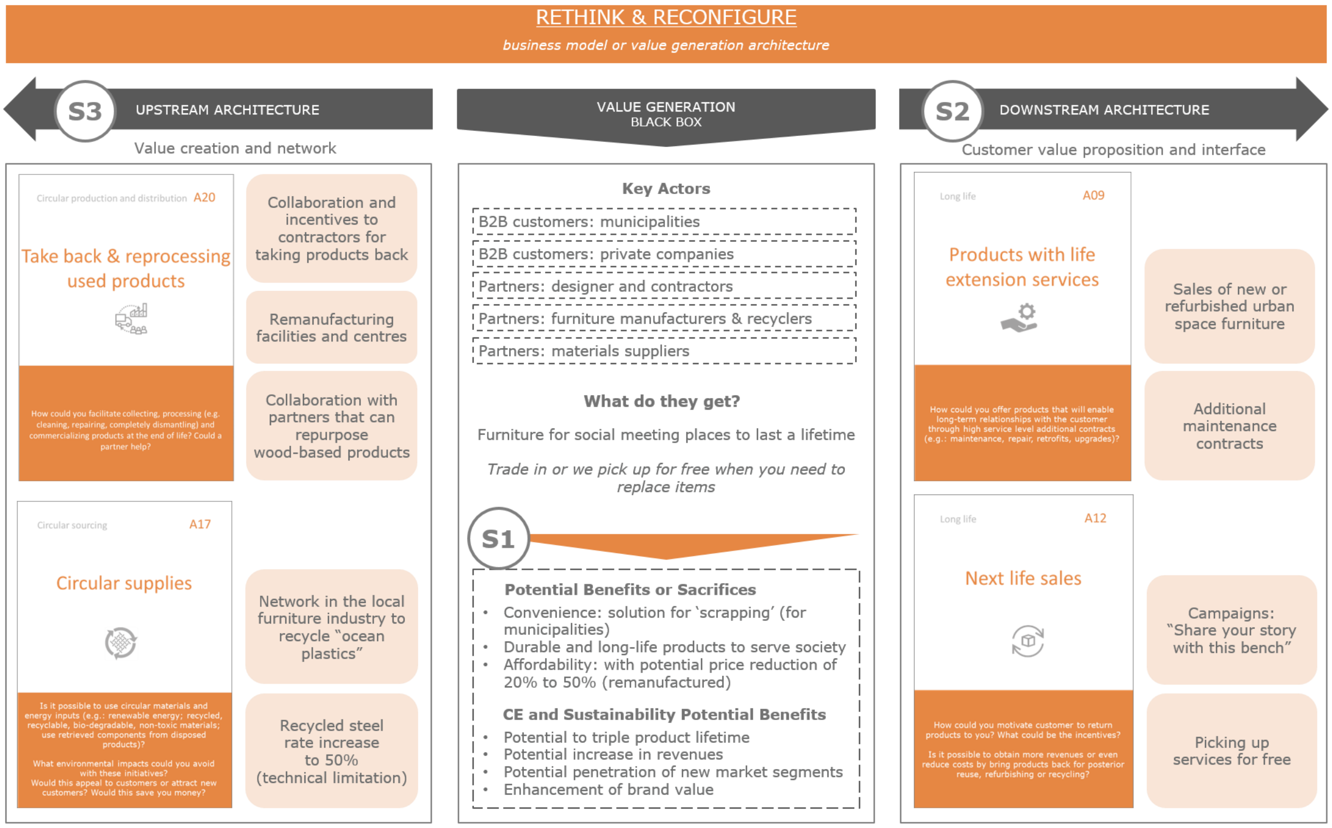


Figure 2 – Example of a CEBM idea after the application of the archetype card deck.

Table 3 shows the selected archetypes for each company. Each company generated at least three BM ideas (see unique codes in Table 3 – e.g., 1, 2), and together they summed up to twenty-seven. Each idea could combine different archetypes (see repeating codes for different archetypes in Table 3). By the end of the ideation, the companies had to prioritise which ideas they would like to continue exploring to detail them completely (see 'x' in Table 3).

Five archetypes were not employed by any company: Encourage sufficiency (A02); Sharing economy (A04); Asset management (A15); Industrial Symbiosis (A16); and Cleaner production and eco-efficiency (A19). The absence of archetype A16 could be related to the absence of companies from bio-based industries in the sample studied. The absence of archetypes A03 and A04, which are related to other concepts of sustainability such as sufficiency, democratisation, or inclusiveness, could indicate that although companies in the sample had CE as part of their strategy, their vision is still limited regarding the broader scope of social and environmental sustainability. All companies proposed BM ideas based on the archetypes: Access model (A06); and Take back & reprocessing used products (A20). High interest was also demonstrated towards the archetypes: Next life sales (A12); Dematerialised services (A01); Demand reduction services (A02); Performance or result model (A07); and Premium products/brands with life extension services (A09).

Table 3 – Archetypes selected (A01-A20) by companies in the action research cycles.
Legend: letter + number (e.g. B1) = code of single BM idea generated by companies during workshops; x = prioritised archetypes.

| | Companies | | | | | | | | | | | | Usage per company | Usage per BM idea | Prioritisation per company |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | | B | | C | | D | | E | | F | | | | |
| DOWNSTREAM | | | | | | | | | | | | | | | |
| A01 | A1,A2, A3,A4, A5 | x | | | C1, C4 | x | D1, D3 | | | | F1,F2 | x | 67% | 41% | 50% |
| A02 | A5,A7 | x | B5 | | C1, C4 | | | | | | F2 | | 67% | 19% | 17% |
| A03 | | | | | | | | | | | | | 0% | 0% | 0% |
| A04 | | | | | | | | | | | | | 0% | 0% | 0% |
| A05 | A2,A6 | x | B4 | x | C3 | | | | | | | | 50% | 15% | 33% |
| A06 | A3,A7 | x | B1,B2 | x | C1 | x | D2 | x | E3 | | F2 | x | 100% | 30% | 83% |
| A07 | A1 | | B3 | | C2 | | | | | | F1 | x | 67% | 15% | 17% |
| A08 | | | | | | | D1 | | | | | | 17% | 4% | 0% |
| A09 | A4 | | | | | | D1 | x | E2 | | F3 | | 67% | 15% | 17% |
| A10 | | | | | C4 | | | | | | | | 17% | 4% | 0% |
| A11 | A6 | x | | | | | | | | | F1,F2 | | 33% | 11% | 17% |
| A12 | A6 | x | | | C1 | x | D1 | x | E1 | x | F3,F4 | | 83% | 22% | 67% |
| A13 | | | | | | | D1 | x | E1 | x | F1,F2, F3,F4 | x | 50% | 22% | 50% |
| A14 | | | | | C4 | | | | | | F1,F2, F3,F4 | | 33% | 19% | 0% |
| UPSTREAM | | | | | | | | | | | | | | | |
| A15 | | | | | | | | | | | | | 0% | 0% | 0% |
| A16 | | | | | | | | | | | | | 0% | 0% | 0% |
| A17 | | | B1,B2, B3,B4 | x | | | D1 | | | | | | 33% | 19% | 17% |
| A18 | | | B6 | | | | D4 | | | | | | 33% | 7% | 0% |
| A19 | | | | | | | | | | | | | 0% | 0% | 0% |
| A20 | A1,A3,A6 | x | B1,B2, B3,B4 | x | C1 | x | D1, D2 | x | E1, E3 | x | F1,F2, F3,F4 | x | 100% | 59% | 100% |

*3.3. Evaluating the application of the archetypes and exploring improvement opportunities*

The feedback provided by individual participants through questionnaires enabled an evaluation of the usability (i.e., level of satisfaction with the application) and usefulness (i.e., level of satisfaction with the obtained results from the application) of the card deck based on CEBM archetypes. The majority of participants scored both usability and usefulness of the cards as ‘satisfactory’, and no criteria were scored as ‘unsatisfactory’ (Figure 3). In general, they were positive and considered the cards as “quite helpful”, “motivating” and “great tool”. According to the declarations, the stated strengths of the archetype cards included "the use of examples to stimulate ideation"; "cases/examples of companies experimenting with circular BMs and the information of what works"; and the “visualisation with the boards [i.e., *typology and combination frameworks*] [that] helped the conversation among people from different departments”.

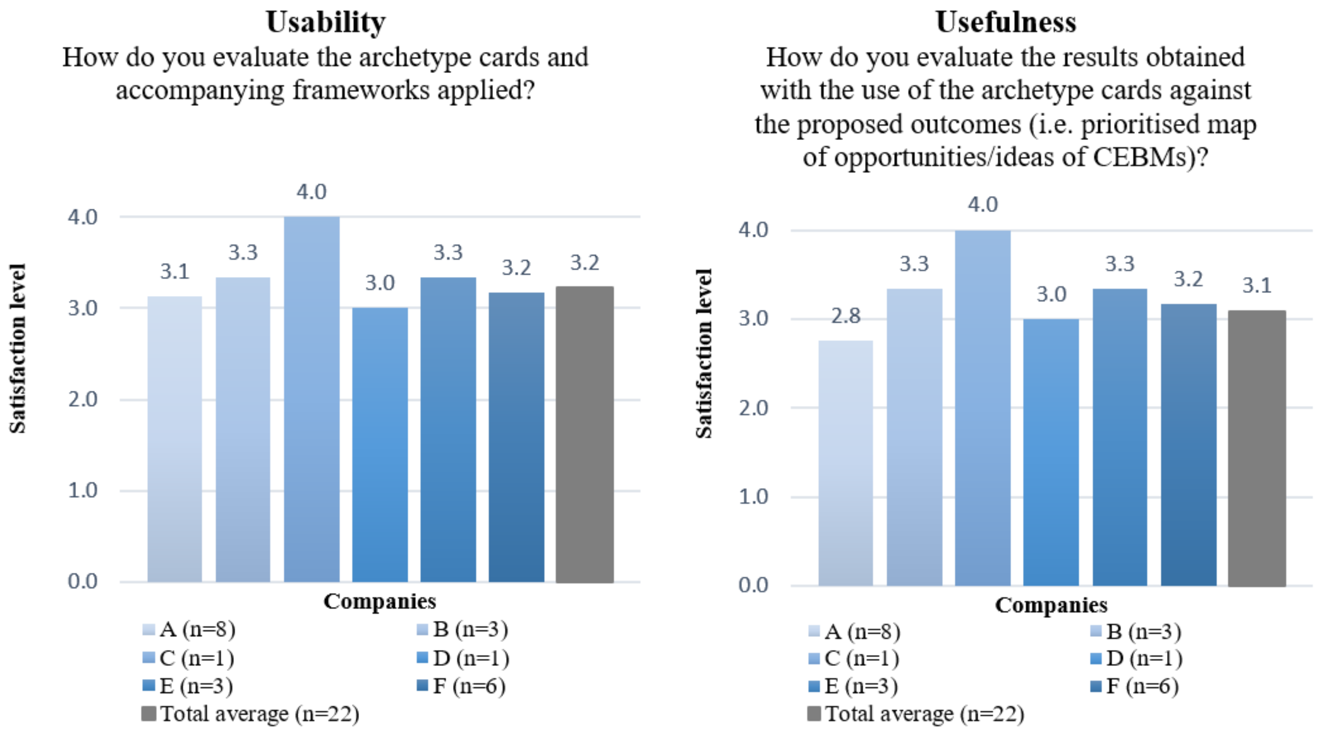

Figure 3 – Feedback of companies regarding usability and usefulness of the card deck. Legend – Satisfaction levels: 1 = Unsatisfactory; 2 = Needs improvement; 3 = Satisfactory; 4 = Very satisfactory/ n = number of participants.

However, improvement opportunities were also identified based on their feedback and observations from the researchers, such as:

*Cycle 1*

- I01: some companies presented difficulties in assimilating concepts that could be applied in their sector, but were illustrated with an example from a very different sector (e.g., application in the heavy machinery sector with cases of textiles/clothing).
- I02: the archetypes are heterogeneous and without a standard structure to represent the CEBMs. They address a different number of elements of a BM, and in some cases some elements are underrepresented or not represented at all. Consequently, they prompted incomplete ideas with different levels of abstraction. This made it difficult for companies to organise, cluster, combine and prioritise them at the end of the ideation.

*Cycles 1 and 2*

- I03: there are too many cards (i.e., archetypes), and some companies had difficulties in prioritising. Participants asked for more prescriptive approaches that could guide them to focus on the selection of cards and archetypes, which could be driven by problem-based approach.
- I04: the description and terminology in the cards (i.e. archetypes) should be simple and clear, avoiding academic language. Instructions and additional definitions could be provided to allow for independent use by companies.
- I05: the cases provided in the backside of the archetype cards should contain more information showing how the companies are applying the BMs and how they work in practical terms.

An overview and discussion about how improvement opportunities could be addressed in future research are presented in the following sections.

## 4. Discussion

This section summarises the results concerning the research questions (section 2) and discusses the key findings of the study in light of previous literature.

Research Question I

On the basis of available academic and grey literature, this study identified, compared and systematised a set of twenty archetypes to describe CEBMs. The archetypes were organised in a typology framework (Figure 2) according to the source (i.e. downstream or upstream) and type of value generated to the market (i.e. mainly through services or products), exchanged with the network of collaborators/partners (i.e. mainly through services or materials/energy exchange), and captured by the organisation/shareholders (i.e. additional revenues or savings). The typology revealed that the majority of CEBM archetypes are focused on the downstream architecture, i.e. changing value proposition offered to customers and interface, which includes pricing and sales model. Another finding is the identification of BM archetypes that are mentioned more frequently in literature, such as *Sharing or pooling system/platform*, and *Access model*, presented in more than 90% of the analysed sample. Other archetypes frequently mentioned by literature are *Next life sales* (80%), *Extending resource value* (80%), and *Performance or result model* (70%). These results are consistent with recent findings in CE literature demonstrating the most common BM archetypes (i.e. use-oriented PSS and recycling) (Rosa et al., 2019), and indicating that literature still holds a reductionist approach, interpreting BMs solely as commercial or revenue model configurations, with limited attention to the downstream value logic related to an ecosystem or collaborative view (Pieroni et al., 2019).

Similar results were noted by Henry et al. (2020), which identified that upstream innovations are the least targeted area by circular start-ups. Recent research contributes to advancing knowledge on the downstream value logic by proposing sub-types (i.e. facilitators, redistributors or doers) of actors in the ecosystem of the archetype *Access Model* (A06) (Whalen, 2019). Similarly, Henry et al. (2020) points out that circular start-ups (e.g. nature-based, waste-based, platform based) could work jointly with manufacturers to generate disruption in the linear BMs at the ecosystem level.

By answering the first research question, the article contributes to academia by proposing a common language for CEBM archetypes which consolidates the current contributions from literature (currently spread across in the sixteen identified articles).

Research Question II

This study proposed and explored the application of the consolidated CEBM archetypes in a real context, based on the development of the archetype cards. The cards, inspired by Design Heuristics, were applied by six manufacturing companies during ideation sessions for designing (i.e. identifying opportunities, generating ideas, and prioritising) CEBMs. The initial evaluation of the application by the companies revealed that the archetypes satisfactorily supported companies in the task of designing CEBMs. Highpoints were indicated as the suggestion of practical examples and the frameworks (i.e. *typology and combination*) that supported guiding and structuring the use of the cards. This evaluation provides favourable evidence to the validity of the first hypothesis investigated in the study. Although the uptake of the cards by the companies was positive, improvement opportunities were recommended, suggesting the need for a different type of approach. The improvement suggestions requested contextualisation of archetypes and sectorial examples; standardisation of the abstraction level and structure of archetypes; and guidelines on how to select cards (i.e. archetypes). These challenges mentioned by companies are consistent with literature in the CE field, pointing to the importance of contextual factors in determining the nature of value creation (Ünal et al., 2019) or to the need of quantitative rigour for generating BM archetypes (Ertz et al., 2019). These observations provide evidence that invalidates the second hypothesis of the study.

Due to the limited sample of companies, the initial findings need to be further validated and some modifications could already be incorporated into future experiments. Hence, three new hypotheses (H) are deployed based on improvement opportunities (section 3.3):

- H03: contextualising archetypes to focus on the specific sectors of application can improve the acceptance of practical tools by companies.
- H04: a different design approach to represent more precisely the structure of a BM architecture in a detailed level of abstraction (i.e. elements and interconnections or possible combinations) can improve the design effectiveness (i.e. higher number of ideas advancing to detailing stage) and acceptance of practical tools by companies.
- H05: a logic for screening and combining the building blocks (i.e. archetypes or other approaches) can improve the acceptance of practical tools by companies.

To explore these hypotheses, future research could focus on other design approaches and representations that enable more detailed and organised decomposition of the BM architecture (i.e. sub-models, elements, variables, design options) while considering the complex interconnections among the pieces. For instance, Ertz et al. (2019) proposed recently a methodology to classify types of BMs following a more rigorous *taxonomy* structure. Another alternative is the concept of *solution patterns*, which emerged from the Design Sciences in the architecture of buildings and has been largely employed by conventional BM innovation literature (REMANE et al., 2017), recently emerging in works from the sustainability-oriented (Lüdeke-Freund et al., 2018) and CE-oriented BM innovation literatures (Lüdeke-Freund et al., 2019b; P. P. Pieroni et al., 2019).

Finally, the application of the archetype cards by the manufacturing companies revealed initial insights about the recurrence of archetypes in practice, contributing to addressing calls for research (Bocken et al., 2019; Rosa et al., 2019). Compared to the recurrence of archetypes in literature mentioned in the beginning of this section, the practical recurrence (Table 3) provides initial evidence in favour of assumptions from previous research (Ritala et al., 2018), which indicated that action research could support companies in adopting a transition to more radical forms of innovation for sustainability and CE. For instance, the archetype *Extending resource value (A14)*, which is one of the most frequent in literature, was marginally adopted by companies in the action research. Although in general the companies demonstrated to be curious and saw potential in archetypes that can disrupt linear models generating high value for CE, their choices when they prioritised the BM ideas for further detailing were less ambitious and more averse to too many risks. For instance, ideas based on archetypes such as *Next life sales (A12)* or *Access model (A06)* were preferred when compared to *Performance or result model (A07).* This final observation is consistent with previous works in the field of CE and PSS, revealing the difficulties in disseminating *Performance or result models* (de Pádua Pieroni et al., 2018; Tukker, 2004b). Moreover, institutional voids related to regulative (e.g. certain countries impose restrictions on data usage for monitoring and operation of products), normative (e.g. compliance practices applied to product instructions impeding reuse), and cultural aspects (e.g. consumer lacking awareness/interest) might have hampered the acceptance/adoption of disruptive CEBMs by the sample of companies and shall be further explored (Kirchherr et al., 2018; Levänen et al., 2018).

One of the limitations of this research is related to literature review techniques applied for systematising archetypes, which relied on grey literature and could have generated selection bias. Additionally, the generalisation of the results' validity is limited due to practical application within six companies. These aspects and the improvement opportunities identified by this research require future work. Next steps could involve expanding the typology to consider additional archetypes related to the downstream architecture; modifying the deck of cards to apply it with a more extensive sample of companies; or creating a new tool based on a different design approach (e.g. solution patterns) that could fulfil better the practical requirements for designing CEBMs. Another important aspect to consider in future research is how to identify the necessary conditions (Kjaer et al., 2019) and potentially quantify the gains in resource decoupling for each BM archetype for CE (Kravchenko et al., 2019).

## 5. Conclusion

By reviewing academic and practical literature, this article identified and *systematised twenty archetypes of BMs fit for CE according to a typology framework* based on the source (i.e. downstream or upstream) and type of value generated to the market (i.e. mainly through services or products), exchanged with the network of collaborators/partners (i.e. mainly through services or materials/energy exchange), and captured by the organisation/shareholders (i.e. additional revenues or savings).

Based on the initial analysis of archetypes and application of the card deck with six manufacturing companies, key findings and insights were identified: (i) existing archetypes hold a reductionist approach with limited attention to the downstream value logic; (ii) practical application of archetypes requires improvement towards contextualisation to sectorial examples and guidelines on how to select archetypes; (iii) standardisation of the abstraction level and modifications in the structure of archetypes is necessary; and (iv) action research facilitates exploration of more radical forms of innovation for CEBMs. These findings shed light on future research opportunities for the CEBM field.

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## Appendix A

Figure A describes the research methodology based on a hypothetic-deductive approach (Gill and Johnson, 2002).

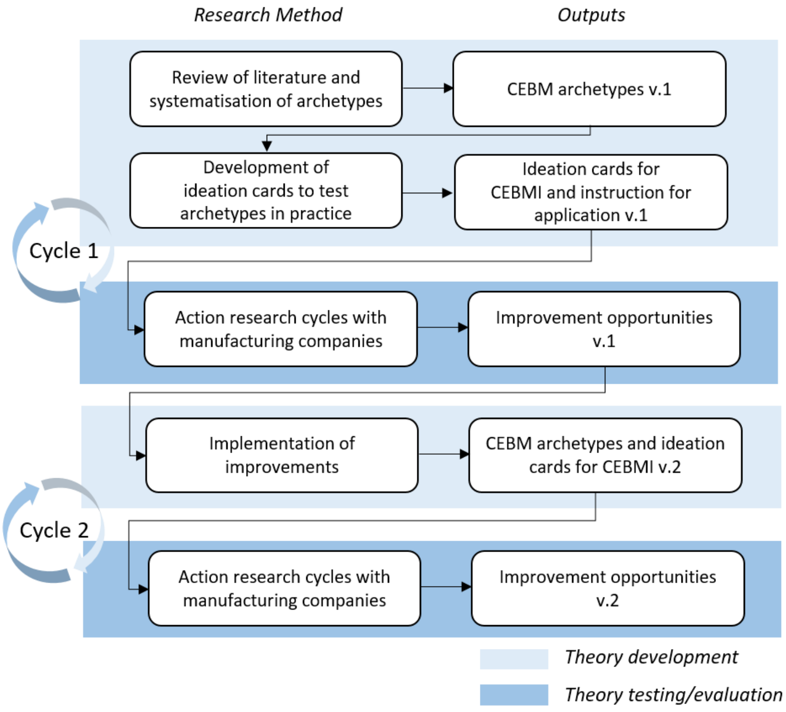


Figure A - Research methodology

## Appendix B

Figure B depicts an example of card developed from the business model archetypes for Circular Economy.

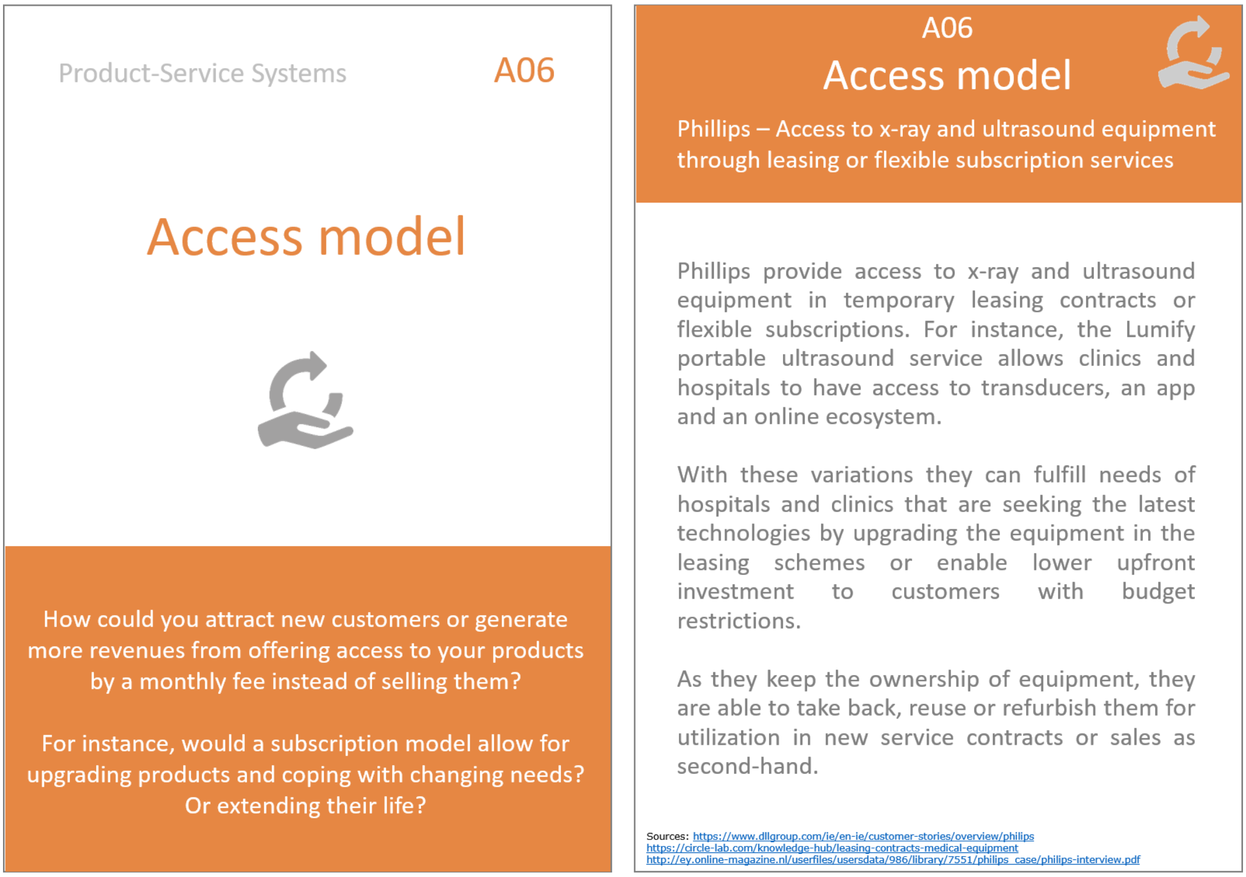


Figure B - Example of ideation card (front and back) for testing the archetypes.
Inspired by Design Heuristics cards from Leahy et al. (2018), with cases obtained in secondary sources (Knowledge Hub, 2018)).

# Appended Publication 4

Pieroni, M.P.P., McAloone, T.C. and Pigosso, D.C.A. (2020), “Circular Economy business model innovation: sectorial patterns within manufacturing companies”, (Manuscript under review at Journal of Cleaner Production).

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# Circular Economy business model innovation: sectorial patterns within manufacturing companies

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## Abstract

The market penetration of business models for Circular Economy is limited in most manufacturing sectors due to shortcomings in capabilities of companies to execute Circular Economy Business Model (CEBM) innovation. Available approaches are still generic and provide limited help for contextualised solutions within sectorial challenges. This paper introduces sectorial business model patterns to support manufacturing companies to reduce complexity and uncertainty within CEBM. Based on a multidimensional scaling analysis of more than 180 cases of companies that implemented CEBM, a number of sectorial patterns were consolidated for six selected sectors. The patterns prescribe a combination of business models configuration options and architectures for tackling specific sources of structural waste. Testing with manufacturing companies revealed the potential of the sectorial patterns to support: (1) visualisation of viability and feasibility of Circular Economy business models, which strengthens motivation and arguments for their implementation; and (2) reduction of uncertainties and complexity, which facilitates the exploration of business models with higher impact for Circular Economy. In addition to providing insights about pattern variations across sectors, a procedure for the development of business model patterns is put forward, which can be expanded to other sectors and/or emerging cases.

**Keywords:** circular economy; business model innovation; business model patterns; manufacturing sector

## 1. Introduction

Fundamental changes are required in the social, industrial and consumption systems (Böhringer and Rutherford, 2015) to implement Circular Economy (CE), a promising approach to achieve sustainable development (Geissdoerfer et al., 2017; Schroeder et al., 2019). At the industrial level, manufacturing[1] companies play a critical role due to their influence in the definition of the products' life cycle and potential to create value decoupled from resource consumption (Lieder and Rashid, 2016; McAloone and Bey, 2009). In practice, that translates to changing their existing business models (BM) to create CEBMs that are able to redefine the overall value generation logic (Blomsma et al., 2019; Lieder and Rashid, 2016).

Nevertheless, the market penetration of CEBMs within the manufacturing sector is still limited (Ritala et al., 2018; Urbinati et al., 2017), accounting for no more than 5-10% of revenues for most manufacturing sectors (OECD, 2018). Significant differences can be observed among sectors. BMs for product-life extension based on remanufacturing, for example, contribute to 4% of the market share in the machinery sector, while the market share in the electric and electronic equipment sector ranges from 1% to 8%.

Several external barriers contribute to the limited market penetration of CEBMs within the manufacturing sector, such as: customers' preferences, regulatory restrictions, or lack of infrastructure (Guldmann and Huulgaard, 2020; Kirchherr et al., 2018). Furthermore, internal organisational barriers such as shortcomings in capabilities of manufacturing companies to execute CEBM innovation are highly relevant (Bocken and Geradts, 2019; Khan et al., 2020). When compared to linear BMs, designing and implementing CEBMs lead to higher uncertainties regarding financial value creation and complexity of operationalisation

[1] Secondary manufacturing with a degree of control over their supply chain, excluding primary production or contract manufacturers.

(Bocken et al., 2018; Lieder and Rashid, 2016). Hence, manufacturing companies require guidance, knowledge, and convincing evidence to trigger changes and support strategic decision-making for the development and implementation of CEBMs (Bocken and Geradts, 2019; Khan et al., 2020; Lieder and Rashid, 2016).

CEBM innovation within manufacturing companies can be prompted by approaches that demonstrate advantages, viability, and economic feasibility of different CEBMs (Lieder and Rashid, 2016). According to Bocken et al. (2019) and Pieroni et al. (2019a) , several approaches relying on the notion of best-practices or problem-solution mechanisms exist in literature. They comprise BM patterns, BM archetypes and inspirational cases of companies that have successfully implemented CEBMs. Additionally, the authors indicate that these approaches are still conceptual and generic (Bocken et al., 2019; Pieroni et al., 2019a). Moreover, they have a limited practical perspective and provide very limited contextualised solutions for specific sectorial challenges. Context-specific solutions are fundamental to reduce uncertainties in the context of CEBM (Wells, 2016).

To address these gaps and respond to a call for the creation of knowledge for action (Lüdeke-Freund et al., 2019a), this paper introduces an approach for the development of CEBM patterns for specific manufacturing sectors, guided by the question "*How can sectorial BM patterns be developed to support CEBM innovation within manufacturing companies?"*.

A BM pattern is a "combination of configuration options, which repeatedly occurs in successful BMs" (Amshoff et al., 2015). The development of the CEBM patterns comprised multidimensional scaling analysis (Amshoff et al., 2015; Borg and Groenen, 2005) of more than 180 cases of CEBM implementation within manufacturing companies from six sectors. The sectorial CEBM patterns are accompanied by recommendations of how to combine multiple patterns to compose robust BMs. Together, they offer the potential to support manufacturing companies in reducing uncertainties and complexity; ultimately accelerating the implementation and dissemination of CEBMs within manufacturing companies.

The following sections present the literature background about BM patterns (section 2) and explain the research methodology (section 3). Results of the development approach of the sectorial CEBM patterns and combinations are described (section 4). Lastly, discussion and conclusions concerning key insights, applicability, limitations, and contributions are presented (section 5).

## 2. Literature background: patterns for BM innovation, sustainability and CE

Patterns are used to identify, classify, and document problem-solution mechanisms or best practices in fields such as architecture, organisation & software development, interaction design, and engineering design (Lüdeke-Freund et al., 2019a). Traditional BM innovation relies on patterns to support the conceptualisation and specification of new BM (e.g. Remane et al. (2017) systematised 182 BM patterns available in literature in a database tool). BM patterns are usually generic about the context of the application (Lüdeke-Freund et al., 2019b, 2018). However, Amshoff et al. (2015) demonstrated the benefits and a process for generating BM patterns for a specific purpose, such as supporting the development of a particular technology or a specific industry sector.

According to Amshoff et al. (2015), there are two categories of BM patterns, characterised by their abstraction level: (i) *Prototypical BM patterns* (logic of an industry or role of actors in the value chain); or (ii) *Solution BM patterns (*building blocks or elements of one BM of a specific company). This research focuses on both types of patterns for two different purposes. Solution patterns can be used to support manufacturing companies to change their own BMs first, before influencing changes in the ecosystem (i.e. roles of actors in the value chain), while prototypical patterns can be used for describing needs for collaborations (i.e. actors in the ecosystem to close the loops). Since single solution patterns only represent parts of a BM, an overall framework is necessary to organise the collection of patterns (AMSHOFF et al., 2015).

Despite the many BM patterns developed in the traditional BM literature, few of them focus on the environmental perspective. For example, only 1 out 182 patterns reported in Remane et al. (2017) are directly related to resource efficiency/effectiveness practices that could contribute to CEBM innovation. Specific patterns for sustainability-related issues have recently emerged. Some examples include: BM patterns for sustainability (Lüdeke-Freund et al., 2018); CE patterns (Lüdeke-Freund et al., 2019b; Whalen, 2019); and pattern-based approaches for designing product-service systems (PSS) (Hellek et al., 2013; Kwon et al., 2019). Lüdeke-Freund et al. (2019b) presented six generic CEBM patterns that represent major CEBMs in relation to closing the loop approaches. As acknowledged by the authors, their objective was not to provide 'ready-made' BMs, but to provide conceptual knowledge. Hence, the level of detail presented is not adequate for practitioners. Moreover, the CEBM patterns are prototypical, i.e., focused on an ecosystem perspective and on describing roles of different actors (e.g. recyclers, retailers). Similarly, Whalen (2019) proposed specific CEBM patterns for extending product value. However, the focus is also on the ecosystem level and only prototypical patterns are considered. Kwon et al. (2019) presented 53 BM solution patterns for PSS, however, only 3 patterns are related to improving resource efficiency/effectiveness.

In general, the aforementioned seminal works remain conceptual and lack clarity about how the use or implementation of the patterns could occur in practice. Additionally, they are generic, disregarding relevant sectorial specificity for CE (Wells, 2016). Lastly, they provide limited information to incentivise the combination of multiple patterns. This is necessary to design a complete CEBM concept, since a solution pattern usually addresses different parts or elements of a BM (Amshoff et al., 2015).

## 3. Research Methodology

To tackle the aforementioned gaps, this research was structured in two phases: (1) development of patterns for CEBMs within specific sectors; and (2) testing of the proposed patterns within manufacturing companies. The key activities and output of each phase are illustrated in Fig.1.

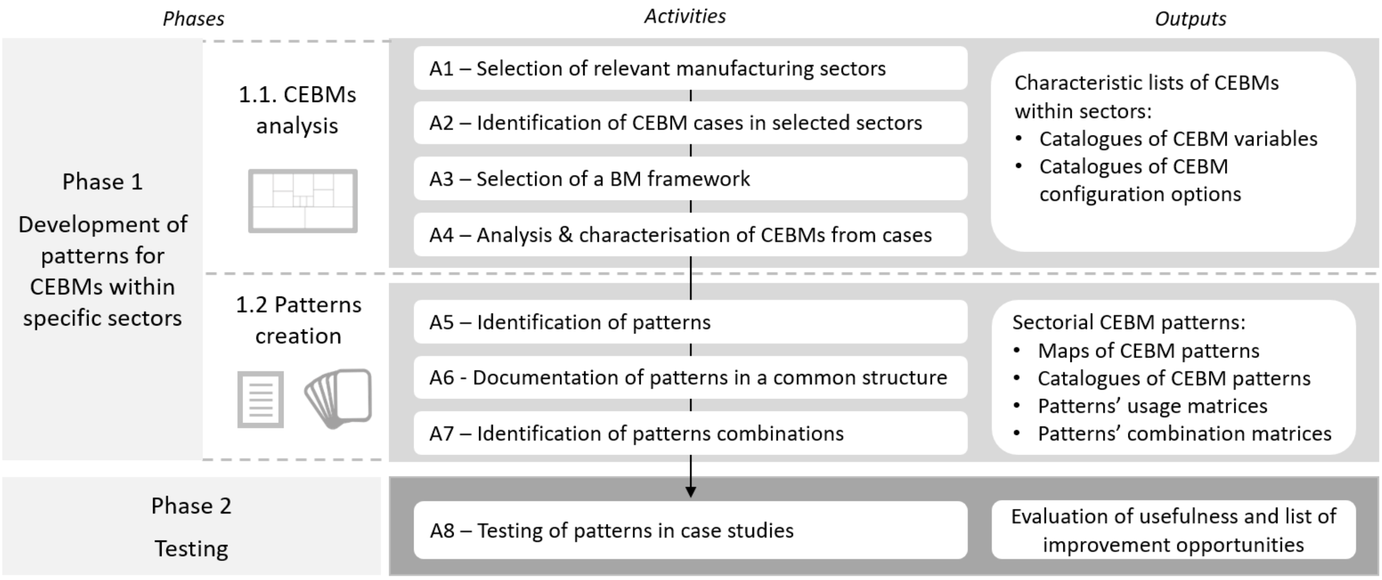


Fig. 1 - Research approach.

### *3.1. Phase 1 – Development of patterns for CEBMs within specific sectors*

The methodology proposed by Amshoff et al. (2015) to identify emerging BM patterns was adapted to investigate how patterns arise due to CE implementation in specific sectors. Phase 1 followed an inductive approach and was divided into two sub-phases:

Phase 1.1 - CEBM analysis

The purpose of this sub-phase was to identify characteristics of CEBM within specific sectors. It comprised four activities (A):

A1 - Selection of relevant manufacturing sectors: the selection was based on the relevance of the sectors concerning environmental impacts and potential opportunities for CE (OECD, 2018). Moreover, a variety of sectors was considered to explore their particularities, which is the core of this research. In total, six sectors were selected: electrical and electronic equipment and appliances [E]; furniture [F]; heavy machinery [H]; medical devices and equipment [M]; textile and apparel [T]; and agricultural/food products [A].

A2 - Identification of CEBM cases in selected sectors: CEBM cases in the selected sectors were identified from secondary sources (i.e. Ellen MacArthur Foundation (EMC)[2] and the Circle Economy[3] databases). The cases were filtered in the search engines by sectors and/or sector-specific keywords (Table 1) and selected whenever they: (i) explicitly presented examples of CEBM; (ii) matched with the selected sectors (i.e. including cases of manufacturers or closely related partners such as service providers); and (iii) had data reliability verified by primary sources (i.e. companies' websites, public reports, or direct communication). Selected cases were catalogued in a template containing: code; company name; size; sector; geographical location (headquarters and operation); product category; customer segment; product types; case title; and description. Table 1 summarises the amount of cases extracted and selected per sector.

Table 1 - Cases per sector.

| Sector | Keywords [EMC] | Filter [Circle Economy] | Quantity of cases from search/2018 | Final sample |
|---|---|---|---|---|
| Electrical and electronic equipment and appliances [E] | Electrical; electronic | Electrical and electronic equipment; Electronics and appliances | 88 | 30 |
| Furniture [F] | Furniture | Home and office furnishings | 46 | 42 |
| Heavy machinery [H] | Machinery; capital goods | Machinery | 29 | 25 |
| Medical devices and equipment [M] | Medical; healthcare | Healthcare services | 42 | 16 |
| Textile and apparel [T] | Fashion | Fashion and textiles | 211 | 39 |
| Agricultural and food products [A] | Food; Agriculture | Agri-Food | 193 | 36 |

A3 - Selection of a BM framework: the BM framework employed in this study was adapted from a previous work (Kraaijenhagen et al., 2016). Although many frameworks are available in literature (Pieroni et al., 2019a), the one selected fulfilled better the recommended characteristics for developing CEBM innovation tools proposed by Bocken et al. (2019). The selected framework contains four partial models/architectures (Fig. 2): (i) upstream architecture (i.e. value creation processes; partnerships & collaborations); (ii) downstream architecture (i.e. offerings; value delivery processes; revenue mechanisms; target customers); (iii) value generation architecture (i.e. overall benefits; value propositions; value for partners; value for customers), and (iv) financial architecture (i.e. cost structure; financing options) (Biloslavo et al., 2018; Kraaijenhagen et al., 2016; Urbinati et al., 2017).

[2] https://www.ellenmacarthurfoundation.org/case-studies
[3] https://circle-lab.com/knowledge-hub/all-content

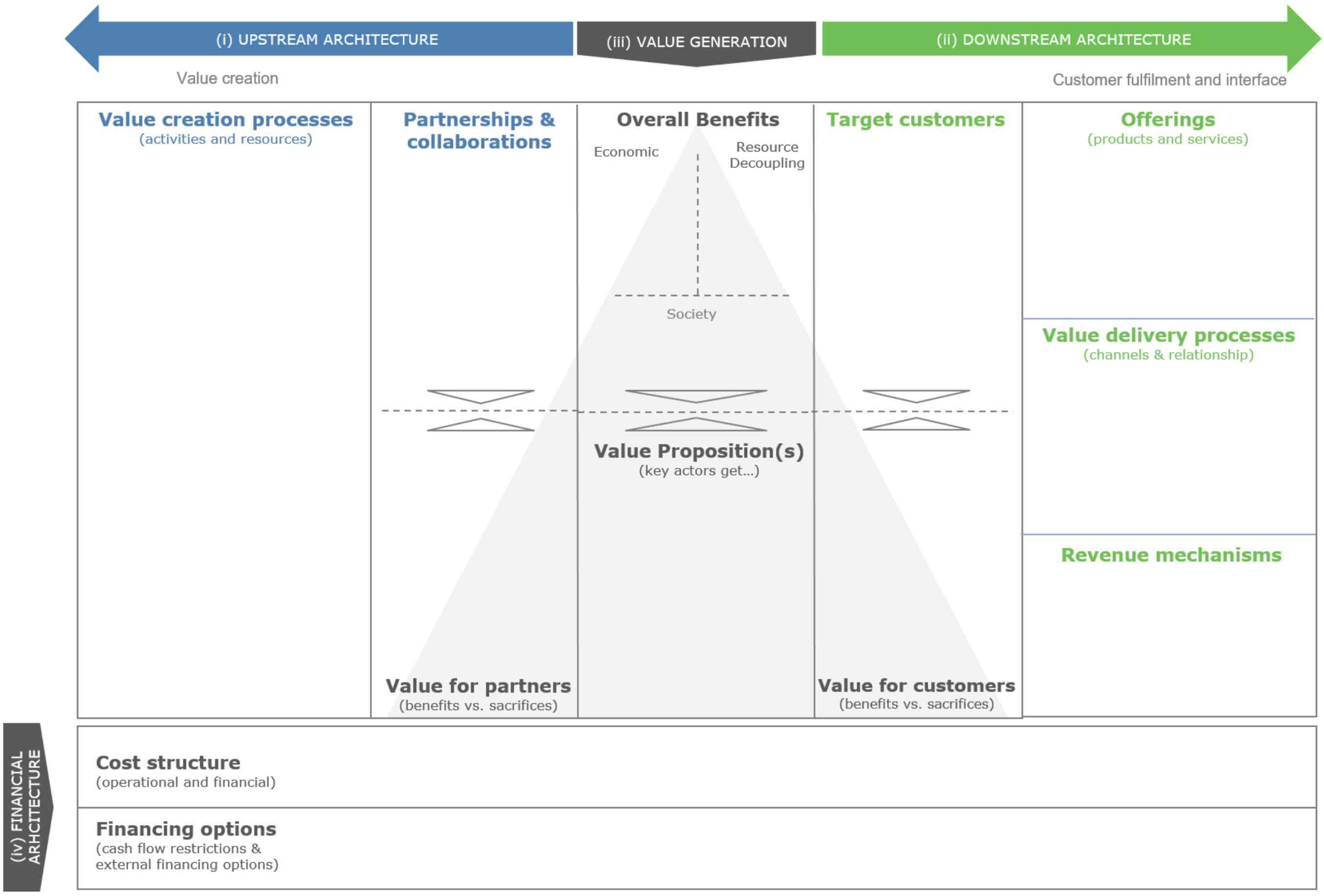


Fig. 2 - Framework for analysis of CEBMs.

A4 Analysis and characterisation of CEBMs from cases: the CEBM cases were analysed based on the elements *upstream* and *downstream architecture* of the BM framework (Fig. 2). Those two elements were used for analysis as they can be determined and generalised for companies within a certain sector and with similar characteristics. The remaining elements were not analysed because the financial architecture depends on the definition of the upstream and downstream architectures (Amshoff et al., 2015) and the value generation is very sensitive to each company's context in the case of CE.

The BM elements were described for each sector by:

- BM variables: levers a company uses for active BM design (Amshoff et al., 2015);
- CE configuration options: available alternatives for shaping a BM variable (Amshoff et al., 2015).

'Binding of contract with customers' is an example of BM variable for the BM element 'value delivery processes'. Configuration options for shaping this variable can be: 'long-term', 'short-term', 'activity-based', 'subscription', 'shared revenue/commissions for multisided platforms', or 'no formalised contract'.

Finally, a binary *characteristics list* was created to indicate the configuration options that each company used in their CEBMs. The characteristics list was structured in a way to show the composition of the CEBMs regarding the downstream and upstream architectures.

Phase 1.2 - Patterns creation

The purpose of the second sub-phase was to consolidate the CEBM patterns for the selected sectors. This comprised three activities (A).

A5 - Identification of patterns: repeating groups of CE configuration options across cases were mapped and clustered for the identification of potential patterns for the upstream [U] and downstream [D] architectures. A multi-dimensional scaling analysis (MDS) was employed (Amshoff et al., 2015; Borg and Groenen, 2005) to provide an approximation of the potential clusters of configuration options, which represent the patterns of CEBM (Hill and Lewicki, 2006). These steps resulted in the *CEBM pattern maps* for each sector.

A6 - Documentation of patterns in a common structure: the identified CEBM patterns were then documented in a common structure including five components: i) pattern code and name; ii) CE problem description (i.e. type and source of resource or energy waste); iii) solution description (i.e. configuration options included by the pattern derived from the CEBM variables catalogue); iv) case examples; and v) BM architecture (i.e. description of configuration options for BM elements). This activity resulted in *CEBM pattern catalogues* for each sector.

A7 - Identification of pattern combinations: to build upon single patterns (which represent only parts of a BM), an investigation of the relationship among patterns was carried out in this activity to support their combination for designing 'fully circular' BMs (Urbinati et al., 2017). The likelihood of combination among different patterns was identified based on their recurrence in the cases in two steps (for each sector):

(i) a *pattern usage matrix* was created to describe which patterns were present in the CEBM cases;
(ii) a *pattern combination matrix* was generated to specify how often a pattern was combined with a certain other pattern regarding within the case sample.

The *combination matrix* was calculated by multiplying the pattern usage matrix by its transposed matrix. The CEBM pattern combination matrix is the basis for the recommendation of *CEBM patterns for a specific sector.* It comprises the collection of all BM patterns derived from the CEBM architectures and the logic of patterns combinations (with their likelihood).

3.2. *Phase 2- Testing*

A8 – Testing of patterns in case studies: following a deductive approach, the usefulness of sectorial CEBM patterns was tested based on case studies for theory testing (Dul and Hak, 2008), in three steps: *(I) cases selection; (II) data collection; and (III) data analysis.*

*(I) Cases selection:* the criteria for company selection included: (i) manufacturing companies within the specific sector being tested; (ii) with intention to innovate their BMs for CE; and (iii) availability/willingness to provide data as feedback. To control contextual variations, the selected companies were (iv) European and (v) with limited experience in CE. Despite the inevitable sample size limitation for testing, the aforementioned synergistic characteristics of companies, plus the opportunity to go into considerably more depth (due to smaller sample size) outweigh limitations for this type of study.

*(II) Data collection:* a digital prototype (described in Pieroni et al. (2019b)) was created to enable the application of the CEBM patterns (output of Phase 1) by companies. The CEBM patterns were applied by companies in a three-hour workshop with the objective of mapping ideas for new CEBMs. The usefulness of the patterns was evaluated by means of seven criteria (detailed in section 4.2) assessed by companies via a structured questionnaire with a combination of multiple-choice (using a four-point Likert scale) and open-ended questions (Dul and Hak, 2008). To guarantee triangulation (Yin, 2011), documents resulting from the application of the patterns were collected, and an interview of one hour was conducted to clarify answers from the questionnaire. The interview was recorded to enable the compilation of comments.

*(III) Data analysis:* the consolidation and analysis of the data collected in the questionnaires, documents and interviews enabled the evaluation of the usefulness in the application of the CEBM patterns within companies. This resulted in the identification of insights and improvement opportunities.

## 4. Results

Section 4.1 presents an overview of the development of the CEBM patterns (phase 1), exemplified by the furniture sector (sections 4.1.1 and 4.1.2). An overview of the final number of CEBM patterns and key variations within all six selected sectors are presented in section 4.1.3. Section 4.2 describes the testing of the sectorial CEBM patterns by manufacturers from three sectors (phase 2).

### *4.1. Phase 1 – Development of patterns for CEBMs within specific sectors*

#### 4.1.1. Phase 1.1. – CEBM analysis

<u>A2: Identification of CEBM cases in selected sectors</u>

The generation of CEBM patterns for the furniture sector relied on 42 CEBM cases (Table 2). The complete catalogue of cases is presented in the Supplementary Materials. The distinct characteristics of cases allowed broad coverage of contextual possibilities for the generation of patterns within the furniture sector.

Table 2 – Characteristics of cases (furniture sector).

| Characteristics | Options | Quantity of cases |
|---|---|---|
| (i) Size of companies | SME | 30 |
| | Large | 12 |
| (ii) Geographical location | Americas (Canada, Chile, and USA) | 12 |
| | Northern Europe (Denmark, Finland, Norway, Sweden) | 11 |
| | Southern Europe (France, Greece, Italy, the Netherlands, UK) | 19 |
| (iii) Category of products | Interior furniture for home or commercial purposes | 12 |
| | Hotel, restaurants, or event furniture and solutions | 2 |
| | Office furniture and workspace solutions | 22 |
| | Outdoor furniture and urban space solutions | 6 |
| (iv) Target customer segment<br>Note: some companies have more than one target customer segment. | Business-to-business (B2B) | 38 |
| | Business-to-consumer (B2C) | 14 |
| | Business-to-government (B2G) | 9 |
| | Business-to-business-to-consumer (B2B2C) (i.e. platform BMs) | 2 |

<u>A4: Analysis and characterisation of CEBMs from cases</u>

The case analysis enabled the characterisation of CEBMs. In the furniture sector, 26 CEBM variables and 166 configuration options were created to support the characterisation of the CEBMs, which were classified according to the BM elements (Fig. 2). Table 3 illustrates seven CEBM variables and respective configuration options for the element '*offerings'* in the *downstream architecture.*

Table 3 - CEBM variables and configuration options for the element ‘offerings’ (furniture sector).

| CEBM Variables | CEBM Configuration options | |
|---|---|---|
| DF0601<br>CE characteristics of products | DF0601A | Modular |
| | DF0601B | Durable (i.e., not affected by fashion, changes, resistant) |
| | DF0601C | Bio-materials based, biodegradable or produced with reused water and energy |
| | DF0601D | Locally made |
| | DF0601E | Refurbished or remanufactured |
| | DF0601F | Idle or second-hand (i.e., used furniture) |
| | DF0601G | Repurposed or based on recycled materials (e.g. textiles, coffee grounds, flowers) |
| | DF0601H | Equipped with monitoring devices (e.g., smart bed legs against bed bugs) |
| DF0602<br>Type of products | DF0602A | Carpets and flooring solutions |
| | DF0602B | Beds and mattresses |
| | DF0602C | Office or workspace furniture and interior solutions (e.g. chairs, desks) |
| | DF0602D | Residential furniture (e.g. kitchenware, bed linen) |
| | DF0602E | Outdoor or urban spaces furniture (e.g. benches, lamps) |
| DF0701A<br>Basic initial services | DF0701A01 | Long-term guarantee or warranty |
| | DF0701A02 | Spare-part ordering service |
| | DF0701A03 | Extensive manuals and guidance to help customers to take care of their furniture |
| | DF0701A04 | Consultancy for design and layout of spaces, furniture selection, and fitting |
| | DF0701A05 | Installation |
| | DF0701A06 | Delivery |
| DF0701B<br>Services for extending the product use-cycles | DF0701B01 | On-going maintenance |
| | DF0701B02 | Repair |
| | DF0701B03 | Inventory management and value assessment |
| | DF0701B04 | Booking management for temporary use of furniture |
| DF0701C<br>Services for enabling new use-cycles and life-cycles | DF0701C01 | Upgrade, update, or reconfiguration |
| | DF0701C02 | Consultancy for renovation with end-of-use management |
| | DF0701C03 | Quantification of sustainability benefits (e.g. BREEAM or LEED reporting) |
| | DF0701C04 | Renovation or refurbishment |
| | DF0701C05 | Continuous optimisation of spaces with periodic inspection |
| | DF0701C06 | Disassembly, removal, and take-back |
| | DF0701C07 | Logistics handling |
| | DF0701C08 | Inventory storage |
| DF0701D<br>Business support services | DF0701D01 | Planning and development of a custom service offering with mapped processes and contractual service provider agreements to achieve desired outcomes |
| | DF0701D02 | Planning and development of user-centric customised environments according to events/meetings goals or activities |
| | DF0701D03 | Communication, training, personalised workflow management centre with easy access to representatives for service requests, order initiation and/or follow-up |
| | DF0701D04 | Project management with expert consultants, designers, and installers to help deliver an exceptional event with service around the clock |
| | DF0701D05 | Hosting of events with onsite concierge |
| | DF0701D06 | Measurement and reporting with insights about achievement of results and improvements needed based on observation and ethnographic techniques, behaviours, activities and preferences of events’ guests |
| | DF0701D07 | Measurement and reporting of services provision |
| | DF0701D08 | Measurement and analysis of the use of the spaces and the user experience |
| DF0701E<br>Efficiency services | DF0701E01 | Monitoring for efficiency & predictive maintenance of furniture in urban spaces (e.g., benches, waste bins, street lamps) |

Although the CEBM variables of the element offerings are similar for the other five selected sectors, the configuration options have particularities in each sector. These variations (explored in details in section 4.2) add value to support companies with specific CE problems for their sectorial context.

The final analysis of cases resulted in the *list of characteristics of CEBMs* for each case of the furniture sector (main outcome of Phase 1.1), illustrated in Fig. 3. For example, case CF02 shows a CEBM that provides service *offerings* such as furniture *delivery (DF0701A06)* and *disassembly, removal, and take-back (DF0701C06)* by the end of contracts. The CEBM of case CF04 only offers *basic initial services* including, *long-term guarantee (DF0701A01)*, *spare-part ordering (DF0701A02)*, *user manuals (DF0701A03)* and *delivery of furnishings (DF0701A06)*. The complete catalogue of variables, configuration options and CEBM characteristics lists for the furniture sector is available in the Supplementary Materials.

**List of Characteristics for the Downstream Architecture of CEBMS within the furniture sector**

Is configuration option DFxxxxi (row) part of the CEBM in case company CFxx (column)?
1= yes
0=No

| | Variable | Configuration option | No. | CF01 Auping 1 | CF02 Auping 2 | CF03 Biofurniture | CF04 Brabantia | … | CF41 Martela 2 | CF42 Martela 3 | 42 SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Offerings | Basic initial services | Long-term guarantee or warranty | DF0701A01 | 0 | 0 | 0 | 1 | | 0 | 0 | 6 |
| | | Spare-part ordering service | DF0701A02 | 0 | 0 | 0 | 1 | | 0 | 0 | 4 |
| | | Extensive manuals and guidance to help customers to take care of their furniture | DF0701A03 | 0 | 0 | 0 | 1 | | 0 | 0 | 5 |
| | | Consultancy for design and layout of spaces, furniture selection, and fitting | DF0701A04 | 0 | 0 | 0 | 0 | | 0 | 0 | 13 |
| | | Installation | DF0701A05 | 0 | 0 | 0 | 0 | | 1 | 1 | 11 |
| | | Delivery | DF0701A06 | 0 | 1 | 0 | 1 | | 1 | 1 | 20 |
| | Services for extending the products use-cycles | On-going maintenance | DF0701B01 | 0 | 0 | 0 | 0 | | 1 | 1 | 10 |
| | | Repair | DF0701B02 | 0 | 0 | 0 | 0 | | 0 | 0 | 6 |
| | | Inventory management and value assessment | DF0701B03 | 0 | 0 | 0 | 0 | | 0 | 0 | 5 |
| | | Booking management for temporary use of furniture | DF0701B04 | 0 | 0 | 0 | 0 | | 0 | 0 | 3 |
| | Services for enabling new use-cycles and life-cycles | Upgrade, update, or reconfiguration | DF0701C01 | 0 | 0 | 0 | 0 | | 0 | 0 | 5 |
| | | Consultancy for rennovation with end-of-use management | DF0701C02 | 0 | 0 | 0 | 0 | | 0 | 0 | 6 |
| | | Quantification of sustainability benefits (e.g. BREEAM or LEED reporting) | DF0701C03 | 0 | 0 | 0 | 0 | | 0 | 0 | 4 |
| | | Renovation or refurbishment | DF0701C04 | 0 | 0 | 0 | 0 | | 0 | 0 | 2 |
| | | Continuous optimisation of spaces with periodic inspection (e.g. every 12 months) | DF0701C05 | 0 | 0 | 0 | 0 | | 1 | 1 | 2 |
| | | Disassembly, removal, and take-back | DF0701C06 | 0 | 1 | 0 | 0 | | 1 | 1 | 20 |
| | | Logistics handling | DF0701C07 | 0 | 0 | 0 | 0 | | 0 | 0 | 1 |
| | | Inventory storage | DF0701C08 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 |

Fig. 3 - Extract from the list of characteristic of CEBMs (furniture sector).

### 4.1.2. Phase 1.2 - Patterns creation

A5: Identification of patterns

The map identifying potential CEBM patterns for the furniture sector was generated based on the list of characteristics of CEBMs by applying multidimensional scaling analysis (MDS). The complete map is available in the Supplementary Materials.

Fig. 4 illustrates an extract of the map of CEBM patterns for the downstream architecture originated from the MDS. Each cluster of configuration options represents a pattern. For example, the CEBM pattern ‘Furniture or furnishings as through-life care services in customisable time-based contracts’ (FPD0302 shaded in grey in the top) includes the following configuration options for *offerings:* ‘Design layout, furniture selection and fitting consultancy’ (DF0701A04); ‘Installation’ (DF0701A05); ‘Delivery’ (DF0701A06); ‘On-going maintenance’ (DF0701B01); ‘Disassembly, removal and take-back of furniture’ (DF0701C06). These offerings are provided as ‘temporary services’ (DF0801B) in ‘long-term (e.g., 36 months) (DF0903A)’ and ‘customisable contracts (DF0904B)’ concerning the service level required (e.g., frequency of maintenance). The expected ‘service level (DF0901C)’ and the ‘obligation of customers to return the furniture back to the provider with acceptable conditions by the end of use (DF0902E)’ are formalised in contract.

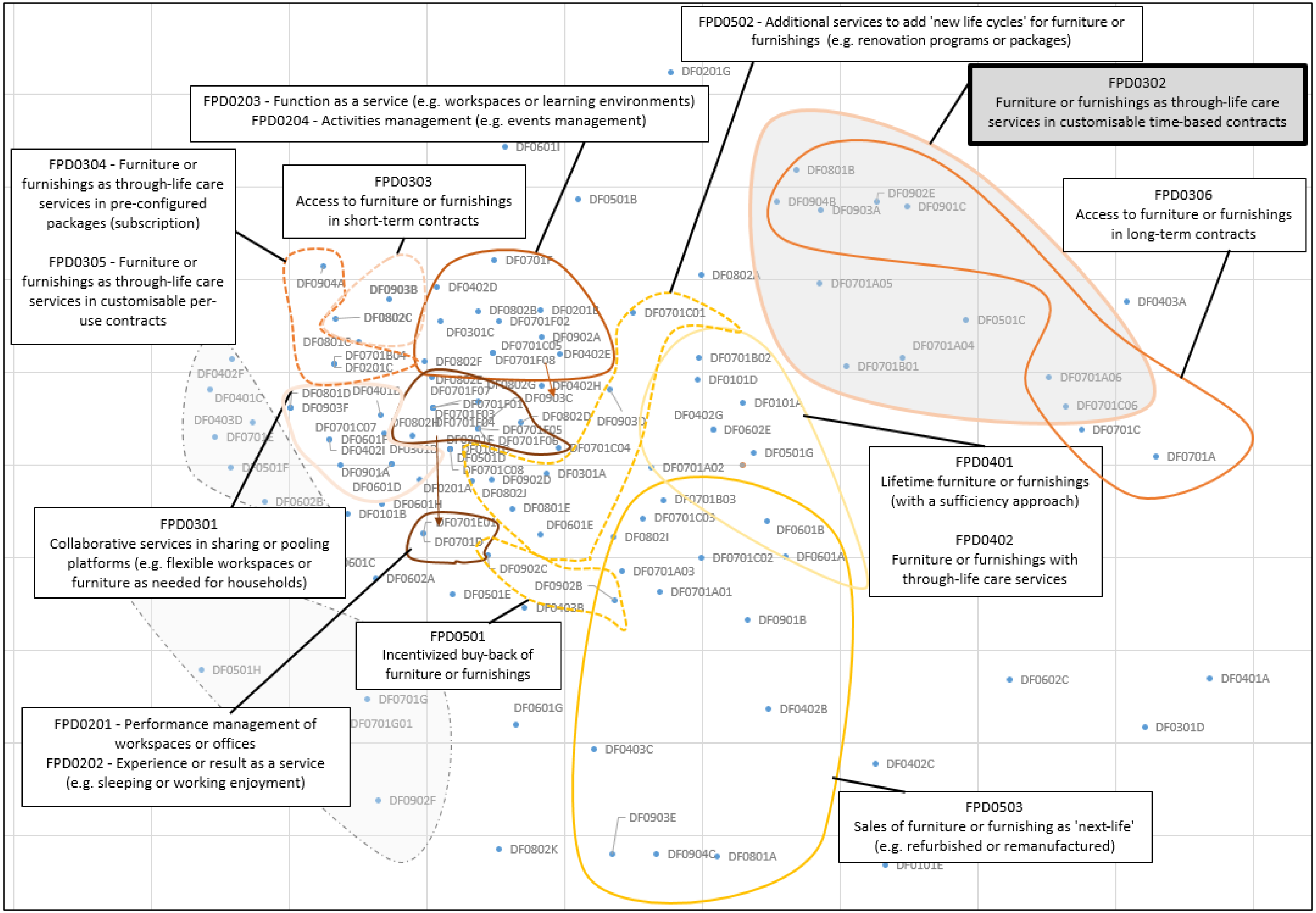


Fig. 4 – Extract of the map of CEBM patterns for the downstream architecture (furniture sector).

In total, 46 CEBM patterns were identified for the furniture sector and documented in a catalogue. Fig. 5 illustrates the patterns for the downstream and upstream architectures. The upstream architecture contains two groups of patterns: 13 solution patterns describing the internal value creation (FPU0101-FPU0307) and 13 prototypical patterns (FPU0401-13) describing types of actors required for collaborations.

**UPSTREAM ARCHITECTURE**

- FPU0101 - Sourcing of biodegradable or bio-materials produced with reused water and energy (e.g. wood, metal, cotton, seaweed, wool)
- FPU0102 - Sourcing of pre-used materials (e.g. textile scraps, flowers or coffee grounds)
- FPU0103 - Sourcing of recycled or recyclable material (e.g. metal)
- FPU0104 - Regional or local sourcing of materials
- FPU0201 - Co-located production of furniture or furnishing (e.g. local 'craftsman')
- FPU0202 - Manufacture furniture on demand
- FPU0301 - Support network or team for life-extension services (e.g. upgrading, packaging for moving)
- FPU0302 - Own reverse operation for refurbishment
- FPU0303 - Own remanufacturing operation
- FPU0304 - Internal recycling process (e.g. metal, plastics, wood)
- FPU0305 - Sales of recovered parts or materials
- FPU0306 - Service delivery management
- FPU0307 - Development and management of digital marketplace and logistics operation
- FPU0401 - Collaboration to transform textile into furniture
- FPU0402 - Collaboration to transform bio-mass (e.g. coffee grounds) into coating for furniture
- FPU0403 - Collaboration to transform PET bottle into furniture
- FPU0404 - Cooperatives or communities for collecting ocean plastics or fishing nets
- FPU0405 - Collaboration with redistributors of furniture (e.g. take back, remanufacture centre, resale)
- FPU0406 - Collaboration for reuse/donation platforms for furniture (i.e. reuse facilitators)
- FPU0407 - Collaboration with reprocessors of furniture (e.g. cleaning, sterilisation, refurbishment)
- FPU0408 - Collaboration with technology providers for recycling materials/products (e.g. DSM)
- FPU0409 - Collaboration with original material supplier recyclers (e.g. plastic, steel)
- FPU0410 - Collaboration with waste management facilities
- FPU0411 - Collaboration with local makers
- FPU0412 - Collaboration with designers or ethnography experts
- FPU0413 - Collaboration with technology/platforms for monitoring/efficiency management

**DOWNSTREAM ARCHITECTURE**

- FPD0101 - Data-driven services for efficiency management of maintenance or operations for urban spaces, workspaces or hotel rooms
- FPD0102 - Dematerialised services (e.g. virtual products)
- FPD0103 - Services to support consumption rationalisation or demand reduction in urban spaces or workspaces
- FPD0201 - Performance management of workspaces or offices
- FPD0202 - Experience as a service (e.g. sleeping or working enjoyment)
- FPD0203 - Activities management (e.g. events management)
- FPD0204 - Function as a service (e.g. workspaces or learning environments)
- FPD0301 - Collaborative services in sharing or pooling platforms (e.g. flexible workspaces or furniture as needed for households)
- FPD0302 - Furniture as through-life care services in customisable time-based contracts
- FPD0305 - Furniture as through-life care services in customisable per-use contracts
- FPD0303 - Furniture as through-life care services in pre-configured packages (subscriptions)
- FPD0304 - Access to furniture in long-term contracts
- FPD0306 - Access to furniture in short-term contracts
- FPD0401 - Lifetime furniture (with a sufficiency approach)
- FPD0402 - Furniture or furnishings with through-life care services
- FPD0501 - Incentivised buy-back of furniture
- FPD0502 - Additional services to add 'new life cycles' for furniture (e.g. renovation programs)
- FPD0503 - Sales of furniture as 'next-life' (e.g. refurbished or remanufactured)
- FPD0504 - Direct trade and reuse or donation of furniture among customers or users
- FPD0601 - Locally made furniture

Fig. 5 - CEBM patterns (furniture sector).

## A6 Documentation of patterns in a common structure

Fig. 6 provides an example of how the patterns were documented in the catalogue using the template (complete catalogue in Supplementary Materials).

| Pattern No./Name | Context and CE problem | Solution | Examples of cases |
|---|---|---|---|
| FPD0204<br><br>Function as a service<br>(e.g. workspaces and learning environments) | - Changes in modern teaching and working culture are requiring companies and educational institutions to promote continuous adaptation of the learning environments and workplaces.<br>- These changes imply in frequent substitution of furniture or interior solutions to fulfil functional needs.<br>- As a consequence, furniture life-time is shortened.<br>- Opportunities from seizing gains from the expertise in spaces configuration or workspaces optimization are lost. | - Furniture manufacturers offer **services based on the functionalities** of the product.<br>- They **charge accordingly to the agreed contract** and provide turnkey solutions.<br>- The **ownership** of the furniture is usually not transferred to the customer, **returning back to the manufacturer to be reused**.<br>- Benefits for circular economy: manufacturer is stimulated **to use the minimum** amount of resources/energy to **increase its operational margin**. | • Martela<br>*Workspace as a Service and Learning Environment as a Service for dynamic offices, co-workspace and dynamic educational institutions.*<br>The contracts include the development of user-centred environments, continuous monitoring and optimization to fulfil the changing life-cycle needs of workspaces and learning environments. |

**CEBM pattern representation:**

UPSTREAM ARCHITECTURE | DOWNSTREAM ARCHITECTURE

**Target customers**
- [B2B] Large offices and companies with multiple locations
- [B2B] Educational institutes
- [B2B] Co-work spaces or companies in need of flexible space to work

**Offerings**
- Planning and development of user centric customized environments
- Free delivery and installation
- On-going maintenance
- Measurement and analysis of the use of spaces and user experience
- Continuous optimization of the environment (e.g. annually)
- Disassembly, removal & take back
- Long-lasting furniture for functional workspaces (e.g.: learn; strategize)

**Value for customers**
(benefits vs. sacrifices)
- Single point of accountability with measurable & consistent service levels
- Powerful and purposeful events or spaces
- Affordability - reduced up-front investment
- Affordability: lower/ controlled costs (e.g., less resources/consumption; avoided disposal costs; longer life-time)

**Value delivery processes**
(channels & relationship)
- Long-term customisable contracts (e.g. 36 months)
- Develop and manage the service level agreed in contracts
- Collect used furniture when delivering new ones

**Revenue mechanisms**
- Leasing or service fee agreement with pricing depending on volume, service level or function

Fig. 6 - Documented CEBM pattern (furniture sector).

## A7: Identification of pattern combinations

Complementarily to the database of CEBM patterns, pattern combinations were developed to indicate CEBM patterns' relationships. The pattern combinations rely on the *usage and combination matrices* (Supplementary Materials). Fig. 7 illustrates the pattern combinations for the furniture sector.

When the pattern 'Furniture or furnishings as through-life care services in customisable time-based contracts' (FPD0302) (red rectangle) is selected, the combinations logic indicates other highly recommended patterns (HR or dark green): 'Service and support network or team for life-extension activities' (FPU0301), 'Own reverse operation for refurbishment' (FPU0302), 'Own remanufacturing operation' (FPU0303), and 'Service delivery management' (FPU0306). Moreover, it suggests potential patterns to be considered (MR or yellow), e.g., 'internal recycling process' (FPU0304), 'collaboration with reprocessors of furniture' (FPU0407), 'collaboration with original materials supplier/recycler' (FPU0409). Patterns selected by light yellow colour (SR) or not selected can also be chosen by the user, even though they appeared sparsely or not at all in the observed CEBM cases.

**UPSTREAM ARCHITECTURE**

| | FC | |
|---|---|---|
| | 0% | FPU0101 - Sourcing of biodegradable or bio-materials produced with reused water and energy (e.g. wood, metal, cotton, seaweed, wool) |
| SR | 17% | FPU0102 - Sourcing of pre-used materials (e.g. textile scraps, flowers or coffee grounds) |
| SR | 17% | FPU0103 - Sourcing of recycled or recyclable material (e.g. metal) |
| | 0% | FPU0104 - Regional or local sourcing of materials |
| | 0% | FPU0201 - Co-located production of furniture or furnishing (e.g. local 'craftsman') |
| | 0% | FPU0202 - Manufacture furniture on demand |
| HR | 50% | FPU0301 - Support network or team for life-extension services (e.g. upgrading, packaging for moving) |
| HR | 50% | FPU0302 - Own reverse operation for refurbishment |
| HR | 50% | FPU0303 - Own remanufacturing operation |
| MR | 33% | FPU0304 - Internal recycling process (e.g. metal, plastics, wood) |
| | 0% | FPU0305 - Sales of recovered parts or materials |
| | 67% | FPU0306 - Service delivery management |
| | 0% | FPU0307 - Development and management of digital marketplace and logistics operation |
| | 0% | FPU0401 - Collaboration to transform textile into furniture |
| | 0% | FPU0402 - Collaboration to transform bio-mass (e.g. coffee grounds) into coating for furniture |
| | 0% | FPU0403 - Collaboration to transform PET bottle into furniture |
| | 17% | FPU0404 - Cooperatives or communities for collecting ocean plastics or fishing nets |
| | 0% | FPU0405 - Collaboration with redistributors of furniture (e.g. take back, remanufacture centre, resale) |
| | 0% | FPU0406 - Collaboration for reuse/donation platforms for furniture (i.e. reuse facilitators) |
| MR | 33% | FPU0407 - Collaboration with reprocessors of furniture (e.g. cleaning, sterilisation, refurbishment) |
| | 0% | FPU0408 - Collaboration with technology providers for recycling materials/products (e.g. DSM) |
| MR | 33% | FPU0409 - Collaboration with original material supplier recyclers (e.g. plastic, steel) |
| | 0% | FPU0410 - Collaboration with waste management facilities |
| | 0% | FPU0411 - Collaboration with local makers |
| | 0% | FPU0412 - Collaboration with designers or ethnography experts |
| | 0% | FPU0413 - Collaboration with technology/platforms for monitoring/efficiency management |

**DOWNSTREAM ARCHITECTURE**

| | FC | |
|---|---|---|
| FPD0101 - Data-driven services for efficiency management of maintenance or operations for urban spaces, workspaces or hotel rooms | 0% | |
| FPD0102 - Dematerialised services (e.g. virtual products) | 0% | |
| FPD0103 - Services to support consumption rationalisation or demand reduction in urban spaces or workspaces | 0% | |
| FPD0201 - Performance management of workspaces or offices | 0% | |
| FPD0202 - Experience as a service (e.g. sleeping or working enjoyment) | 0% | |
| FPD0203 - Activities management (e.g. events management) | 0% | |
| FPD0204 - Function as a service (e.g. workspaces or learning environments) | 0% | |
| FPD0301 - Collaborative services in sharing or pooling platforms (e.g. flexible workspaces or furniture as needed for households) | 0% | |
| FPD0302 - Furniture as through-life care services in customisable time-based contracts | 100% | S |
| FPD0305 - Furniture as through-life care services in customisable per-use contracts | 17% | SR |
| FPD0303 - Furniture as through-life care services in pre-configured packages (subscriptions) | 0% | |
| FPD0304 - Access to furniture in long-term contracts | 17% | SR |
| FPD0306 - Access to furniture in short-term contracts | 0% | |
| FPD0401 - Lifetime furniture (with a sufficiency approach) | 0% | |
| FPD0402 - Furniture or furnishings with through-life care services | 0% | |
| FPD0501 - Incentivised buy-back of furniture | 33% | MR |
| FPD0502 - Additional services to add 'new life cycles' for furniture (e.g. renovation programs) | 17% | SR |
| FPD0503 - Sales of furniture as 'next-life' (e.g. refurbished or remanufactured) | 17% | SR |
| FPD0504 - Direct trade and reuse or donation of furniture among customers or users | 0% | |
| FPD0601 - Locally made furniture | 0% | |

**Caption:** Selected CEBM pattern (S) | Sparsely recommended (SR) <20% | Frequency of combination (FC) | Moderately recommended (MR) | Highly recommended (HR) >80%

Fig. 7 – CEBM patterns and combinations recommendations (furniture sector).

### 4.1.3. Overview and key variations among the CEBM patterns within the considered sectors

The number of CEBM variables, configuration options, and patterns varied across sectors (Fig. 8). Fig. 8 brings a categorisation of the selected sectors in the overall spectrum from consumer to capital goods.

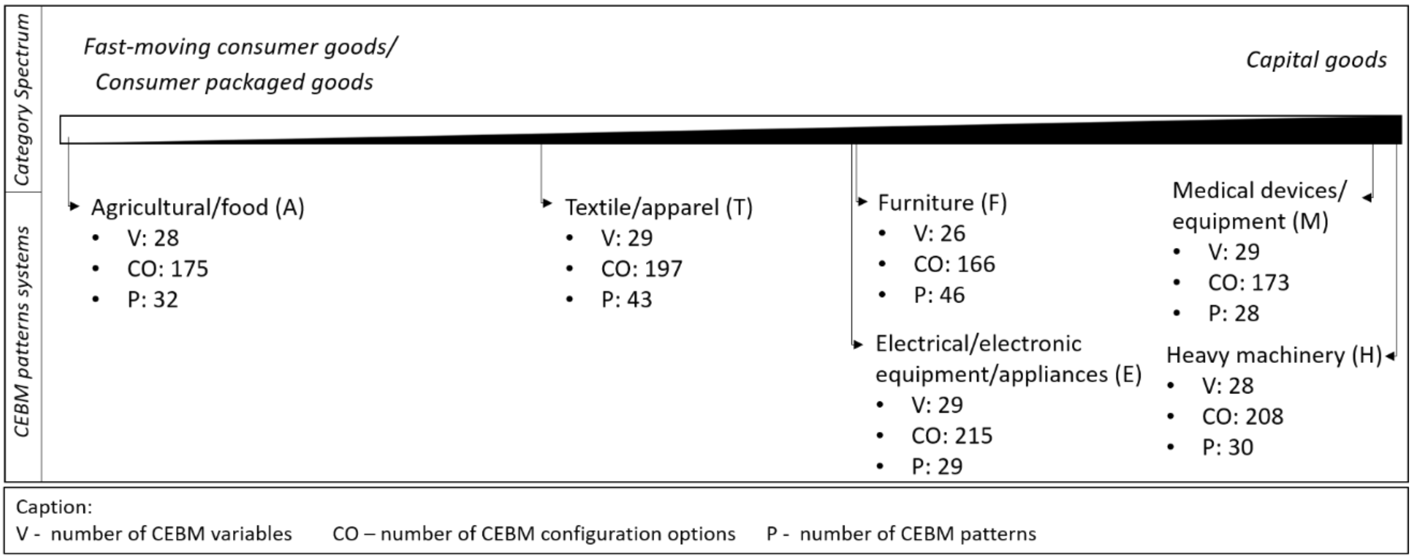


Fig. 8 – Number of CEBM variables, configuration options, and patterns within sectors.

Table 4 summarises the variations and exemplifies the key characteristics of CEBM patterns for each sector. Key features of a sector were identified as influence factors for the CEBM patterns'variations. For example: the type of predominant materials in products (biocycle or technocycle); the lifetime of products; the level of regulatory restrictions; the type of business (e.g. B2B, B2C).

The differences in CEBM practices were greater among sectors located in the opposite extremes of the manufacturing categories spectrum (Fig. 8). CEBM patterns for the agricultural and food sector (A) were very specific, contextualised, and distinct from the heavy machinery (H) sector. This is related to the nature of products and consumption behaviours in the different sectors. For example, sector A is composed mainly of materials from the 'biocycle' while sector H relies predominantly on materials from the 'technocycle'.

Sectors located in the region of the spectrum closer to capital goods (i.e. electrical/electronic equipment/appliances (E), medical devices/equipment (M), and heavy machinery (H)) presented more similarities at the level of patterns. Nevertheless, sector E also presented characteristics related to the biocycle, due to the relevance of consumables (e.g. energy, coffee capsules) for the development of function/activities as service CEBMs. Sector M presented fewer patterns and configuration options than the others due to existing restrictions in this highly regulated sector.

Furniture (F) and textile/apparel (T) sectors presented hybrid characteristics. The products within these sectors present the potential for lasting longer. However, the consumption behaviour influenced by rapidly changing fashion preferences, specially in B2C, resembles characteristics of fast-moving consumer goods. Cases for sector F revealed a high effort from companies in changing this scenario, with the adoption of CEBM patterns that present higher potential for fighting overconsumption (e.g. offering products or functions as service). The same trend was not observed in cases of sector T, which are mainly focusing on closing the loop with take-back initiatives instead of disrupting consumption patterns. Despite the similarity at the patterns level for some sectors, the variability for the specific level of details of configuration options and the combination recurrence of patterns was considerably high (e.g., variety of service offerings or types of collaborations).

Table 4 – Variations of CEBM patterns for selected sectors

| Sector | Examples of key variations within sectors: *CE problems (i.e. source of structural waste)* | *Solution patterns characteristics within sectors* |
|---|---|---|
| Agricultural/food | • Overproduction and overconsumption of food and agricultural products<br>• Large volume of single use packaging or containers with low recyclability rates | Downstream architecture<br>• Trade of surplus food or agricultural products in systems or platforms<br>• Food or bio-based products from cascaded ingredients or nutrients (e.g. fertilisers from coffee grounds)<br>• Multiple cash flows from farming processes by-products or waste (e.g. cattle or cheese)<br>Upstream architecture<br>• Industrial symbiosis or trade of products from recovered food or crops (e.g. beer; mushrooms, enzymes)<br>• Packaging swap or return systems<br>• Efficiency management of food processing operations to avoid waste (e.g. tracking and monitoring) |
| Textile/apparel | • Overconsumption and early disposal of clothing and textile due to:<br>○ Fashion preferences<br>○ Low durability, quality, and price<br>○ Seasonal demand (e.g. baby clothes)<br>• High water consumption for washing<br>• Lack of infrastructure, incentives and instructions for reuse and recycling | Downstream architecture<br>• Platform for accessing clothing and textile per temporary use<br>• Recycling management services for professional textiles or work wear<br>• Multiple mechanisms to incentivise customers to take clothing back to manufacturers after use cycles (e.g. deposit; reward or reimbursement schemes; buy-back schemes; take-back certificates; or donation campaigns)<br>• Multiple collection mechanisms for take-back, e.g., in-store or collection point exclusive for own brand or accepting all brands; mail back with free shipping; pick-up for work wear/industrial textile<br>• Resale of used/repaired clothes on proprietary second-hand web stores or outlet stores<br>Upstream architecture<br>• Platforms for shared management of raw materials in the ecosystem, e.g. fibres, granulate, yarn, fabric;<br>• Sourcing of recycled parts and materials, e.g. zippers and buttons; polyester; wool for fillings;<br>• Collaborations for sustainable washing processes, technologies, and packaging solutions; collaboration with re-commerce (e.g. take back, repair, refurbish, online re-sale, redistribution) and recycling platforms (e.g. within the sector and to other sectors such as furniture and construction). |
| Furniture | Early substitution/disposal of furniture due to:<br>• Aesthetical preferences for renovation or customisation in the style of environments<br>• Seasonal/temporary events (e.g. meetings, fairs, pop-up shops, living abroad)<br>• Working culture with rapidly changing functional needs (e.g. learning or agile workspaces) | Downstream architecture<br>• Offering of function as services instead of products (e.g. learning environments as service)<br>• Platform for accessing furniture per temporary use<br>• Sharing of furniture/furnishing solutions<br>Upstream architecture<br>• Modular furniture to allow customisations and multiple assembles/use cycles;<br>• Ethnographic skills and user-centred design to develop function/activity-based furniture;<br>• Sourcing of recycled/recovered materials from other value chains (e.g. plastics, coffee grounds, textile)<br>• Refurbishment/remanufacturing facilities or collaboration with reprocessors;<br>• Collaboration with architecture/design firms and local workshops/craftsman for life-extension services;<br>• Collaboration with redistributors for commercialisation of second-hand furniture. |

| | | |
|---|---|---|
| Electrical/electronic equip/app. | • Hybrid offerings comprising long-lasting electrical/electronic equipment and 'fast moving' consumables (e.g. coffee machines and coffee grounds/capsules; machines for chemical treatments and catalysers/reactants)<br>• Inefficient operation/maintenance of equipment and overconsumption of energy or consumables due to lack of expertise from customers (i.e. not their core activity) | Downstream architecture<br>• Function as services instead of products (e.g. coffee brewing as service includes the coffee machine, consumables such as coffee grounds, life-extension services for equipment and recycling of waste form consumables)<br>• Consumables as services per subscription or per volume of use (e.g. molecules or coffee as service)<br>• Offering of experience or result as services with pricing models relying on the performance of savings of energy and materials (i.e. cool rooms as service, optimal illumination as service)<br>Upstream architecture<br>• Design of smart products<br>• Digital technologies and industry 4.0 infrastructure<br>• Collaboration with providers of consumables for the electronic appliances/machines (e.g. coffee beans, chemicals or catalysers/pallets) |
| Medical devices/equipment | • Substitution of medical equipment and instruments before the design life-time is reached due to technological upgrades;<br>• Varying demand for medical equipment in different facilities/regions<br>• Strict regulations, risks to health safety, and complexity of ecosystems with powerful actors 'controlling' the market dynamics (e.g. insurance companies, hospitals) impede reuse and recycling. | Downstream architecture<br>• Medical equipment fleet management as service<br>• Clinical processes efficiency management as service<br>• Platforms to share medical equipment with excess capacity among different facilities<br>Upstream architecture<br>• Collaboration with local reprocessors and service centres of excellence for cleaning, sterilisation, repair, and refurbishment of medical equipment and instruments with original manufacturer quality standards<br>• Mobile repair centres and workshops to enable quick and in loco fixes (e.g. repair trucks and vans). |
| Heavy machinery | • Early deterioration of core components of heavy machinery and industrial vehicles due to improper operation or functioning<br>• Reduced productivity and waste of resources due to lack of expertise of customers to deal with complexity of processes and operations supported by machinery (e.g. large jobsites, several actors, safety issues)<br>• Temporary needs for using machinery and vehicles due to seasonal activities or behaviour in the market (e.g. no construction in winter, varying demand within locations) | Downstream architecture<br>• Digital services for tracking, tracing, and managing maintenance of machinery/industrial vehicles fleets<br>• Digital services for productivity and sustainability performance management of operations supported by machinery/industrial vehicle fleets<br>• Heavy machinery/industrial vehicles as service<br>• Remanufactured heavy machinery sales<br>• Function or experience as a service (e.g. material handling as service)<br>• Platforms for capacity management, sharing, and trade of heavy machinery/industrial vehicle fleets.<br>Upstream architecture<br>• Design of smart products<br>• Digital technologies and industry 4.0 infrastructure<br>• Collaboration with digital service providers, marketplaces, transportation and insurance companies<br>• Financing partners for investment on initial stocks of machinery for scaling-up service-based offerings |

*4.2. Phase 2 - Testing*

In order to exemplify the results, tests were focused on the furniture sector, including two small or medium enterprises (SMEs) (companies A and B) and one large company (company C). Moreover, tests with two SMEs from the heavy machinery (company D) and electrical/electronic equipment/appliances (company E) sectors were conducted to evaluate the applicability of the patterns in multiple sectors.

Fig. 9 illustrates how companies from furniture (A-C), heavy machinery (D) and electric/electronic equipment/devices (E) evaluated the use of the CEBM patterns and the recommendations of combinations according to seven criteria (C1-C7).

Most participants considered the CEBM patterns comprehensive (C1) to address the CE problems in their existing BMs (C2). Moreover, the patterns were applicable to their context (C3) with moderate customisation effort (C4). This effort was acceptable by companies and fulfils one of the objectives of this tool, which is facilitating the design of CEBMs to companies of specific sectors. The combinations suggested for the CEBM patterns were logical and applicable (i.e. no technical impediments) after adaptations (C5) and enabled the visibility of the viability of the CEBM concepts (C6) by most companies. Lastly, patterns enabled straight-forward exploration of ideas (C7) for designing new CEBMs.

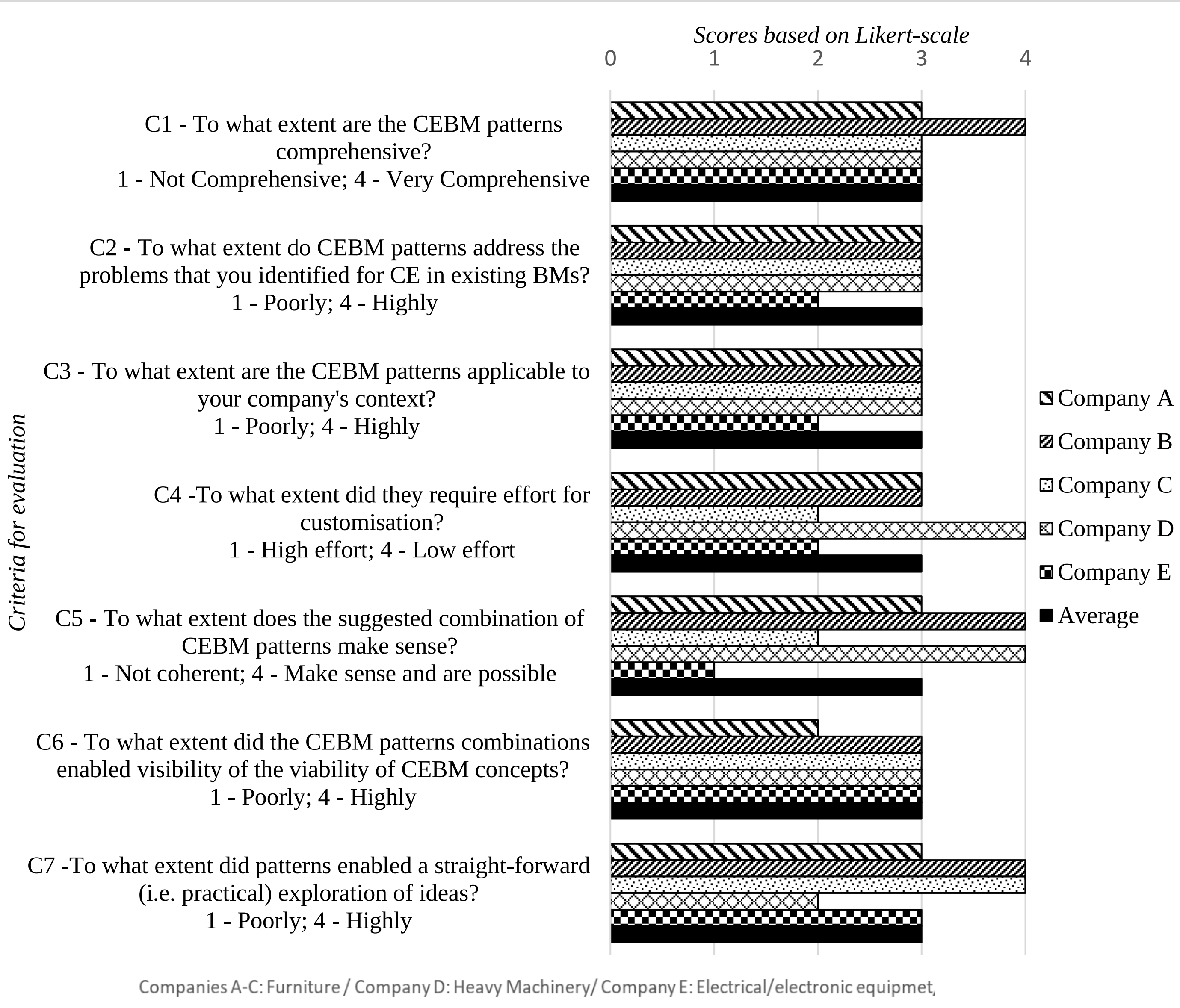


Fig. 9 – Evaluation by furniture, heavy machinery, and electrical/electronic equipment/appliances manufacturers.

## 5. Discussion and conclusions

This section is structured in three main areas: key insights (5.1); applicability, limitations and opportunities for future research (5.2), and contributions (5.3).

### *5.1. Key insights*

Key insights emerged from the comparison of more than 180 existing CEBM cases used for the generation of patterns, which revealed how companies from different manufacturing sectors have been exploring or focusing on different CEBM patterns (section 4.1.3). This enabled the visibility of aspects that can drive future research on CE, for example:

- The nature of products (e.g. composition of materials from the 'biocycle' or 'technocycle') and consumption behaviours (e.g. overconsumption, early substitution, seasonality) within manufacturing sectors tend to present different sources of structural waste, which requires different CEBM patterns. Furthermore, the identified high variability of details in configuration options (e.g. variety of service offerings or types of collaborations) and the recurrence of patterns combination across sectors endorse the development and use of sectorial CEBM patterns by companies.
- Highly controlled manufacturing sectors (e.g. medical devices/equipment) seem to face difficulties for diversification of CEBMs, presenting a reduced number of possible patterns. These observations are consistent with previous research (Damha et al., 2019; Schröter and Lay, 2014) that also identified limitations or specific patterns for servitisation in the medical devices/equipment sector due to regulatory restrictions or strong influence of few actors in the value chain (e.g. public hospitals and insurance companies).
- In some manufacturing sectors (e.g. electrical/electronic equipment/appliances, furniture, and textile and apparel), the potential of products for lasting longer is still being undermined by rapidly changing fashion preferences or the absence/inadequate decisions from companies. Especially in the textile and apparel sector, the cases indicated a trend of manufacturing companies preferring CEBMs to close the loop (e.g. take-back and recycling) instead of adopting CEBMs with higher potential for disrupting overconsumption (Stål and Jansson, 2017; Todeschini et al., 2017) and promoting more impactful results for resource decoupling (e.g. products as service or sharing/subscriptions) (Kjaer et al., 2019).

### *5.2. Applicability, limitations and opportunities for future research*

A number of applications of the sectorial CEBM patterns during tests with practitioners (carried out in stage 2) points towards the flexibility of the approach. The number of explored CEBM alternatives and the usefulness of the sectorial CEBM patterns varied according to the company's objective and strategy. For example, as Company C was a large organisation they had the capacity and intention to explore multiple CEBMs simultaneously to expand their portfolio and market penetration in multiple segments. On the other hand, as demonstrated in section 4.2.1, Company B (which was a SME) decided to focus on optimising one core configuration.

The variety of organisations involved in the evaluation points to the applicability of the sectorial CEBM patterns and the recommendations of combinations for manufacturing companies of different sizes (i.e. SMEs and large manufacturers) and sectors (e.g. furniture, heavy machinery, and electrical/electronic equipment/appliances).

The process for developing the CEBM patterns demonstrated in this paper was solid and state-of-the-art, because it combined inductive and deductive approaches. These approaches are rarely combined by similar studies for patterns generation, which usually rely either on inductive (Amshoff et al., 2015) or on deductive approaches independently (Lüdeke-Freund et al., 2019b). The applied inductive approach was robust, comprising the exploration of more than 180 CEBM case studies within the six manufacturing sectors.

The deductive approach was thorough, comprising a quantitative evaluation of the usefulness of CEBM patterns by multiple manufacturers. This is strongly recommended for CEBMI tools/methods (Bocken et al., 2019), but not extensively performed by previous studies of CEBM patterns. The deductive approach involved a number of companies for theory-testing (Dul and Hak, 2008). The evaluation was able to reveal a positive uptake of CEBM patterns by more than one company in one single sector (furniture) and provided at least an indication of potential applicability in more than one sector (e.g. heavy machinery and electrical/electronic equipment/appliances).

Despite the above-mentioned strengths, the work present limitations. The test with manufacturers showed that the considered recommendations were applicable in a set of companies beyond the original cases. However, expansion of the database with more cases could indeed enhance roubsutness of recommendations. Despite the high coverage of cases used for the development of the patterns, it is important to continuously keep the cases database updated, as to clearly reflect developments in the field. Additionally, validation with a broader sample is required. In addition to supporting a further falsification of the research hypothesis (i.e. that the patterns work for the six selected manufacturing sectors), these tests could also be useful to identify whether other contextual variations or preferences in the usability of patterns exist. For example, whether the size or maturity of companies would require different ways of applying the patterns. Moreover, experiments could be conducted to refine the arguments about how the use of patterns developed for specific manufacturing sectors adds value to companies in comparison to the use of generic patterns. For that, previous generic patterns structures available in literature could be used (Lüdeke-Freund et al., 2019b). Alternatively, generic patterns could be created at the level of ‘fast-moving and packaged consumer goods’ or ‘capital goods’.

Lastly, improvement opportunities recommended by companies shed light on future prospects for research related to CEBM patterns, such as providing or developing:

- Support for the selection of core CEBM patterns and the final combinations (i.e. aligned with the company’s strategy and vision for CE), with the development of adequate criteria for narrowing down choices and prioritising the final CEBM concepts.
- Specific guidelines according to the scope of application of the CEBM patterns (e.g. redesign/transform the existing BM (i.e. ‘business as usual) into a CEBM, or to design a completely new CEBM that will reflect a future strategy of the company).
- Simpler interfaces and flexible software or web-based tool for using patterns and their logic of combinations.

### *5.3. Contributions to practice and CE theory*

In this research, we have demonstrated how to develop CEBM patterns for specific sectors to support manufacturing companies in performing CEBM innovation. The evaluation with practitioners from three sectors indicated that the developed sectorial CEBM patterns have the potential to effectively support manufacturing companies in exploring and understanding the viability and feasibility of CEBMs. According to declarations of companies participating in the evaluation process, the sectorial CEBM patterns and recommendations of their combinations added value by:

- Enabling straight-forward exploration of ideas and promoting the discovery of new ideas for CEBMs that companies had not previously anticipated (especially for SMEs);
- Providing specific case examples, which supported the ideation and design of CEBM concepts (e.g. “cases were helpful in disseminating the ideas within the company”; “cases helped understanding how CEBM concepts can function in practice”);
- Revealing the need for collaborations or new actors in the companies’ ecosystems to close resources loops;
- Showing clear alternatives of CEBMs for exploration (i.e. assessment and experiments).

As another practical contribution, the evaluation with companies pointed out to the potential of sectorial CEBM pattern to stimulate the adoption of CEBMs with larger impact for resource productivity.

This could be related to the comprehensiveness of the sectorial CEBM patterns and their logic of combinations, which encouraged the exploration of a broad spectrum of synergistic ideas. The achievement of more impactful configurations suggests that the sectorial CEBM patterns can indeed help companies in reducing uncertainties, dealing with complexity, and gaining confidence to enlarge market penetration of impactful CEBMs within different sectors (OECD, 2018).

Concerning academic contributions, this research enabled the systematisation and organisation of knowledge for action in CE (Lüdeke-Freund et al., 2019a; Pieroni et al., 2019b). Both the development process and the resulting sectorial CEBM patterns addresses a number of research calls by providing:

- An *useful CEBM pattern structure and language* (Lüdeke-Freund et al., 2019a) that advances available generic approaches (Lüdeke-Freund et al., 2019b) to strengthen discussion at the required level of granularity for implementation of CEBMs by focusing on *purpose* and *contextualisation* (Lüdeke-Freund et al., 2019a; Pieroni et al., 2019a; Urbinati et al., 2017; Wells, 2016). In this research, this means supporting the *development of CEBMs* within *manufacturing companies* from *six specific sectors* (electrical/electronic equipment/appliances; furniture; heavy machinery; medical devices and equipment; textile and apparel; and agricultural/food products).
- The sectorial CEBM patterns resulting from this research comprises *both solution and prototypical patterns to help manufacturing companies in transforming their own BM while leading/triggering change in other BMs or actors within ecosystems.* Different than previous studies that focus on prototypical patterns (Lüdeke-Freund et al., 2019b; Whalen, 2019), the sectorial CEBM patterns are flexible and able to trigger CEBM innovation both at the company or ecosystem levels (Lieder and Rashid, 2016; Pieroni et al., 2019a).
- *A clear procedure for the continuous development of CEBM patterns* and potential to *expand to other sectors*. This enables maintaining the patterns database up-to-date. Thus when innovative configurations of CEBMs appear in the market, new cases can be analysed following the same procedure presented by this article to identify the emerging patterns. Potentially, this mechanism could be automated with support of artificial intelligence in the future. Moreover, it can support the creation of patterns to other sectors. This aspect of clarity regarding the development procedure and maintenance of patterns' structures is absent in previous works (Lüdeke-Freund et al., 2019b).
- A *prescriptive* guidance for manufacturing companies on how to *combine the CEBM patterns* to create innovative BMs, which enable larger impact for resource productivity. This is accomplished by the accompanying combination recommendations for patterns that instruct about synergistic configurations, which has been narrowly explored or only discussed at a conceptual level in previous works (Lewandowski, 2016; Lüdeke-Freund et al., 2019a; Pieroni et al., 2018).

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# Configuring New Business Models for Circular Economy through Product–Service Systems

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**Abstract:** Product—service systems (PSSs) are often outlined as potential enablers of new business models for circular economy. However, not all business models based on product-service systems have superior circularity potential. This research demonstrates how the application of a previously developed business model configurator for circular economy can support the design and assessment of customer value, economic and resource decoupling potential for product-service system business models in practice. By applying action research in two Nordic manufacturing companies from the furniture sector, different business model concepts based on product-service systems were proposed and assessed. Results indicate positive uptake by companies regarding the usefulness of the obtained outcomes. This research identified two key findings about 'product-service system business models for circular economy': (i) their configuration should fulfil certain simultaneous conditions—i.e., superior customer value, economic growth, and resource decoupling potential—to contribute to circular economy; and (ii) they are often *'niche solutions'*, fulfilling specific needs and customer segments, and more likely to flourish with certain types/characteristic of products, segments or geographical locations. Lastly, a framework outlining the conditions and trade-offs for assessing the circularity potential of business models based on product-service systems is introduced as one of the key contributions.

**Keywords:** business model innovation; circular economy; product-service system (PSS); configuration; action research

## 1. Introduction

Circular economy (CE) aims to establish a resource-effective and efficient economic system that is more suitable to respect planetary boundaries [1]. CE is often interpreted as one way of achieving economic and environmental sustainability [2], but it also has potential to generate secondary positive effects on the social sustainability perspective [3,4]. To implement CE principles, societal, industrial, and consumption systems will need to shift their foundations to build on renewable energy/materials sources and to reduce waste generation [5] by intentionally narrowing, slowing, and closing material and energy flows [6].

For manufacturing companies, the adoption of CE as a business strategy implies striving to provide and maintain products with the highest value while consuming as few resources as possible [7]. The main idea is to fight against structural waste [5] caused by inherent ineffectiveness of value systems due to bad design (e.g., fast obsolescence), sub-optimal processes, outdated laws, lack of motivation or unconcerned behavior from receivers (e.g., overconsumption or misuse of products) [5,7]. Hence, building organizational (or even interorganizational) capabilities for CE requires as much technological or product innovation as systemic value innovation with the configuration of new business models (BM) which are fit with CE principles [8,9].

A business model for circular economy is defined as "how a company creates, captures and delivers value, with a value creation logic designed to improve resource efficiency through contributing to extending the useful life of products and parts (e.g., through long-life design, repair and remanufacturing) and closing material loops" [10] (p. 13). Product-Service Systems (PSS) are often outlined as one of the potential enablers for configuring new business models for circular economy, stimulating life-extension and product take-back [10–16]. However, PSS- or CE-oriented approaches do not necessarily lead to a reduction in resource consumption or automatically guarantee enhanced environmental or social sustainability [3,17–20]. Despite the availability of an increasing amount of academic content and approaches for BM innovation for CE (including PSS as a strategy) [9], developing resource-efficient and effective business models based on PSS offerings is still reported as challenging for companies [13,21,22]. The main challenges during the design and assessment stages faced by organizations are related to: (i) applying efforts systematically to reinvent the logic of how their business works to simultaneously achieve economic and resource effectiveness/efficiency goals [12]; and (ii) transferring conceptual knowledge/learnings about PSS and circular economy to the real-world practice in an effective, useful, and simple approach [9,23].

The main objective of this research is to reduce these challenges and help organizations in configuring (i.e., designing and assessing) business models for circular economy including (but not limited to) the approach of Product-Service Systems. A previous proposed conceptual process model—entitled the CE-Oriented Business Model Innovation (BMI) Process (documented in [23])—and its accompanying tools were applied and improved in action research cycles with two Nordic furniture manufacturers. The main tool supporting the CE-Oriented BMI Process is the CE-Driven Business Model Configurator (documented in [3]), which intends to guide companies in sensing and making sense of CE opportunities and seizing (or designing and assessing) BMs, based on a number of CE-oriented BM patterns consolidated from reviewing theory and practice (i.e., with retrospective analysis of more than 150 cases). In this research, patterns are defined as the possible combinations of configuration options for the BM elements, which repeatedly occur to enable circular economy principles in companies' business models [24,25]. Different patterns related to PSS are considered in the CE-Driven Business Model Configurator, along with other patterns not necessarily related to PSS. The focus of this article is to show how the application of the configurator supported the design and assessment of the customer value, economic potential, and resource decoupling potential of PSS business models in practice.

The following sections of this article explain the research method (Section 2), describe the application of the selected conceptual process model and tools in the action research cycles with two furniture companies (Section 3), discuss the key findings and insights (Section 4), and present conclusions and future research steps (Section 5).

## 2. Research Method

This section contains two subsections. The first subsection introduces the research approach, including method and materials. The second subsection provides an overview of the conceptual framing—a process model and the main tool applied in the action research cycles for supporting the companies in configuring CE-oriented BMs based on PSS.

### *2.1. Research Approach*

Inspired by aspirations in Management and Design Sciences of promoting 'impactful' academic research, which is able to demonstrate the contribution made 'to' and 'with' business [26,27], this research adopts action research (AR) as methodology. AR is a form of applied research (or engaged scholarship [28]) that combines scientific methods with organizational knowledge, involving the active collaboration of researchers and companies' members to propose solutions to real organizational problems while building theory from observing and interacting with practice [29]. Originated in the Social Sciences, AR has been recognized as an appropriate research method in various fields [30–33].

There are several AR approaches and ways of combining them with other methods [31]. This research followed the overall guidelines proposed by Mathiassen [29] and applied a four-step cyclical process [33] for data collection and analysis.

First, two companies (Ope and Vestre) were selected for the action research according to three criteria: (i) furniture manufacturer in the Nordic region; (ii) intention to explore or start their transformation towards CE from a business model perspective and focus on PSS; (iii) availability/willingness to provide access to processes/people, share information and provide feedback during the ARs. The furniture sector was selected in this study due to its economic representativeness for the European Union (EU) and Nordic markets, the environmental challenges and potential opportunities in a CE context. One-third of furniture commercialized globally comes from the EU, contributing to approximately 1 million jobs, predominantly in small- and medium-sized enterprises (SMEs) [34]. It is estimated that there are 130,000 furniture companies in the EU [35], and approximately 3,000 in Nordic countries [35–37]. Most furniture (around 80–90%) in the EU is destined for landfill when reaching the end-of-life, with only 10% being recycled [34]. Practices for extending the life of furniture (e.g., reuse or remanufacturing) are limited to a small scale. Concerned with such a wasteful and ineffective environmental (and sometimes even economic) scenario, researchers and practitioners have been exploring solutions to improve the furniture sector. CE and PSS are indicated as promising approaches to this end [34,38,39].

The second step in this research entailed the selection of a process model (CE-Oriented BMI Process [23]) along with its tools (the main tool is the CE-Driven Business Model Configurator [3]) to act as conceptual framing for guiding the development of PSS business models for CE in the AR cycles (described in Section 2.2).

As the third step, the test and refinement 'in action' of the proposed CE-Oriented BMI Process and the CE-Driven Business Model Configurator were planned and executed with each company in workshops that occurred within a period of one month. The workshops received up to six participants and included key decision-makers from different functional areas (detailed in Section 3). Data collection methods to evaluate the application of the CE-Oriented BMI Process and the CE-Driven Business Model Configurator comprised a journal with the researcher's observations and post reflection; recordings of the workshops to enable the compilation of comments and verbal feedback; and structured evaluation questionnaires standardized for all companies and answered by the participants at the end of each workshop. The questionnaires comprised a combination of multiple-choice and open-ended questions that aimed to measure the usefulness and usability of the process model and tool in three aspects: (i) overall process and main activities; (ii) results obtained against the proposed outcomes; and (iii) results obtained against expectations. The object of measurement in the questionnaires was satisfaction (i.e., how the process model and tool are perceived as successful by the company). A 4-point Likert scale varying from 'Unsatisfactory' to 'Very satisfactory' [40] was employed as options for answers.

Lastly, the collected data from the research journal, recordings and questionnaires were analysed to enable the evaluation of the application of the process model and tools in the companies, resulting in the identification of improvement opportunities (catalogued following a coding process) for the process model and the tool to be applied in future research.

### *2.2. The CE-Oriented BMI Process and the CE-Driven BM Configurator*

The CE-Oriented BMI Process [23] comprises three stages based on the dynamic capabilities view [41]:

1. Sensing and making sense of CE opportunities in the ecosystem;
2. Seizing the opportunities by designing and assessing new CE-oriented value generation architectures (i.e., CE-oriented BM concepts); and
3. Transforming/renewing operational capabilities accordingly in order to implement the CE-oriented BMs.

The process model allows a holistic approach to companies, in the sense that it suggests activities from design to implementation of CE-oriented BMs [23]. Moreover, it allows a systemic approach that integrates four tangible and intangible perspectives for CE-oriented BM innovation: (i) activities and tools; (ii) business processes and sustainability performance interdependence; (iii) strategic decision-making procedures; and (iv) consideration of social traits and capabilities [23]. The main tool supporting the process model is the CE-Driven BM Configurator [3], which will be the focus in the remainder of this article. Figure 1 illustrates how the Configurator supports the CE-Oriented BMI Process and interacts with the other supporting tools. Figure 2 illustrates details about the interfaces and logic of the Configurator.

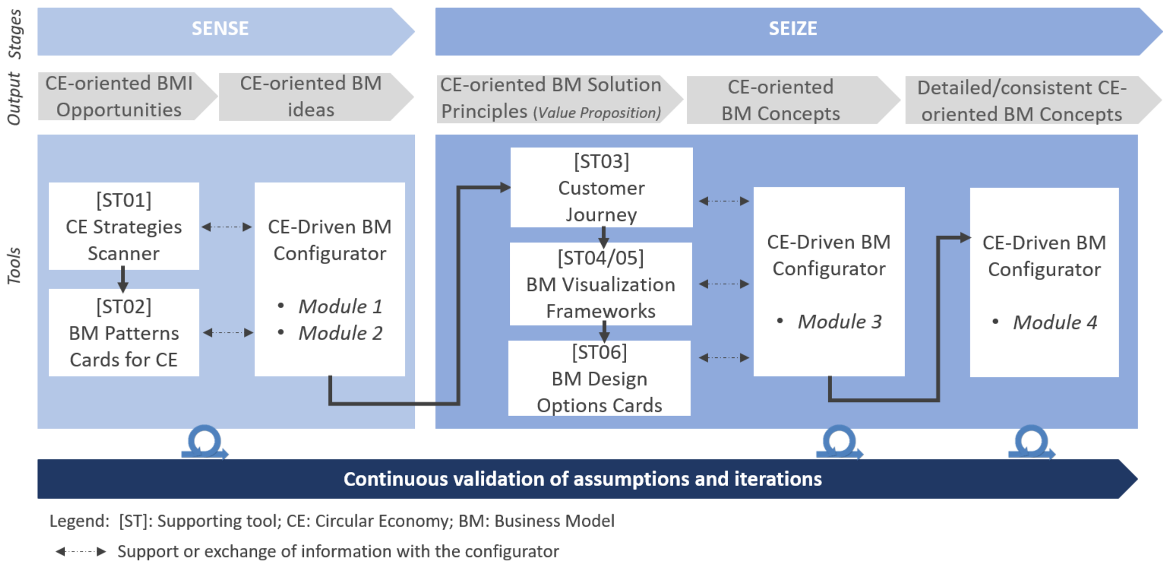


**Figure 1.** Extract from the first two stages of the CE-Oriented BMI Process including expected outputs, supporting tools and the link with the CE-Driven BM Configurator. BMI: Business Model Innovation.

The Configurator supports BM design for CE based on patterns. A pattern is interpreted in this work as a combination of configuration options for the BM elements, which repeatedly occurs in successful BMs for CE [24]. Although a few works apply pattern-based approaches for designing BMs for PSS [42,43], they are still addressing CE superficially. For instance, in Kwon et al. [43], less than 3% of the available configuration options (3 out of 53) for PSS BMs design are related to improving resource efficiency or effectiveness. There is one work applying the pattern-based approach for CE [25]; however, it is still conceptual (i.e., lacking clarity about how the implementation of the framework could occur in practice) and generic (i.e., lacking sectorial specificity or contextualization, which is relevant for CE [26]). Lastly, they lack clarity about the combination of multiple patterns, which is necessary to the complete design since a pattern usually addresses different parts or elements of the business model [24,44]. The CE-Driven BM Configurator tackles those gaps and advances knowledge in respect to the aforementioned research by:

- Facilitating the proposal of business models based on PSS and with a focus on CE, including patterns that address economic and resource decoupling problems/opportunities (Section 3.2);
- Enabling practical application and providing guidance on how to use and combine the patterns along the stages of ideation, design, and evaluation of business models for CE, including simulation of different configurations (scenarios) (Figures 1 and 2; and Section 3.2);
- Introducing a sectorial contextualization to enable more precise and in-depth business model configurations for CE.

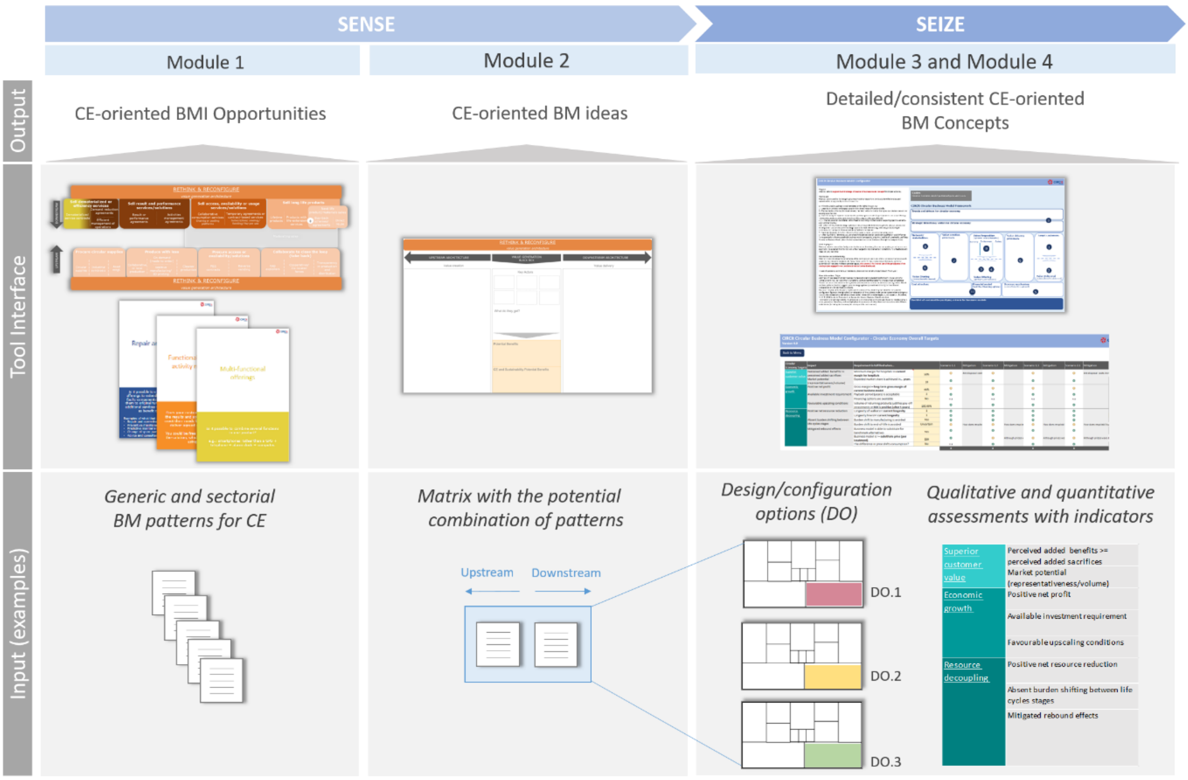


**Figure 2.** Initial version of the CE-Driven Business Model Configurator (adapted from [3]).

Inspired by previous research in the PSS field [45], the Configurator is a planning tool suited for the early stage of when manufacturing companies decide to move towards BMs for CE. The purpose is to trigger a change of mindset towards CE by acting around the dynamic capabilities concept (individual managerial and organizational skills) [41]. CE will require 'breaking industry recipes' [46] and the silo/organizational-centric view. However, according to recent research in CE [47], some actor in the value chain has to take the lead and start thinking about CE first internally, then absorb the concepts, and then influence other actors and lead the initiatives that will occur collaboratively. The Configurator seeks to incentivize more of those individual actors acting in the position of manufacturers to change their perspectives and way of operating and inevitably to influence others. Hence, the Configurator starts with the organizational-centric approach (e.g., using BM frameworks that are inheritances from linear economic logic or having one company leading the process), but it leads the manufacturing companies to gradually realize the importance of collaborations and the organizational or ecosystem view for CE. For instance, one of the patterns' categories available in the configurator is called 'collaborative value creation with third parties,' and it comprises several actor configurations in the value chains of specific industries (or cross-industries) to guarantee product/material circularity. In the furniture sector, 13 out of 41 patterns address collaborations.

For the initial version, the Configurator was structured in a spreadsheet, which was used as a facilitating tool for the application in the action research cycles, generating information to populate interactive frameworks (e.g., collection of printed patterns in the format of cards, and a printed template for combination of patterns) that were suitable for group discussions and flexible to enable 'live change requirements' (Figure 2).

The Configurator comprises four modules. Modules 1 and 2 are applied during the 'sense' stage of the process model (Figures 1 and 2). Module 1 focuses on the *identification of opportunities* for designing new BMs for CE. It contains a collection of CE-oriented patterns for upstream and downstream BM architecture [3]. Different types of PSS are considered as patterns in the configurator, along with other patterns not necessarily related to PSS (e.g., multi-cash flows originated through industrial symbiosis). These patterns were compiled following previous methodologies for pattern generation in traditional

BM literature [24,44], in two steps: (i) identification and consolidation of previously developed generic patterns of business models for CE available in literature (listed in [9]); and, (ii) retrospective analysis of more than 150 cases in six industry sectors [3]. Furniture is one of the target sectors in the configurator, comprising approximately 35 cases (Supplementary Materials: Table S1). The patterns are presented in the configurator in two formats; a list in an Excel database or as printed cards for interactive workshops (ST02 in Figure 1). Each pattern is accompanied by a definition and examples of real-case applications. In addition to the pattern cards, a template containing a list of possible CE strategies developed from [11,48] and entitled Circular Strategies Scanner (ST01 in Figure 1) is used as a boundary object to organize and combine the patterns.

Module 2 focuses on transforming opportunities into *BM ideas*, which means combining different BM patterns and adapting them to make sense for the company's context. This is grounded on previous research that identified that the majority of BM innovations are outcomes of recombination of existing patterns [49,50]. Module 2 is supported by a matrix with potential combinations of patterns, based on sectorial case studies for CE-oriented BM innovation. This module emerged as a response to an improvement required during the first action research cycle; therefore, it was applied only in the second cycle (i.e., Vestre). After the free ideation exercise in Module 1, Module 2 enables the verification, improvement, or creation of other possible combinations, which will trigger iterations in the initial version generated with the tools ST01 and ST02 (Figure 1).

Modules 3 and 4 are applied during the 'seize' stage of the process model. Module 3 focuses on the *configuration of BM concepts* for CE. It is supported by a morphology [51] organizing the common practice or appropriate design/configuration options according to the selected combination of BM patterns. Different design/configuration options are suggested for each business model element: systemic outcomes (i.e., expected economic, environmental, and social benefits); offerings (i.e., products/services); target customers; value delivered (i.e., benefits for customers); network (i.e., partners and collaborations); value shared (i.e., benefits for network); value delivery processes; value creation processes; revenue mechanisms; cost structure; and financing options [3]. The design options were also available in two formats: a list on an Excel spreadsheet or cards to facilitate group working (ST06 in Figure 1). Module 3 interacts with two supporting tools: a Customer/User Journey Map (ST03 in Figure 1), and two types of visualization frameworks for the BM (ST04/05 in Figure 1). The first visualization framework (ST04) is inspired by Brehmer et al. [52] and illustrates the flow of value exchanged (i.e., offering—which can be either services or products—and economic/social flows) among actors for the BM concept. The second framework (ST05) illustrates the BM concept in a 'traditional' canvas view, and is adapted from Kraaijenhagen et al. [53] and Biloslavo et al. [54], which build on the 'value concept' largely disseminated in traditional BM literature by Osterwalder and Pigneur [55] and Richardson [56].

Module 4 comprises preliminary *assessments of the customer value, economic, and resource decoupling potential* for the designed BMs for CE. The assessment provides both quantitative and qualitative measures. The assessment of customer value is qualitative, based on the evaluation of potential trade-offs of potential benefits and sacrifices perceived by the customers with the new BM concept [57]. The assessment of the economic potential is based on cost-benefit analysis and is structured as a 'business case,' applying both quantitative and qualitative measures. The assessment of the resource decoupling potential is based on the guidelines provided by Kjær et al. [17], also including qualitative and quantitative measures. The selection of indicators to compose the quantitative part of the assessments followed guidelines provided by a tool for screening the sustainability potential of CE initiatives [58].

## 3. Action Research Cycles and Their Results

This section presents the results in two subsections. The first subsection introduces the dynamic of the action research cycles and the context of the participating companies. The second subsection explains the application of the configurator and the obtained CE-oriented BM concepts based on PSS.

### *3.1. The Companies Participating in the Action Research Cycles*

This subsection describes the dynamic of each action research cycle as well as the context of the participating companies Ope (AR cycle A) and Vestre (AR cycle B).

#### 3.1.1. Action Research Cycle A

This action research cycle occurred during July 2018 in the company Ope, which is a small Norwegian furniture manufacturer with headquarters in Stavanger. In addition to the main author of this research, the workshops for application of the process model and tools engaged between two and six participants from Ope, including the Sales & Operations Manager (all workshops), an external consultant working with strategy and innovation (all workshops), Marketing and Sales Coordinators (workshops 1, 2 and 5), Product Design Manager (workshop 5) and a Board member (workshop 5).

Ope already presented some capabilities that are expected for CE, for instance, product design. The company offers dynamic and modular furniture systems, allowing the creation of working/living spaces. These are premium products manufactured by third parties, assembled in-house and currently sold by Ope to the business-to-consumer (B2C) segment via their web store and to the business-to-business (B2B) segment via direct sales or partners. Since the products are modular, it is possible to customize (within a range of predefined options) the size of the systems, upgrade them or order additional accessories. The product comprises two key parts, MDF panels and plastic connectors. The technology for guaranteeing the system's modularity was developed and patented by Ope and is fundamental for allowing multiple cycles of disassembly and assembly during use.

Ope had previous knowledge about the concept of CE and sustainability. They were aware that some of their product's characteristics (i.e., modularity and upgradability) could favor and facilitate the implementation of BMs for CE, especially PSS. They also acknowledged some challenges, such as the presence of 'non-circular' components in the composition of the product (e.g., MDF and plastics), lack of formalized life-extension or end-of-life services, no return or 'pro-active action' with the products when they reach end-of-use or absolute end-of-life. Furthermore, they had limited experience with additional basic services for product life-cycle extension occurring in an informal and ad hoc approach (e.g., repair and maintenance, refurbishment services, buy-back scheme). Ope was developing a new product for short-term events, also designed with modular technology. Due to the challenges and the potential (even) shorter usage cycles of the new products, there was a particular interest in exploring different PSS BMs, in order to understand the changes required in their business capabilities and the impacts on resource decoupling and economic outcomes.

#### 3.1.2. Action Research Cycle B

This action research cycle occurred during January 2019 in Vestre, which is also a small Norwegian company with headquarters in Oslo. In addition to the main author of this research, between one and three participants from Vestre were engaged, including the Sustainability and Strategy Manager (all workshops), the Marketing Manager (workshop 1), and the Product Manager (workshop 1). Although only one participant appointed by the company was present in workshops 2 and 3, internal validations of the results were conducted with the other collaborators, which also supported data collection (especially for the calculations in workshop 3) after each workshop and before they replied to the evaluation questionnaire.

Vestre offers outdoor furniture to allow the creation of social meeting places. They have a varied portfolio of premium products manufactured in-house and currently sold in B2B and B2G (business-to-government) segments. The different products are mainly composed of wood and stainless steel. Due to their application in outdoor spaces, design for durability is key to ensure resistance to harsh climate conditions (e.g. wind, rain, sun exposure). The company provides a guarantee on materials, which highlights the importance of the reliability of their products.

Vestre also had previous knowledge about the concept of CE, with a higher focus on the wider scope of environmental and social sustainability. Nevertheless, they were unsure about how they could apply their products' characteristics (e.g., durability) to seize new business models for CE. They also acknowledged a number of challenges, such as: the need to redesign the products to facilitate disassembly or repair; potential difficulties with recyclability or biodegradability due to the presence of toxic materials (e.g., lacquer impregnation and coating used in galvanization); specific requirements from customers potentially hindering the acceptance of CE BMs; and no return or 'pro-active action' with the products when they reach end-of-use or absolute end-of-life. Recently, they have received new requests from customers for products' life-extension services (e.g., refurbishment including re-coating and maintenance). Moreover, they identified the opportunity for increasing market share in a specific segment by providing products as services and greener solutions. Due to both trends, Vestre had interest in exploring different PSS BMs to understand the changes required in their business and the impacts on resource decoupling and economic outcomes.

### *3.2. Application and Results of the CE-Driven BM Configurator for Designing and Assessing CE-Oriented BMs Based on PSS*

This section explains the application of the Configurator and the configured CE-oriented PSS BMs as outcomes for each action research cycle.

#### 3.2.1. Action Research Cycle A

The first module of the configurator was applied in a 3-4 hour workshop with the use of the supporting tools (Figure 1). The Circular Strategies Scanner (ST01 in Figure 1) inspired a free brainstorming with the participants working in a group. The aim was to create new CE-oriented BM ideas based on their experience. After the free brainstorming, the participants received a set of cards with the BM patterns for CE (ST02 in Figure 1) to inspire themselves with real cases featuring different BM patterns (including but not limited to PSS) to enable different initiatives for CE in the furniture sector. The cards were investigated by the group, leading to the creation of eight BM ideas that were added to the Circular Strategies Scanner, of which three were based on PSS (Table 1).

**Table 1.** CE-oriented BM ideas for PSS generated by Ope.

| BM Idea | BM Opportunities (Patterns) | Customer Value Potential | Structural Waste Source/Type | Decoupling Potential (based on [17]) |
|---|---|---|---|---|
| 1—'Digital platform to facilitate access to/or use of modular furniture systems through short-term contracts.' | 1—Access-based solution (use-oriented PSS) | Customer segments (especially B2B) requiring lower total cost of ownership and higher flexibility (e.g., such as project-based organizations); convenience of frequent customization and aesthetic changes required (styling of offices, fairs and events). | 'Real' product-life shortened—i.e., consumption patterns/use causing inferior longevity than design specifications. | Reduce the need to produce new products to fulfil needs. |
| 2—'Furniture bank—digital platform to enable 'depositing furniture in one location and taking out in another place' | 2—Access-based solution (use-oriented PSS) | Customer segments (especially B2C) requiring temporary solutions (e.g., exchange workers) or having dynamic lifestyle (moving frequently to different geographical locations). | 'Real' product-life shortened—i.e., consumption patterns/use causing inferior longevity than design specifications. | Reduce the need to produce new products to fulfil needs. |
| 3—'Optimal workspaces/ people's environment.' | 3—Functional-based solutions with complete life-cycle services (result-oriented PSS) | Offices, particularly the ones adopting open-space structures. | Unnecessary configurations/amount of products; 'Real' product-life shortened—i.e., consumption patterns/use causing inferior longevity than design specifications. | Displace more resource intensive systems. |

Ope prioritized the BM ideas to identify the ones to focus first in the stage 'seize' (modules 3 and 4 of the configurator). After an initial discussion, the participants reached consensus and selected 'BM idea 1' due to two criteria (company's choice): (i) *lower service dependence when compared to other alternatives*; (ii) *less complexity and effort (or time) to develop*. 'BM idea 2' would require the expansion of the available furniture portfolio to provide convenient and comprehensive solutions for customers.

This would probably require collaboration with other furniture manufacturers or the creation of new product lines, which would require long-term for implementation. 'BM idea 3' would require the development of new service-oriented capabilities, related to the actual operation and users' behavior in offices (e.g., ethnographical and user-centered design) not available today.

During the second workshop, Ope applied the third module of the configurator (as aforementioned, module 2 emerged as an improvement after this AR cycle). Module 3 enabled detailing the value proposition and identifying new capabilities required for the new PSS concept. As in the previous module, a free brainstorming was performed in order to create the scenario for the new Customer/User Journey (ST03 in Figure 1). Finally, the business model concept was detailed in two types of visualization frameworks (ST04/05 in Figure 1).

In the initial BM concept proposed by Ope (Figure 3), companies (that are seeking temporary workspace or event solutions) would be able to access and temporarily use the furniture by either subscribing to a service package or agreeing on a determined rental/lease contract directly from the provider's digital platform (application). After using the furniture during the agreed period, the products would be pick-up by the providers, who could facilitate the reuse of system(s) in other nine users/cycles before moving them back to the regional refurbishment/remanufacturing center. With the support of the configurator, Ope identified new required operational capabilities (detailed in Supplementary Materials: Figure S1) to implement this concept. For value creation and delivery, they will have to develop skills for service delivery and build a marketplace including digital capabilities and logistics operations. Collaborations with service providers or dealers will be fundamental to enable these capabilities. Moreover, facilities for recycling and coalitions for collecting ocean plastics will need to be established. Lastly, financing enablers are required, for instance, the possibility to collaborate with existing customers for sharing risks and initial investments.

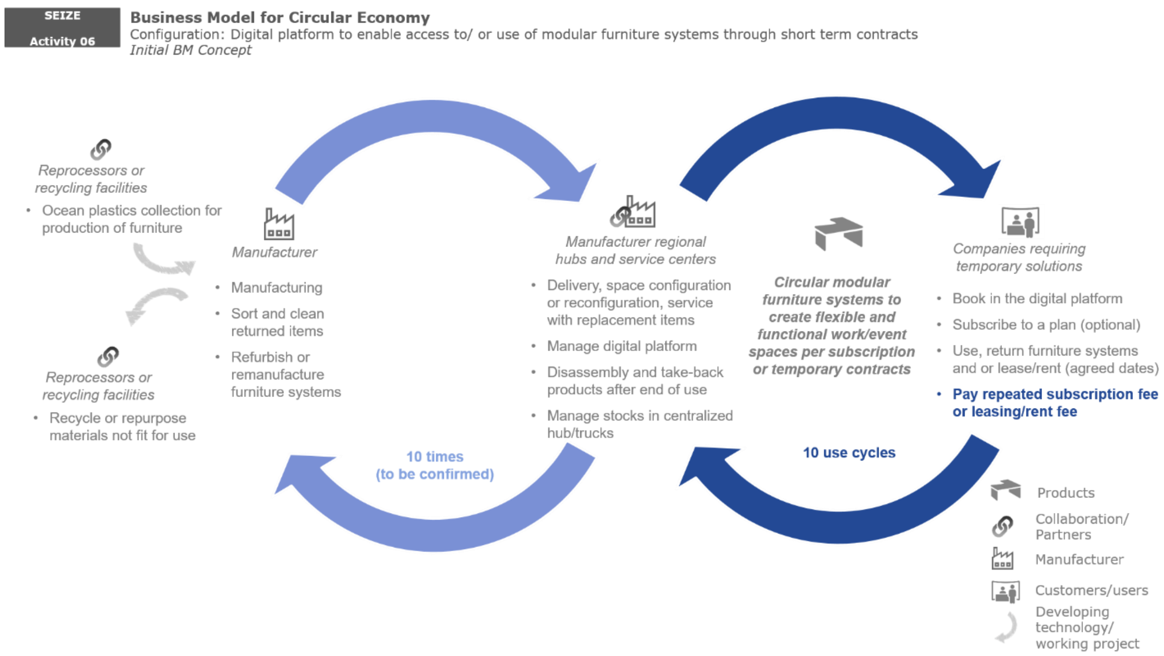


**Figure 3.** Value exchanged among actors in the initial BM configuration designed by Ope.

Lastly, during the third workshop, Ope applied Module 4 to evaluate the potential outcomes of the proposed PSS BM concepts (Table 2). This module, which is one of the main contributions of this paper, provides the opportunity for companies to check the affinity of the proposed concepts with CE outcomes, so they can either improve the concept or decide to start the design/configuration of another concept. It is important for allowing discussions and reconsideration about strategic choices (e.g., differentiation, pricing, and segmentation) in order to guarantee the simultaneous economic and environmental gains to the largest extent possible.

**Table 2.** Potential CE outcomes for Ope. Legend: Dark circle—Requirement is fulfilled; Partial dark circle—Require further investigation or mitigation; Clear circle—Requirement is not fulfilled (developed from Kjær et al. [17], Kravchenko et al. [58], Pieroni et al. [9]).

| **PSS BM concept** | **Digital platform to enable access to/or use of modular furniture systems through short-term contracts (rental, leasing, or subscription).** | |
|---|---|---|
| **Segment/customers** | **B2B (e.g., project-based organizations, offices, event venues)** | |
| | **Requirement is fulfilled when . . .** | **Results:** |
| | PSS → Economic growth | |
| Ensure acceptable net profit ● | . . . profit enabled by new BM concept > = (at least equal to) long-term profit of current business model. | Return on investment, net present value and profit margins (including profit per asset/product) for different subscription, leasing fees, and contract periods were calculated. This helped to adjust a feasible subscription/leasing fee to enable at least a comparable or superior profitability to current BM (in the long term). Pricing definition also considered customer needs/expectations. |
| Foresee and mitigate investment requirements ◐ | . . . breakeven of the new BM concept occurs in an acceptable period, and if external financing capital is necessary it is also available. | Although profitable (positive return on investment), the concept incurs in a delayed breakeven of 10 years. *Mitigation:* Investigation of scenarios for cofinancing of this solution with the participation of investors in the first years. |
| Adjust for and mitigate upscaling challenges ◐ | . . . volume of returning products (for recirculation) justifies/pays off the required investments. This involves dealing with economies of scale. | The estimated return of products and volumes of sales do not pay off investment in refurbishing facilities and marketing campaigns required for launching this concept (i.e., negative return on investment in the first decade). *Mitigation:* This concept will be offered in metropolis to guarantee enough volume. |
| | PSS → Superior customer value | |
| Ensure added benefits and avoid or mitigate sacrifices ○ | . . . added benefits for customers > (are perceived as higher than) added sacrifices in relation to current BM. | Considered added benefits: lower investment costs; simplicity of concept; flexibility to renew furniture constantly. Sacrifices: B2B is used to procure comprehensive furniture packages, with a diversified portfolio to fulfil an entire workspace. As sacrifices are considered larger than benefits, this criterion was not fulfilled. *Mitigation:* apply the concept for events (e.g., industry fairs) and with the new products being developed. Suitable characteristics: they are not a niche product; would be less affected by changes of taste and fashion than the current product; could be maintained in the event venues for multiple uses; combined with the modular systems they would fulfil the key needs of event participants. |
| | PSS → Absolute resource decoupling (effectiveness and efficiency) | |
| Ensure net resource reduction ● | . . . resources needed for needs fulfilment without subscription > (are higher than) resources needed for needs fulfilment with subscription. | 20–45% potential resource reduction (calculated with indicator utility [1]; due to no need to produce new products). *Opportunities for improvement in other concepts:* not possible to capture the 'full circularity potential' of the product (could be used/refurbished for 10 cycles, but it is reaching 2 cycles in this configuration) imposed by market requirements regarding the time taken for products to be returned back and made available for new contracts. |
| Avoid burden shifting between life cycle stages ● | . . . "additional resources are not required during production and end-of-life." | The furniture needs to be designed for easy disassembly and high durability. However, since modular product design was already part of the incumbent BM, this could help avoid burden shifting. One potential risk is shifting the burden to the end-of-life by substituting the current raw material MDF to ocean plastics, in case that recyclability of the latter is not possible. |
| Mitigate rebound effects ◐ | . . . "value-adding low-resource intensive services mitigate or exceed any potential costs-savings." | By not having the upfront investment, customers (especially in the case of offices or project-based organizations) could spend these savings with other resources. *Mitigation:* this could be absent in the case of events' solutions because currently, the venue owners are not necessarily the owners of modular furniture/materials for space creation of stands. |

[1] Calculation of indicator 'Utility' based on Azevedo et al. [59].

Although the *resource decoupling potential* for the proposed BM concept showed positive results, the *customer value criteria* were not fulfilled. Ope judged that the sacrifices perceived by the customers with the proposed concept, i.e., the need for full-office solutions with a diversified furniture portfolio, would surpass their perception of added benefits, leading to a low perceived value. Moreover, even though positive, profitability would occur in the long term, which would require capacity of investment and scalability that were not considered as feasible by Ope.

Based on this assessment (Table 2), Ope concluded that the evaluated BM concept could work more adequately when the new product is ready for launching, since it will be directed to events with considerably shorter use cycles (e.g., ranging from days to a couple of weeks) and could compose synergy with the current products. It was discussed that venue owners could act as partners and potentially share investment and profits to offer the solution for participants (e.g., companies attending the events and in need of organizing their presentation stands/spaces). Hence, a new BM configuration was designed using modules 3 and 4. In relation to the previous BM concept (Figure 3), the new BM concept would be limited to the scope of event spaces/solutions. Participants of the events would have the possibility of booking, using, and paying-per-use (days, weeks) of full preconfigured spaces. Event organizers and venue owners interested in providing this solution for their customers (i.e., event participants) without putting too much effort into services would be able to request the system for their venues by paying a deposit for the initial stocks. As in the previous concept, the systems could be used ten times before being collected and taken by the manufacturer to regional refurbishment/remanufacturing centers. For the manufacturer, this configuration would require less effort with logistics and facilitate scalability.

#### 3.2.2. Action Research Cycle B

Based on the learnings from Cycle A, the application of module 1 was altered for Vestre in order to facilitate the combination of different BM patterns and adaptation to make sense for the company's context. After the identification of *BM Opportunities (patterns)* following Module 1 of the configurator, Module 2 was applied to support the combination of patterns and the generation of *Final BM ideas* (Table 3). Module 2 aims to achieve BM ideas (and subsequently concepts) with as much 'resource decoupling' as possible. Hence, it indicates likely combinations of patterns to guarantee value generation for CE in different stages of the life cycle (e.g., use, end-of-use, end-of-life) and both in the downstream (i.e., new revenue schemes and customer interface) and upstream (i.e., value creation systems, such as product design, reverse logistics) BM architecture. For instance, 'BM Pattern 1' (Table 3) was combined with a pattern entitled 'Incentivized product return for next-life sales.' This implies implementing a buy-back scheme for products reaching the end-of-use but yet with the potential for further use (which could occur in six years for Vestre) in order to refurbish or remanufacture and resell them.

After the configurations, Vestre prioritized the BM ideas with the objective of identifying the ones to focus on the stage 'seize' (modules 3 and 4 of the configurator). A discussion and comparison of the configurations were carried out based on information (i.e., potential benefits for CE and sustainability, potential benefits for customers and potential impact in CE strategies) provided by the new version of the CE-Driven Business Model Configurator. Vestre prioritized 'Final BM ideas 1 and 3' (Table 3) because they require fewer changes in the company's current capabilities (i.e., they are either closely related to the current way of operating or with experiments already occurring). Opportunities requiring new partnerships or radical changes in capabilities (e.g., final BM idea 2 would require capabilities related to digital technologies) were planned for the future.

During the second workshop, Vestre applied the third module of the configurator and obtained two BM concepts. In configuration 1 (Figure 4), the customers (B2B or B2G) would be able to buy the furniture (either new or refurbished). On top of that, they could sign up for a continuous maintenance service package to extend the life of urban spaces. Finally, in the end-of-use, they could require pick-up or buy-back from the manufacturer, which would refurbish the furniture and make it available for new sales. With the support of the configurator, Vestre identified new operational capabilities (Supplementary Materials: Figure S2) required to implement this concept. For value creation and delivery, Vestre will need to structure a system for taking back products at the end of use. This will require negotiations with actors in the current value chain. For instance, 'building contractors' who are responsible for executing urban landscape projects—and the ones installing new furniture or decommissioning existing ones—will have to be engaged in the solution and probably receive financial incentives. New logistic routes will have to be negotiated with transportation companies. Moreover, regional reprocessing facilities will have to be built or new partnerships with local refurbishment centers will have to be established. Lastly, Vestre will have to hire and develop a maintenance team (and the related skills) or collaborate with a network of service dealers.

**Table 3.** CE-oriented BM ideas for PSS generated by Vestre and complemented by combinations.

| Final BM Idea | Original Selected BM Pattern | Combined Patterns | Customer Value Potential | Structural Waste Source/Type | Decoupling Potential (Based on [17]) |
|---|---|---|---|---|---|
| 1—'Furniture for social meeting places to last a lifetime with services for life-extension … trade in or we pick up your used furniture for free.' | 1—Products with through-life care (product-oriented PSS) | Incentivized product return for next-life sales | 1st life: customer segments (especially B2B) requiring modernization or refurbishment of previously acquired products (30 years in use) or 'often' changes in aesthetics. 2nd or further lives: customer segments interested in 'greener choices' (e.g., public procurement). | Lack of solutions for life-extension; 'real' product-life shortened—i.e., consumption patterns/use causing inferior longevity (sometimes 6 years) than design specifications (over 20 years). | Reduce the need to produce new products to fulfil needs. |
| 2—'Furniture for social meeting places to last a lifetime with services for life-extension and efficient management of urban spaces … trade in or we pick up your used furniture for free.' | 2—Products with efficient maintenance management (product-oriented PSS) | 1—Products with through-life care (product-oriented PSS) + Incentivized product return for next-life sales | 1st life: customer segments (especially B2B) requiring modernization or refurbishment of previously acquired products (30 years in use) or 'often' changes in aesthetics. 2nd or further lives: customer segments interested in 'greener choices' (e.g., public procurement). | Lack of solutions for life-extension; 'real' product-life shortened—i.e., consumption patterns/use causing inferior longevity (sometimes 6 years) than design specifications (over 20 years) or lack of proper care (maintenance). | Reduce the need to produce new products to fulfil needs, and reduce the need for resources during use. |
| 3—'Best fit/ configuration furniture for social meeting spaces at a 'monthly maintenance budget.' | 3—Access-based solution (use-oriented PSS) | Own reverse operations (e.g., reprocess, refurbish for reuse in a new contract) | Customer segments (especially B2G) requiring solutions with lower up-front investment; available budget for maintenance or operational expenses. Or, customer segments (B2C) requiring changes in aesthetics. | 'Real' product-life shortened—i.e., consumption patterns/use causing inferior longevity (sometimes 6 years) than design specifications (over 20 years). | Reduce the need to produce new products to fulfil needs. |

Configuration 2 (Figure 5) targets B2G customers with restrictions on their investment budget. Customers could benefit from obtaining the use of furniture or urban spaces solutions in a lease scheme. This solution would include continuous maintenance services from Vestre, as well as take-back at the end-of-contract. Additional new operational capabilities are required for this configuration (detailed in Supplementary Materials: Figure S3). For value creation and delivery, beyond the new capabilities previously mentioned for configuration 1, Vestre will have to review its sales model and create standard contracts with service level agreements.

During the third workshop, Vestre applied Module 4 to evaluate the potential outcomes of the proposed PSS BM concepts (Tables 4 and 5).

Although the *resource decoupling potential* and *business profitability* for configuration 1 (Table 4) showed positive results, some improvement opportunities were identified as a means to mitigate the risks for the BM concept regarding the fulfillment of customer value, the avoidance of rebound effects and burden shifting for other life-cycle stages, and the existence of favorable upscaling conditions.

The mitigation actions would rely on establishing collaborative/strategic partnerships, as well as reviewing considerations (trade-offs) for product design and pricing strategies.

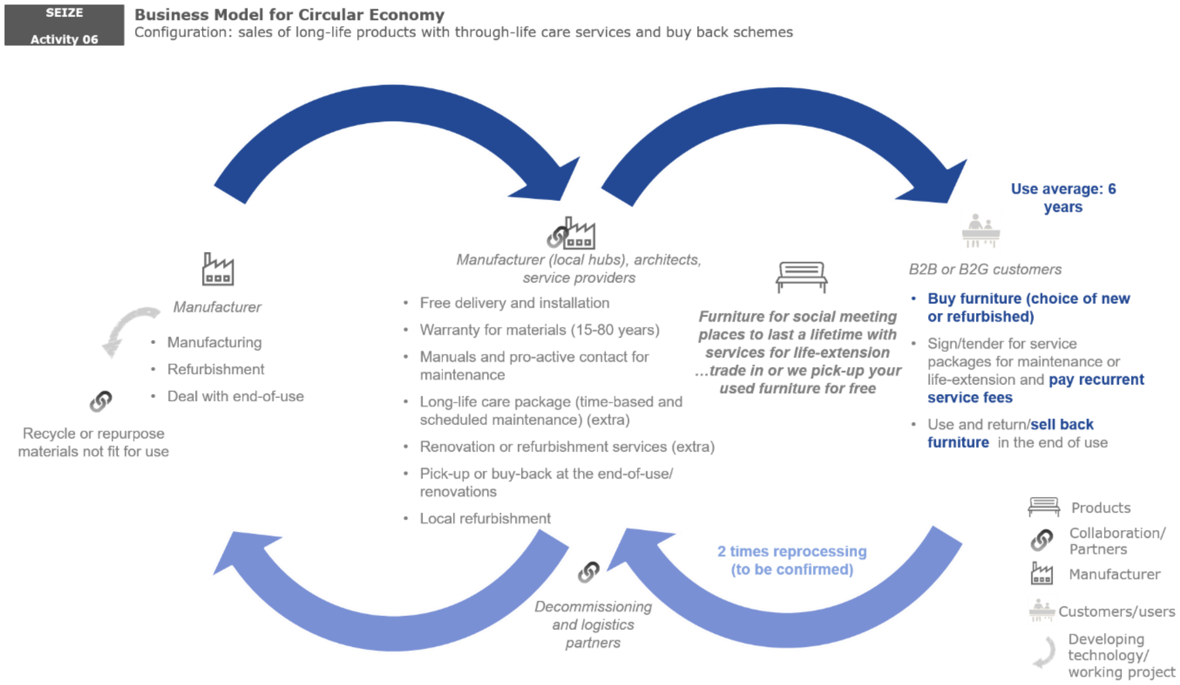


**Figure 4.** Value exchanged among actors in Vestre's BM configuration 1 (from BM idea 1).

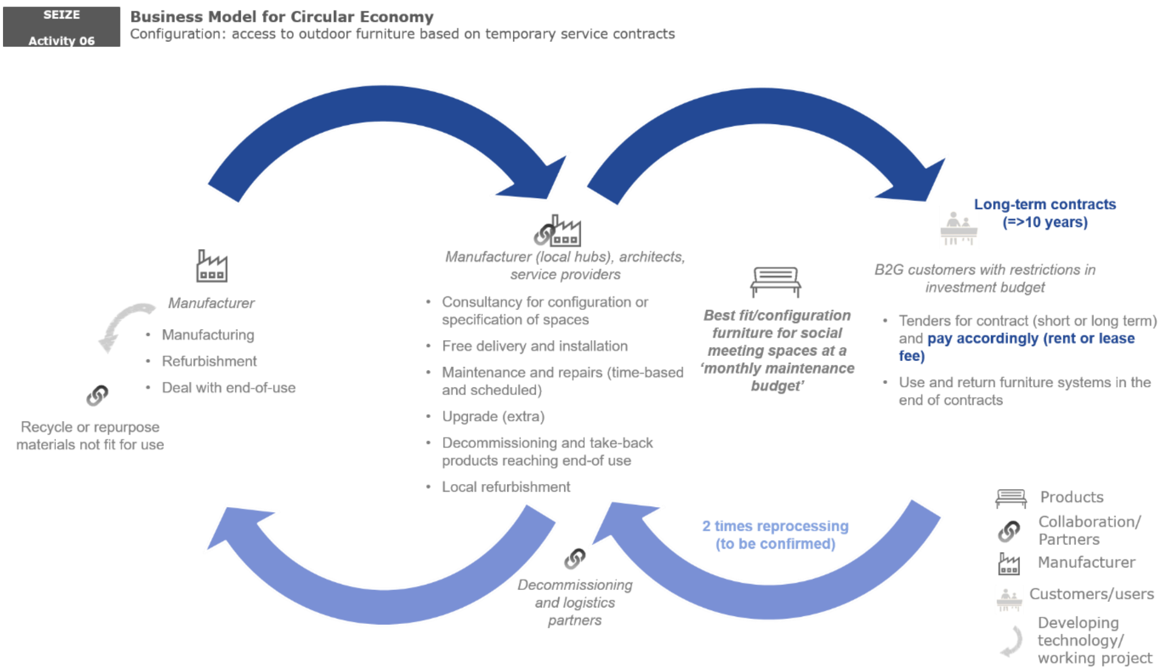


**Figure 5.** Value exchanged among actors in Vestre's BM configuration 2 (from BM idea 3).

**Table 4.** Potential CE outcomes for Vestre's BM Concept 1. Legend: Dark circle—Requirement is fulfilled; Partial dark circle—Require further investigation or mitigation; Clear circle—Requirement is not fulfilled (developed from Kjær et al. [17], Kravchenko et al. [58], Pieroni et al. [9]).

| **PSS BM concept 1.** | **Sales of long-life outdoor furniture with through-life care services and buy-back schemes.** | |
|---|---|---|
| **Segment/customers** | **B2B and B2G** | |
| | **Requirement is fulfilled when …** | **Results:** |
| PSS → Economic growth | | |
| Ensure acceptable net profit ● | … profit enabled by new BM concept > = (at least equal to) long-term profit of current business model. | Return on investment, net present value and profit margins (including profit per asset/product) for different buy-back fees and an average of substitution were calculated. This helped to adjust a feasible price for products or services contracts to enable comparable profitability to current BM (in the long term). Pricing definition also took into consideration customer needs/expectations. |
| Foresee and mitigate investment requirements ● | … breakeven of the new BM concept occurs in an acceptable period for the company, and if external financing capital is necessary it is also available. | The concept presented an acceptable pay-back period for the company (around 6 years), but estimated costs have to be reviewed after negotiation with partners. |
| Adjust for and mitigate upscaling challenges ◐ | … volume of returning products (for recirculation) justifies/pays off the required investments. This involves dealing with economies of scale. | The volume of returning products is small to justify investments in refurbishing facilities. *Mitigation:* outsource or find local partners with the appropriate capabilities/techniques. |
| PSS → Superior customer value | | |
| Ensure added benefits and avoid or mitigate sacrifices ◐ | … added benefits for customers > (are perceived as higher than) added sacrifices in relation to current BM. | Considered added benefits: environmental conscious/compliant option for end-of-use; convenience to 'get rid of old furniture' at the end of use; lower controlled maintenance costs; affordable option/lower investment. Sacrifices: in the case of B2G, it could be complex to convince subcontractors to sort specific furniture from the projects (in the case of renovations) to take back. *Mitigation:* establish partnerships and implement attractive buy-back. |
| PSS → Absolute resource decoupling (effectiveness and efficiency) | | |
| Ensure net resource reduction ● | … resources needed for needs fulfilment without subscription > (are higher than) resources needed for needs fulfilment with subscription. | 7–28% potential resource reduction (calculated with indicators utility and longevity [1]; due to life-extension and no need to produce new products). |
| Avoid burden shifting between life cycle stages ◐ | … "additional resources are not required during production and end of life." | The furniture needs to be designed for easy disassembly. This could have an effect on durability. |
| Mitigate rebound effects ◐ | … "value-adding low-resource intensive services mitigate or exceed any potential costs-savings." | Rebound with the increased demand for resources could occur either if 2nd life furniture (refurbished or remanufactured) is perceived as of inferior functionality or if it is priced lower when compared to new ones [60]. In the discussed BM concepts, price differentiation was considered. *Mitigation:* prices should be equalized in the long term. |

[1] Calculation of indicators 'Utility' and 'Longevity' based on Azevedo et al. [59] and Franklin-Johnson et al. [61].

Configuration 2 (Table 5) fulfils more conditions than configuration 1 (Table 4). However, it is limited to a 'niche' customer segment, represented by specific municipalities with restrictions in investment budget. Moreover, the risks for implementing this configuration are higher than in configuration 1 and, likewise, the effort for executing the mitigation plans is also higher. For instance, in addition to the facilities for reprocessing taken-back furniture, configuration 2 would require hiring and training technicians or a local network of service providers responsible for the installation and maintenance. Additionally, from previous experience and initial experiments with this type of business model, Vestre identified that reconsiderations of product design would be necessary to adapt products for easy assembly and in loco customizations (i.e., different urban landscape projects require adaptations in the installation procedures and slight modifications/adaptations of the products in loco).

**Table 5.** Potential CE outcomes for Vestre's BM Concept 2. Legend: Dark circle—Requirement is fulfilled; Partial dark circle—Require further investigation or mitigation; Clear circle—Requirement is not fulfilled (developed from Kjær et al. [17], Kravchenko et al. [58], Pieroni et al. [9]).

| **PSS BM concept 2** | **Access to outdoor furniture based on temporary service contracts.** | |
|---|---|---|
| **Segment/customers** | **B2G customers with restrictions in the investment budget**<br>**B2C customers with short-term projects or temporary spaces** | |
| | **Requirement is fulfilled when ...** | **Results:** |
| PSS → Economic growth | | |
| Ensure acceptable net profit ● | ... profit enabled by new BM concept > = (at least equal to) long-term profit of current business model. | Return on investment, net present value and profit margins (including profit per asset/product) for different contract periods and prices were calculated. This helped to adjust a feasible price for services contracts to enable comparable profitability to current BM (in the long term). Pricing definition also took into consideration customer needs/expectations. |
| Foresee and mitigate investment requirements ● | ... breakeven of the new BM concept occurs in an acceptable period for the company, and if external financing capital is necessary it is also available. | The concept presented delayed pay-back period (around 9 years).<br>*Mitigation*: the company would self-finance initial projects for strategic purposes. |
| Adjust for and mitigate upscaling challenges ◐ | ... volume of returning products (for recirculation) justifies/pays off the required investments. This involves dealing with economies of scale. | The volume of returning products is small to justify investments in refurbishing facilities during the beginning of the implementation.<br>*Mitigation:* outsource or find local partners with the appropriate capabilities/techniques. |
| PSS → Superior customer value | | |
| Ensure added benefits and avoid or mitigate sacrifices ● | ... added benefits for customers > (are perceived as higher than) added sacrifices in relation to current BM. | Considered added benefits: lower upfront investment; more value received to money; convenience; environmental conscious/compliant option for end-of-use.<br>Sacrifices: binding of 10-year contract (should not be critical). |
| PSS → Absolute resource decoupling (effectiveness and efficiency) | | |
| Ensure net resource reduction ● | ... resources needed for needs fulfilment without subscription > (are higher than) resources needed for needs fulfilment with subscription. | 14–28% potential resource reduction (calculated with indicators utility and longevity [1]; due to life-extension and no need to produce new products). |
| Avoid burden shifting between life cycle stages ◐ | "additional resources are not required for production/end-of-life." | The furniture needs to be designed for easy disassembly. This could affect durability. |
| Mitigate rebound effects ● | "value-adding low-resource intensive services mitigate or exceed any potential costs-savings." | By not having the upfront investment, customers could spend these savings with other resources.<br>In the case of B2G, this is considered as a mitigated risk since they are already with 'limited budget for investment' upfront. |

[1] Calculation of indicators 'Utility' and 'Longevity' based on Azevedo et al. [49] and Franklin-Johnson et al. [51], respectively.

After analyzing the assessments, Vestre discussed how to work with both models in parallel to suit different customer segments, but without cannibalizing each other. They also discussed that configuration 1 should be the target for dissemination in the case that cannibalization is inevitable, mainly taking into consideration the market representativeness of customer segments.

## 4. Discussion

This section summarizes the results obtained with the application of the CE-oriented BMI Process and the CE-Driven BM Configurator to create PSS business model concepts for CE and discusses key findings in light of previous literature.

The focus of this article was to demonstrate how the application of the CE-Driven BM Configurator supported two Nordic furniture manufacturers in configuring (i.e., designing and assessing) PSS business models for CE. From a usefulness perspective, the CE-Driven BM Configurator showed positive results, supporting the manufacturers with fast ideation and simulation workshops providing knowledge about CE and PSS from external sources in an interactive and focused process. Formal feedback provided by individual participants in questionnaires indicates their satisfaction with the obtained results, with testimonials indicating that the configurator "made the process easier" and "has clarified and confirmed many choices that have been based on assumptions earlier." According to their opinion, strengths or differentials of the configurator are: "the use of examples from different industries to stimulate ideation," "interesting/great to see more/different cases/examples of companies experimenting with BMs for CE and the information of what works and trade-offs, also showing cases of discontinuation of initiatives." From the usability perspective, although enhancements were incorporated after the first AR, further improvements are required.

The results of this research are consistent with findings of previous literature [38,39], confirming common barriers or favorable conditions for the implementation of circular economy-oriented PSS in the furniture sector. The *common barriers* were:

- Breakeven delays with negative initial cash flow for access or use-oriented (pay-per-use or leasing) PSS (AR A and B) [38];
- Customer requirement of all-inclusive furniture portfolio/solutions (AR A) [39];
- Long usage time and technical simplicity of office furniture (AR A and B) [39];
- Applicability in regions where customers are geographically widespread (AR A) [39].

The common favorable conditions were:

- Potential customers are likely to be companies that have a lot of short-term project work (AR A) [39];
- Additional services could help improve the attractiveness of the PSS scenario to lock in customers (AR A and B—see Tables 1 and 3) [39].

Despite supporting some arguments from previous research, our findings show some nuanced positions. First, regarding market conditions and legislative/environmental practices identified by Besch [39], which reported a lack of willingness from customers to pay premium prices for environmentally superior products or services, and a lack of attention from manufacturers and incentives in the means of legislation. Fourteen years later since the application of the aforementioned research, this scenario seems to have changed as the companies in the AR cycles were motivated by a larger appeal for or pro-active requirement of environmentally friendly solutions coming from public procurement and customers. Although legislation is still lagging behind, environmental practices and public policies seem to be advancing, at least in the Nordic context.

Moreover, this research contributes to the literature by showing another approach for servitization in the context of CE than that commonly discussed in previous literature [6,15,38], which addresses the occurrence of product development initiatives for CE concurrently with the business model development of PSS. The manufacturers participating in the AR cycles of this research opted for configuring new PSS BMs with existing products, because they already presented characteristics in fit with CE (i.e., modularity for the case of Ope and durability for the case of Vestre). However, minor changes on the product are inevitable, as identified in previous research from the PSS [62] or CE [9,63] fields. Considerations regarding product design/development were triggered during the BM design process, which confirms the potential of the process model and the configurator in eliciting interdependencies with other business processes.

In addition to the confirmation or nuances with respect to previous literature, this research led to the identification of two additional key findings:

*Finding 1: The configuration of PSS business models should fulfil certain conditions (summarized in Figure 6) to contribute to circular economy and qualify as 'CE-Oriented PSS'.*

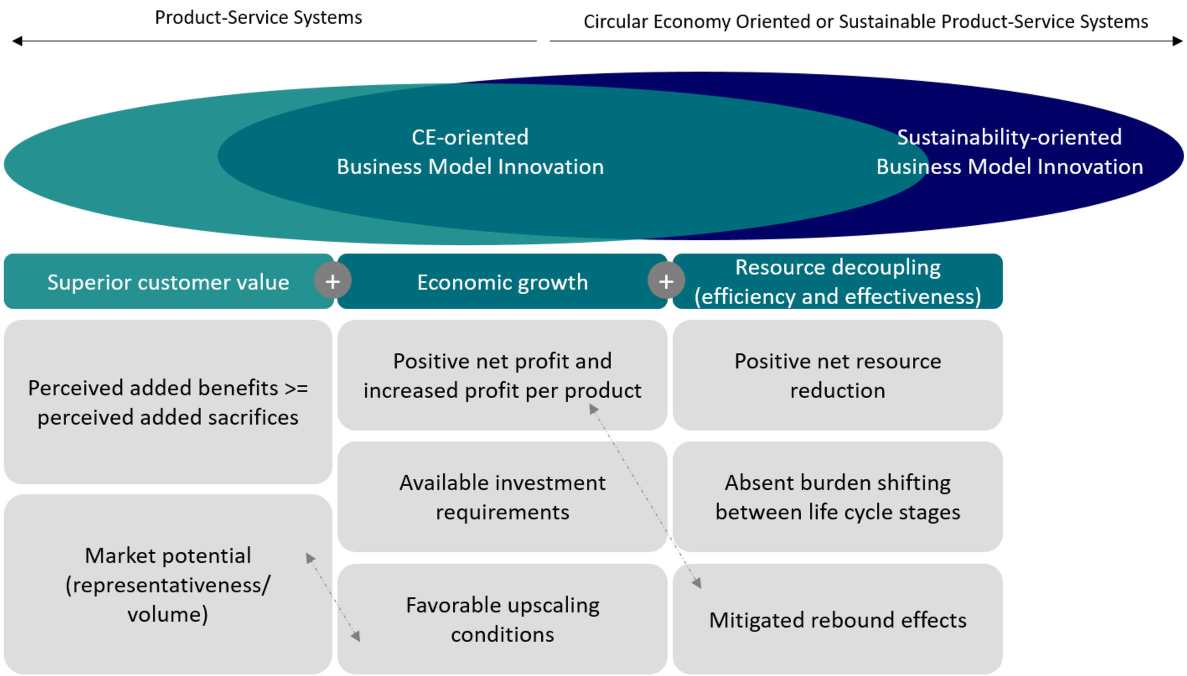


**Figure 6.** Conditions for creating 'CE-Oriented BMs based on PSS' (developed from Kjær et al. [15] and Pieroni et al. [6]).

As exemplified in the AR cycles, the configuration of CE-Oriented PSS business models involves identifying sources of structural waste in the current configurations, occurring simultaneously to new (and synergistic) customer needs, and being able to generate positive economic results for the company. The application of the framework (Figure 6) to assess the proposed PSS BM concepts demonstrated that trade-offs in the conditions are inevitable (indicated by dotted arrows), and that their reconsideration and balance can lead to the improvement of the circularity potential. For instance, environmental rebound effects (e.g., increased demand or consumption) can be mitigated by changes in the pricing strategy; or favorable upscaling conditions (i.e., existing infrastructure or possibility to invest on creating or accessing collection points, reverse logistics, or reprocessing facilities for the products and materials) can be facilitated by the correct selection of a market segment. One can argue that applying higher prices for avoiding rebound effects could bring difficulties for the company to withstand competition. Nevertheless, the additional perceived value enabled by the CE-offerings (i.e., new services) and changing customers' preferences towards sustainable solutions (e.g., in the case of Vestre, customers from the public sector were requiring ecofriendly solutions and willing to pay slightly more for it) could successfully compensate this.

*Finding 2: CE-Oriented PSS BMs are often (but not exclusively) 'niche solutions' in the sense that they fulfil very specific needs and customer segments, and are more likely to succeed with certain types of products or geographical locations.*

This finding could be considered a consequence of finding 1, which imposes many conditions to fulfil the three expected outcomes of CE. In Ope, *finding 2* was observed in the selection of a new product (or portfolio of products), a new customer segment (i.e., events participants and venue owners), and a delimited geographical region (i.e., large capitals) after the assessment of the PSS BM concept. 'AR cycle B' in Vestre also supported this finding, with the identification of a specific category of products (e.g., free-standing) for 'PSS BM Concept A.' Conclusions from Besch [39] about 'renting' BM concepts for office furniture also support *finding 2*. Moreover, other PSS BM concepts disseminated as good examples of CE initiatives in other sectors related to capital goods (e.g., Phillips Pay-Per-Lux [64]; Rolls Royce's Power-by-the-hour [65]) also support this finding, with the existence of 'one-of-its-kind' service contracts tailored for specific customers (e.g., Schiphol Airport [64]; Airbus or Boeing [65]) that represent a large revenue volume. Based on this finding, another condition was added to the category 'superior customer value' on top of the one evaluated in the case companies. This condition, entitled 'Market Potential,' is related to the existence of representativeness of a customer in terms of generated revenues (e.g., large contracts) or enough volume of several potential interested customers.

A final consideration is related to the decision-makers' choices for selecting ideas for new CE-oriented BM PSS. The case companies decided to implement less-complex CE-oriented BMs (sometimes with fewer environmental gains) as a way of seizing immediate results and being able to communicate their success in the short term. Two main reasons justified their decisions. First, the new capabilities required by these solutions would be realistic to achieve, despite already challenging for their context. Additionally, a successful implementation of these concepts could work as 'steppingstones' and help in convincing internal (e.g., sponsors and board members) or external actors (e.g., new investors, suppliers, new partners in the value chain, customers) that CE-oriented BMs can generate business results or additional value, and are worth expanding into more sophisticated solutions. Despite the fact that the CE-Driven BM Configurator offers a broad range of solution patterns (i.e., from more simplistic to more complex configurations) to prompt ideation, the decision-makers' ambitions in embedding CE principles to their BMs are key factors influencing or limiting the achievement of impactful environmental and economic outcomes [9,66]. This reinforces that the transition to CE through new business models is a learning process [67], which will require more than a tool, but a holistic and systemic approach of continuous change [9]. The CE-Oriented Business Model Innovation Process (Figure 1) [23] can support this aspect with an organizational framework to plan for continuous adaptation and change, instead of only treating innovation for CE as a 'single-shot' event.

## 5. Conclusions

This research aimed to guide organizations in configuring business model concepts for circular economy through the PSS approach. By means of action research, this article illustrated how PSS business model concepts for CE were designed and assessed by two Nordic furniture manufacturers with the application of a previously proposed conceptual process model and its main accompanying tool, the CE-Driven Business Model Configurator (documented in [3]).

Results demonstrate a positive uptake by the companies regarding the obtained outcomes. Based on the analysis of the research outcomes, two key findings regarding the configuration of CE-Oriented PSS business models were identified: (i) *the configuration of PSS business models should fulfil certain conditions to contribute to circular economy and qualify as 'CE-Oriented/Eco-PSS business models'*; and *(ii) CE-Oriented PSS BMs are often (but not exclusively) 'niche solutions' in the sense that they fulfil very specific needs and customer segments, and are more likely to succeed with certain types of products or geographical locations.* Connected to our first key findings, our key contribution is consolidated in a framework to support identifying *conditions for configuring 'CE-Oriented PSS business models.'*

This research contributes to the academic community in the intersection of business model innovation, PSS and CE. Building on previous research, it advances knowledge about when (or under which conditions) PSS can lead to enhanced circularity. Regarding practical contributions, this research and, especially the CE-Driven BM Configurator, provides a solution for fast modelling and simulations of scenarios of different CE-oriented BM concepts based on PSS. This can benefit manufacturing companies that are planning to engage in CE through means of PSS and need to define where and how to start. Moreover, since the tool incorporates the learnings from the two aforementioned key findings, it can help manufacturing companies to focus on problem-solving for CE, instead of only trying out any type of PSS concept (which are not necessarily impactful for CE). In its current version, the configurator is limited to six industry sectors (i.e., agriculture and food, heavy machinery, electronics, furniture, medical devices, and textile); however it could be updated following the same procedure described in Section 2.2 to incorporate new sectors or even a generic version (i.e., with a trade-off of losing the sectorial specificity and level of details). The configurator is flexible in terms of customers segments, varying according to the predominance of success cases in each specific sector. In the furniture sector, for instance, the generated business model concepts could be applied for B2B, B2C, or B2G.

The key limitations of this research are the sample (i.e., number of companies) and time constraints for the generalization of assumption/verification of the long-term success of CE-Oriented PSS BM concepts. Future empirical work is required to test the findings with a broader group of manufacturing companies in different organizational contexts and industry sectors. Moreover, as both companies will continue to conduct additional experiments with the initially developed PSS BM concepts, adjustments and/or the selection of new concepts might occur. After further investigations, for instance, Ope has decided not to focus on the 'event solutions' since it would demand a complex system in terms of number of product components and add-on features to offer the expected complete solution. As an alternative, Ope is experimenting with another use-oriented PSS BM concept (i.e., modular furniture systems in a leasing scheme) for two active customers. Hence, a new round of interviews with the companies is required to explore how the CE-Driven BM Configurator can contribute to the implementation stage of the business model concepts. Lastly, the CE-Driven BM Configurator still requires further development (e.g., a more flexible/dynamic software; adjustment in the level of information in the design options; refinement in the logic of suggestion of patterns configurations).

**Supplementary Materials:** The following are available online at http://www.mdpi.com/2071-1050/11/13/3727/s1, Table S1: cases for the Furniture sector embedded in the CE-Driven Business Model Configurator, Figure S1: CE-oriented PSS BM concept for Ope, Figure S2: CE-oriented PSS BM concept for Vestre, configuration 1, Figure S3: CE-oriented PSS BM concept for Vestre, configuration 2.

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# Appended Publication 6

Pieroni, M.P.P., McAloone, T.C., Borgianni, Y., Maccioni, L, Pigosso, D.C.A. (2020), “An expert system for Circular Economy business modelling: advising manufacturing companies in decoupling value creation from resource consumption”, (Manuscript under review at Journal of Cleaner Production).

# An expert system for circular economy business modelling: advising manufacturing companies in decoupling value creation from resource consumption

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**Abstract:** Shortcomings in manufacturing companies' capabilities to execute circular economy business modelling have delayed a broader dissemination of circular business models beyond the stage of pilot projects in niche markets. Circular economy poses additional uncertainties for innovation that are not common for manufacturing companies' traditional activities and business as usual. To cope with such challenges, they lack systematised practices and proactive advice, which are scant in available literature and approaches. The paper presents the development of an expert system for circular economy business modelling within manufacturing companies, intended to address these limitations. Based on systematised business modelling practices for circular economy and proactive advice on potential circular business model configurations, the expert system enhances strategic thinking for circular economy, supporting companies to come up with varied alternative business models with reasonable and viable value propositions to deploy circular benefits accordingly. The expert system was streamlined based on literature review, development, testing and evaluation with 12 practitioners from 10 companies. The paper discusses the main functionalities of the expert system and the results of its application into varied manufacturing companies. The application of the expert system has demonstrated to benefit companies with: inspiration for best practices on circular business modelling, a structured framework for confirming assumptions and a logic structure that prompts decision-making and reduces uncertainties.

**Key-words:** circular economy, sustainability, business model, innovation, tool

**Acronyms**

| | |
|---|---|
| AR | Action research |
| BM | Business model |
| BMI | Business model innovation |
| CE | Circular economy |
| CEBMI | Circular economy business model innovation |
| CEBM | Circular economy business model |
| CEBMn | Circular economy business modelling |
| CEBMES | Circular economy business modelling expert system |
| CO | Configuration option |
| DS-I | Descriptive study I |
| DS-II | Descriptive study II |
| ES | Expert system |
| Pc | Performance criteria |
| PC | Principal Component |
| PCA | Principal Component Analysis |
| PS | Prescriptive study |
| RC | Research clarification |
| SLR | Systematic literature review |
| SME | Small and medium enterprises |

## 1. Introduction

Circular economy (CE)[1] promises to slow down the exploitation of resources to respect Earth's capacity, whilst enabling economic development. By promoting a vision of decoupling resource consumption from value creation, CE can contribute to a series of goals related to the green transition (e.g. the European Green Deal) and sustainable development (e.g. achievement of Sustainable Development Goals) (European Commission, 2019; Schroeder et al., 2019).

CE implementation requires fundamental changes in the societal, industrial and consumption foundations (Böhringer and Rutherford, 2015). Manufacturing companies have a driving role in CE implementation due to their influence in the definition of value offerings and products' life cycles (Blomsma et al., 2019; Lieder and Rashid, 2016; McAloone and Bey, 2009). To be able to achieve ambitious targets, companies will need to innovate their business models (BM) for CE, to promote disruptive changes able to generate higher impact, as opposed to acting solely on reactive and end-of-life strategies (e.g. recycling).

CE business models (CEBMs) have hitherto limited penetration within the manufacturing sector and are still covering a niche market (OECD, 2018). CEBMs are currently only at a pilot level in the manufacturing industry. There is a need to systemically align CEBMs with the manufacturing companies' core corporate strategies to reach all the potential benefits (Khan et al., 2020; Urbinati et al., 2017).

Several external barriers have contributed to this limited dissemination of CEBMs (e.g. customers' preferences for 'new' products, regulatory restrictions, lack of infrastructure) (de Jesus and Mendonça, 2018; Kirchherr et al., 2018; OECD, 2018). Shortcomings in manufacturing companies' capabilities and skills to execute CEBMI are within the most relevant bottlenecks (Bocken and Geradts, 2019; Chiappetta Jabbour et al., 2019; De los Rios and Charnley, 2017; Guldmann and Huulgaard, 2020; Khan et al., 2020; Kirchherr et al., 2018). CEBM innovation (CEBMI) comprises the process of designing CEBMs (e.g. finding opportunities, configuring and implementing viable and promising CEBMs), influencing aspects (e.g. transformation, ecosystem), and outcomes (i.e. the innovative CEBMs) (Foss and Saebi, 2017). The process of designing CEBMs is called CE business modelling (CEBMn) in this paper, and deals with elements such as activities, methods and tools to promote innovation within organisations (Bocken et al., 2013; Rohrbeck et al., 2013). Manufacturing companies require knowledge and science-based approaches to conduct CEBMn (Bocken and Geradts, 2019; Khan et al., 2020; Lieder and Rashid, 2016), since designing CEBMs lead to additional uncertainties when compared to traditional BMs, such as changes in financial value creation and enhanced operations complexity (Bocken et al., 2018; Lieder and Rashid, 2016).

CEBMI body of knowledge is still in a conceptualisation stage and is characterised by fragmented and sometimes incongruent literature (Merli et al., 2018; Nußholz, 2017; Pieroni et al., 2019a). The field has developed so far with seminal publications arguing for the relevance of the topic (Linder and Williander, 2017) or outlining the concept (Nußholz, 2017). Some publications have focused on the development of approaches (i.e. methods/tools) to support companies with CEBMn. However, such approaches are still immature and present challenges for practical application (Bocken et al., 2019; Khan et al., 2020; Pieroni et al., 2019a). For example, they are still scattered and lack systematisation of managerial practices in a holistic structure (i.e. set of management activities to support the execution of a business process with varied methods and tools). In particular, they have an atomistic discussion level with focus on the early development stages of CEBMs in detriment of processes that cover all innovation stages from ideation to implementation. Moreover, existing approaches lack support to enable companies to cope with increased uncertainties of CEBMn, since they are heavily based on abstract workshop-based tools and activities, thus hindering documentation, iterations and repeatability of the CEBMn process. Additionally, analytical and decision-support activities are not explicitly considered (Ünal et al., 2019b). Finally, CEBMn approaches remain conceptual and essentially descriptive, with limited empirical demonstration and limited potential to offer advice for independent application by practitioners (Bocken et al., 2019; Kirchherr and van Santen, 2019; Lieder and Rashid, 2016; Pieroni et al., 2019a).

In summary, to bridge the existing gap between scientific knowledge and action (Lüdeke-Freund et al., 2019), CEBMn approaches need to provide systematised knowledge and proactive advice to companies. The objective of this paper is to develop a tool for CEBMn within manufacturing companies. Based on systematised CEBMn practices and proactive advice on CEBM alternatives, the tool aims to enhance *strategic thinking for CE* by supporting companies to come up with varied alternative CEBMs. Those are to be featured by reasonable and viable value propositions to deploy CE benefits (e.g. long-term value creation and resource consumption reduction) according to companies' sector and other contextual factors.

The tool was developed in the format of an expert system (ES). An ES uses databases of expert knowledge to offer advice and decision-making support in specific areas (Liao, 2005). Similar to a human consultant, an ES can also contextualise and explain the advice provided. Usually presented as a computer-based system (or software), an ES is designed to simulate the decision-making ability of a human expert to solve complex organisational problems by reasoning through bodies of knowledge (Liao, 2005).

ES's have been used successfully in diverse domains and for multiple purposes ranging from Medicine (supporting medical planning/diagnosis) to Management (supporting decision-making in complex organisational problems) (Liao, 2005). Beyond the varied types of applications, multiple methodologies are available as a means to underpin the development of ES's. For example, Im and Cho (2013) proposed an ES based on morphological analysis and integrated fuzzy approach to support companies with developing, evaluating and selecting BMs to meet their business objectives. However, this approach was limited to traditional business modelling and lacks CE focus, which is, conversely, explicitly targeted in this research.

This paper focuses on illustrating how the ES for CEBMn (CEBMES) was (i) conceptualised (i.e. based on previously systematised CEBMn practices and proactive advice that serve as foundations for the ES) and (ii) thoroughly evaluated regarding its applicability and usefulness within manufacturing companies.

The paper describes the research methodology (Section 2), the proposed CEBMES with its elements (section 3) and the evaluation results of its application within manufacturing companies (section 4). Finally, section 5 discusses the applicability, limitations, contributions, and future research possibilities.

## 2. Research Methodology

This section introduces the foundations for this research (section 2.1) and explains the approach and methods (section 2.2).

### 2.1. Conceptual and empirical foundations

The conceptualisation of the CEBMES relied on the identification of: (i) previously systematised CEBMn practices and (ii) proactive advice that can serve as content for the ES. The paper builds on CEBMn frameworks previously developed by the authors. They were selected as foundations due to their enhanced methodological robustness that included detailed studies with complete evaluations across a considerable number of manufacturing companies, which is superior than most approaches available in CEBMI field (Bocken et al., 2019; Kirchherr and van Santen, 2019; Rosa et al., 2019). These frameworks are:

(i) *CEBMn process model* (Pieroni et al., 2019b): developed from systematisation of CEBMn practices from literature and testing with seven companies through action research (A-G in Table 2). The practices comprised by the CEBMn process include 14 deliverables (e.g. CEBMI opportunities, CEBM ideas), 14 activities (e.g. map CE characteristics in current BMs and estimate circularity potential), 8 decision gates (e.g. screen value propositions according to CE gains), 10 change enablers/catalysers (e.g. ability/willingness to question linear dogmas) and 14 tools (e.g. Circular Strategies Scanner, SWOT). These practices were used as foundations for the deployment of the modules and steps of the CEBMES (explained in section 3).

(ii) *CEBM patterns* (Pieroni et al., in review): developed from multidimensional scaling analysis (Amshoff et al., 2015) of 180 cases of companies that implemented CEBMs. Moreover, they were complemented by insights from industrial experts (companies H-P in Table 2). The patterns were used in the CEBMES as a means to provide advice about possible configurations of CEBM for different contexts and sectors (explained in section 3).

The following section 2.2 explains how these frameworks were employed for developing the CEBMES.

## 2.2. Research approach and methods

The research approach adopted was the Design Research Methodology (Blessing and Chakrabarti, 2009) and comprised four stages (Figure 1).

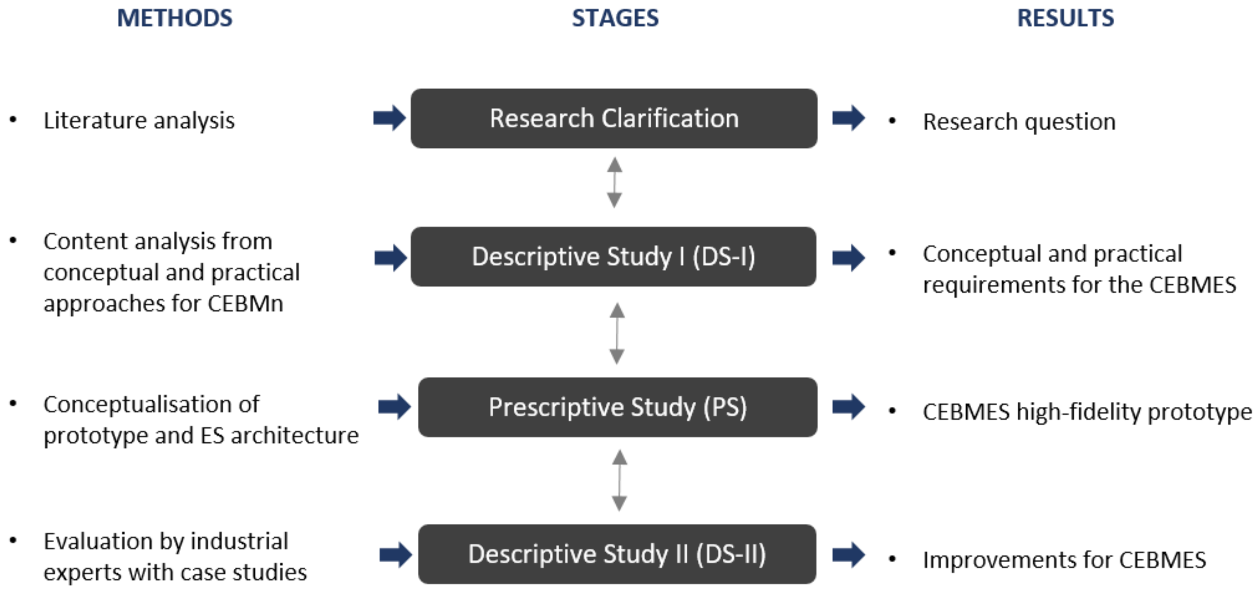



Figure 1 - Research approach.

### 2.2.1. Research Clarification (RC)

RC identified the research gap which is the lack of a structured approach able to provide guidance and advice to manufacturing companies for CEBMn, beyond the level of ad hoc workshops and discussions of existing tools. This gap led to the need for scientific investigation in the format of a research question: *How can an expert system be developed to provide advice to manufacturing companies on CEBMn?*

### 2.2.2. Descriptive Study I (DS-I)

DS-I identified/prepared the foundations to build the CEBMES. First, 21 conceptual and practical development requirements were compiled (Pieroni et al., 2020). Conceptual requirements (R1-R11 in Table 1) were collected based on content analysis (Dresch et al., 2015) from previous systematic literature reviews about best practice CEBMI (i.e. including CEBMn) methods/tools; gaps of methods/tools in providing advice to companies; and recommendations for developing new methods/tools (Bocken et al., 2019; Pieroni et al., 2019a; Rosa et al., 2019). Practical requirements (R12-R21 in Table 1) were collected from a previous detailed practical study that applied the CEBMn process model (section 2.1) with seven manufacturing companies from varied sectors (Table 2) (documented in P.P. Pieroni et al. (2019b)). The conceptual/practical requirements were prioritised in 'must-be' or ‘attractive’ depending on their degree of importance according to literature and users (companies A-G in Table 2) (Kano et al., 1984).

DS-I also envisioned the identification of foundations for the CEBMES development, i.e., the CEBMn Process Model and CEBM Patterns (explained in section 2.1). Table 1 illustrates how these frameworks fulfil the requirements for the CEBMES development, and highlights which requirements will be created/enhanced by functions developed within the CEBMES.

Table 1 - Requirements for the CEBMES. Adapted from Pieroni et al. (2020).

| Code | Requirements | Relevance | Fulfilment of requirements | | |
|---|---|---|---|---|---|
| | | | CEBMn Process model | CEBM Patterns | Created/ enhanced by CEBMES |
| R1 | Simple and not too time-consuming | Attractive | | | ✓ |
| R2 | Enables adaptations to different contexts | Must-be | ✓ | ✓ | |
| R3 | Provides advice – i.e. prescriptive tool | Must-be | | ✓ | ✓ |
| R4 | Provides a transparent procedure and application guidance | Must-be | ✓ | | ✓ |
| R5 | Enables low requirement of external facilitation - i.e. knowledge embedded in the tool | Attractive | | | ✓ |
| R8 | Inspires/triggers business change | Must-be | ✓ | | |
| R9 | Safeguards CE or broader sustainability objectives | Must-be | ✓ | ✓ | ✓ |
| R10 | Guides ideation with different types of CEBMs | Must-be | ✓ | ✓ | ✓ |
| R11 | Envisions all elements of a BM | Must-be | | ✓ | |
| R12 | Supports decision-making with focus on business value – i.e. quantification of economic/resource decoupling gains | Must-be | ✓ | | ✓ |
| R13 | Enables a holistic approach - i.e. from design to implementation | Must-be | ✓ | | ✓ |
| R14 | Provides suggestions to inspire new CEBMs with cases | Attractive | | ✓ | |
| R15 | Focuses on specific sectors | Must-be | | ✓ | |
| R16 | Supports a logic flow of decisions | Must-be | ✓ | | ✓ |
| R17 | Supports communication and teamwork | Must-be | | | ✓ |
| R18 | Considers the ecosystem and collaborations | Attractive | | ✓ | |
| R19 | The value proposition definition follows an iterative process with explicit guidelines | Attractive | ✓ | | |
| R20 | Enables comparison of CEBMs | Attractive | | | ✓ |
| R21 | Enables a repeating process, with data storage and migration | Attractive | | | ✓ |

### 2.2.3. Prescriptive Study (PS)

Based on the requirements, key CEBMES' functions were identified and organised according to an overall architecture by describing:

(i) Specific modules and steps - i.e. what users need to accomplish;
(ii) Functionalities - i.e. what the ES can do for users to support them with the steps within the ES modules;
(iii) Logic and content for the different levels of information - i.e. front-end, back-end and databases.

The architecture was deployed into a high-fidelity prototype hosted on a spreadsheets software.

### 2.2.4. Descriptive Study II (DS-II)

DS-II evaluated the usefulness/applicability of the CEBMES. Case studies for theory testing with industrial experts were carried in three steps (Dul and Hak, 2008): *case selection; data collection;* and *data analysis.*

*Case selection* comprised manufacturing companies (Table 2) from: (i) varied sectors, (ii) with pre-existing intention to innovate their BMs for CE, and (iii) availability/willingness to provide data as feedback and (iv) to be trained and apply the CEBMES independently. (v) Northern European (i.e. Denmark, Finland, Germany, Iceland, Norway, Sweden) companies (vi) with limited experience in CE were considered to control contextual variations.

*Data collection* occurred during/after the training and independent application of the CEBMES by the companies (approximately six weeks). The collection was based on structured standard questionnaires, which included four-point Likert scale questions and open-ended questions to evaluate 48 performance criteria about the CEBMES and identify company-(e.g. size) and user-related aspects (e.g. self-assessed experience in CE) (Appendix A). To enable triangulation for data consistency (Yin, 2006), an interview to clarify the provided answers was conducted/recorded and documents resulting from the CEBMES application were collected.

*Data analysis* comprised:

*(i)* Histograms with quantitative data about the CEBMES usefulness according to multiple performance criteria;

*(ii)* Statistical analysis to explore the contextual conditions of the companies'/users' characteristics that favoured/disfavoured the application or perception of the CEBMES performance (e.g. willingness to move forward throughout modules). The analysis was limited to Module 1, because the sample of those using the subsequent modules was deemed too restricted to infer considerations (see section 4).

(iii) Content analysis and clustering (Dresch et al., 2015) of qualitative replies obtained from the questionnaire/comments from interviews, including: (a) suggestions of improvements for the CEBMES modules; and (b) comments to support/refute the performance evaluation presented in histograms and correlations with contextual factors.

Table 2 - Companies participating in the research (Legend: SME-Small and Medium Enterprises).

| Company | Sector | Size | Collection of practical requirements | CEBMES evaluation |
|---|---|---|---|---|
| **A** | Electrical/electronic equipment/appliances | SME | ✓ | |
| **B** | Heavy machinery | Large | ✓ | |
| **C** | Furniture | SME | ✓ | ✓ |
| **D** | Electrical/electronic equipment/appliances | SME | ✓ | |
| **E** | Furniture | SME | ✓ | |
| **F** | Textile | SME | ✓ | |
| **G** | Medical devices | Large | ✓ | |
| **H** | Electrical/electronic equipment/appliances | SME | | ✓ |
| **I** | Heavy machinery | SME | | ✓ |
| **J** | Furniture | Large | | ✓ |
| **K** | Furniture | SME | | ✓ |
| **L** | Furniture | SME | | ✓ |
| **M** | Agricultural and food products | Large | | ✓ |
| **N** | Generic (Outdoor goods) | Large | | ✓ |
| **O** | Generic (Outdoor goods) | SME | | ✓ |
| **P** | Generic (Construction) | SME | | ✓ |

## 3. Circular Economy Business Modelling Expert System (CEBMES)

The CEBMES is an ES with a step-by-step approach to support manufacturing companies in designing, configuring and evaluating BM alternatives that, when implemented, will meet business and CE needs. The CEBMES is composed of four modules and seven steps with the objectives:

- *Module 1:* sensing and identifying opportunities for CEBMs (steps 1/2);
- *Module 2:* designing CEBM alternatives (step 3);
- *Module 3:* configuring the detailed elements of CEBM alternatives (step 4);
- *Module 4:* evaluating, selecting and optimising CEBM alternatives based on their economic and resource decoupling potential (steps 5/6/7).

The steps of the CEBMES were deployed from activities embedded on the CEBMn Process Model, to guarantee the full coverage from design to implementation (R13 in Table 1).

Each step correlates with three levels of the ES architecture (Figure 2):

- *Front-end:* spreadsheets/interfaces visible for the users and tailored for each step. Address 14 core functionalities to fulfil 21 requirements (Table 1). In each spreadsheet/interface, user inputs serve as basis for the provision of advices for CEBMn (i.e. outputs).
- *Back-end:* spreadsheets for calculations or knowledge processing to generate advice that emerge as outputs in the front-end. The back-end logic relies on two methodologies (Liao, 2005): (i) rule-based system for Modules 1/4 and (ii) case-based reasoning for Modules 2/3.
- *Databases:* knowledge bases that provide scientific and empirical foundations about CEBMn to support the generation of advices at the back-end.

The following subsections explain the CEBMES modules, including details of the required steps, functionalities and logic of modules. Additionally, examples of results from applications of the CEBMES in manufacturing companies are provided. The CEBMES is freely accessible from the Technical University of Denmark's (DTU) repository (https://doi.org/10.11583/DTU.11798655).

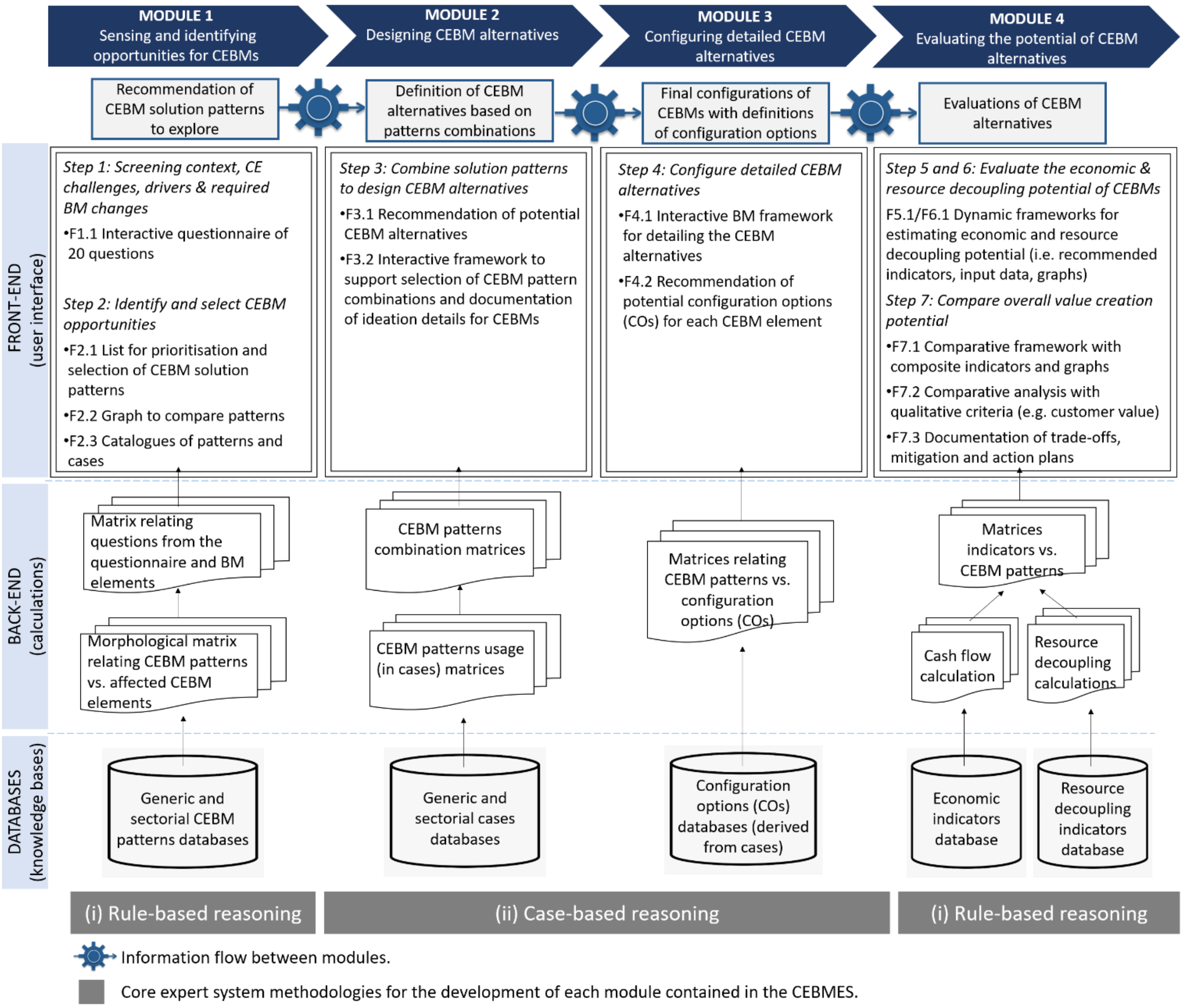


Figure 2 – CEBMES architecture. Adapted from: Pieroni et al. (2020).

### 3.1. Module 1- Sensing and identifying opportunities for CEBMs

This module includes two steps that foresee screening of companies' context, CE challenges and drivers and advice and selection of CEBM opportunities. As outputs, companies obtain the characterisation of their CE challenges (Step 1) and potential opportunities for designing CEBMs (Step 2).

#### 3.1.1. Step 1 – Screening context, CE challenges, drivers and required BM changes

The front-end comprises one core functionality (F1.1): *an interactive and structured questionnaire to support the evaluation of company's context and characterisation of CE challenges and opportunities.* Companies shall answer 20 questions that screen four categories: (i) product and sector of current BM; (ii) challenges and weaknesses of current BM; (iii) trends and drivers for CE; and (iv) strategic intentions with CE and enablers in the company's ecosystem. An example of question in the category (i) is "3 - What is the level of complexity of the offerings, i.e. product or services?". The complete questionnaire can be accessed on the second spreadsheet of the CEBMES.

At the back-end, Module 1 (i.e. Steps 1 and 2) relies on rule-based reasoning to represent information in the form of rules (e.g. IF-THEN) that can be used to process the answers to the questionnaire (Liao, 2005). The set of rules for Step 1 is recorded on a *matrix that relates the answers in the questionnaire with affected BM elements.* This enables the identification of the elements of the company's BM that require changes for CE.

The questions and relationship with changes in BM elements were developed based on previous research that proposed similar screening approaches to characterise existing BMs in companies (Kwon et al., 2019; Remane et al., 2017). They were adapted to the context of CE based on insights identified with the application of CEBMn in companies (A-G in Table 2), e.g. key aspects that drove companies to change their BMs for CE collected through a SWOT analysis and qualitative screening of their circularity based on implemented CE strategies (Blomsma et al., 2019). The CEBMES considers a BM framework that contains 12 elements: overall benefits (i.e. E01-economic, E02-environmental and E03-social); E04-target customers; E05-benefits for customers; offerings (i.e. E06-products and E07-services); E08-revenue mechanisms; E09-value delivery processes; E10-value creation processes; E11-partnerships and collaborations; and E12-benefits for partners (adapted from Kraaijenhagen et al. (2016) and Biloslavo et al. (2018)). For example, question 3 mentioned above affects E06 and E07.

#### 3.1.2. Step 2 - Identify and select CEBM opportunities

The front-end comprises three functionalities:

- F2.1 A list with six *recommended CEBM solution patterns for companies*, based on outputs from Step 1. The CEBM solution patterns represent best-practice configuration alternatives for BMs to solve a specific identified and repeatable CE challenge (Amshoff et al., 2015). Each CEBM pattern is described by name, explanation of the CE challenges and the CEBM solution, inspirational cases, and potential resource decoupling/economic benefits. Companies can use the list to prioritise up to three CEBM patterns for exploration.
- F2.2 A *graph to support companies in comparing/prioritising the six recommended CEBM patterns* according to their adherence to the screening questionnaire (Step 1) and the degree of change promoted in BMs (i.e. from linear to circular).
- F2.3 Access to *the complete database of CEBM patterns*, which contains further detailing and references to original cases.

At the back-end, the CEBMES relies on another *morphological matrix relating CEBM solution patterns with corresponding affected BM elements*. This matrix was developed according to Remane et al. (2017). Based on outputs of Step 1, different BM elements are diagnosed as requiring changes to enhance circularity. Based on these elements, different CEBM patterns can be identified as relevant in the morphological matrix and recommended by the CEBMES (Figure 3).

At the databases level, Step 2 relies on *CEBM solution patterns databases* (development explained in section 2.1 and documented in Pieroni et al. (2020)). The databases are available for four specific manufacturing sectors (i.e. heavy machinery; electrical and electronic equipment and appliances; furniture;

agriculture and food) and in a generic version applicable for any manufacturing sector. The complete list of patterns can be accessed in the CEBMES.

| | Questions | 1 - What the company expects to solve or achieve with circular economy implementation? | | | | | | | ... | 7 - What is the customer's core reason for changing or stopping the use of products? | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Affected BM elements (E) | E02 - Environmental benefits promoted by the BM | | | | | | | ... | E04/E05 - Target customers/ Benefits for customers | | | | |
| **Pattern** | **Code for pattern** | **Absolute decoupling** Strive for 'zero' resource intake | **Narrow or reduce** Optimise and reduce directly resource intake for production or | **Intensify** Reduce product idleness and indirectly resource intake | **Slow or postpone** Extend product lifetime and indirectly resource intake | **Close or recover** Reduce pollution, waste and landfilling | **Multiple effects** | **Not specified or no direct impact on resource decoupling** | ... | **1- Sensible to aesthetics changes** E.g. product becomes old-fashioned | **2- Sensible to technological changes** E.g. product becomes outdated | **3- Seasonal needs** E.g. product becomes small, not necessary | **Multiple effects** | **Not specified or no direct relevance** |
| Collaborative services in sharing or pooling platforms | P6 | | | x | | | | | | x | | x | x | |
| Product as a service in customized temporary contracts | P7 | | | x | | | | | | | x | | | |
| Product as a service in pre-configured packages | P8 | | | x | | | | | | | x | | x | |
| Lifetime products sales | P9 | | x | | x | | | | | | | | | x |
| Products with through-life care services | P10 | | | | x | | | | | | x | | | |
| Incentivized buy-back of products | P11 | | | | x | | | | | | | | | x |
| Additional services to add 'new life cycles' for products | P12 | | | | x | | | | | x | x | | | |
| ... | ... | ... | | | | | | | | | | | | |

Figure 3 - Extract of morphological matrix at the back-end of Module 1.

Figure 4 exemplifies the result presented by the CEBMES after the completion of Module 1. In this example, the CEBM pattern P08 ('Product as a service in pre-configured packages') was recommended as the most favourable opportunity to solve the challenges of the company (i.e. highest adherence to screening), while contributing to CE targets for resource decoupling (i.e. highest degree of change from linear logic). The CEBM pattern P12 ('Additional services to add new cycles for products') can also tackle challenges identified by the company regarding its current BM, however they will probably cover fewer challenges (i.e. lower adherence to screening) and with lower potential to disrupt the linear logic (i.e. resource decoupling benefits might be more modest) than P08.

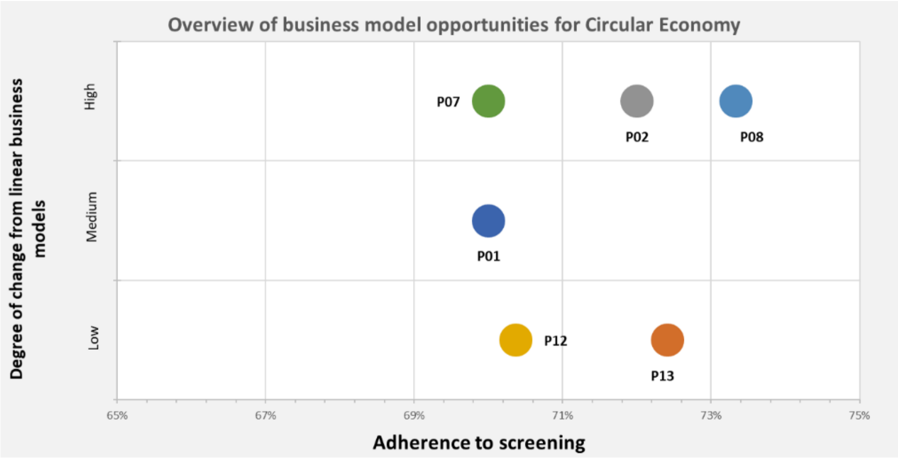



Figure 4 – Example of results for Module 1.

### 3.2. Module 2- Designing CEBM alternatives

Module 2 supports the further detailing selected patterns from Module 1 into complete CEBM alternatives, through suggestions of potential synergies among different CEBM patterns and a framework that enables the adaptation of pattern combinations to the company's context. Module 2 comprises one step:

#### 3.2.1. Step 3 – Combine patterns to design CEBM alternatives

The front-end comprises three functionalities:

F3.1 *Advice on potential CEBM alternatives, which are based on likely combination of solution patterns* for the upstream and downstream architectures. The CEBM patterns are divided into downstream (i.e. affecting offerings; target customers; value delivery processes; revenue mechanisms) and upstream (i.e. affecting value creation processes; partnerships/collaborations). Therefore, different types of patterns shall be combined to enable the configuration of complete CEBMs. Up to three CEBM alternatives can be generated based on patterns selected in Step 2.

F3.2 A framework that enables:

a) Exploration of CEBM alternatives based on the *selection of CEBM pattern combinations for the upstream and downstream architectures*.
b) *Support to ideation and documentation of details*, with definition of key stakeholders (e.g. customers, suppliers), value proposition, and key benefits for stakeholders and CE (i.e. economic, resource decoupling).

At the back-end, Module 2 relies on case-based reasoning, which adapts solutions that were used to solve previous CE problems and use them as sources of inspiration to create CEBMs addressing similar problems (Liao, 2005). The advice on the combination of CEBM patterns for a specific company relies on *matrices of usage and of potential combinations of CEBM patterns in previous cases*. The likelihood of a CEBM pattern (selected in Step 2) being related with another pattern is calculated based on their recurrence in the *sample of 180 CEBM cases*, which composes the knowledge base for the databases level of Module 2. The usage and combination matrices and the cases' knowledge base were developed as explained in section 2.1 and documented in Pieroni et al. (2020).

Figure 5 illustrates the results presented in the CEBMES after the completion of Module 2 by an electrical equipment manufacturer. The red rectangle under the block 'downstream architecture' indicates the CEBM pattern originally selected in Step 2 (EPD0202). The green rectangles represent the advice provided by the CEBMES regarding synergistic patterns to enable the configuration of a complete CEBM based on previous cases within this sector (e.g. EPD0102 for the downstream and EPU0301 for the upstream architecture). The outer columns entitled 'Select' show the CEBM patterns chosen by the company (i.e. Yes) among the recommended ones after their ideation session. The company used the 'value generation box' (i.e. the central block) to outline specific customers; potential suppliers and partners that will need to be engaged; what customers/partners will receive; and how the new CEBM could benefit the company and contribute to CE targets.

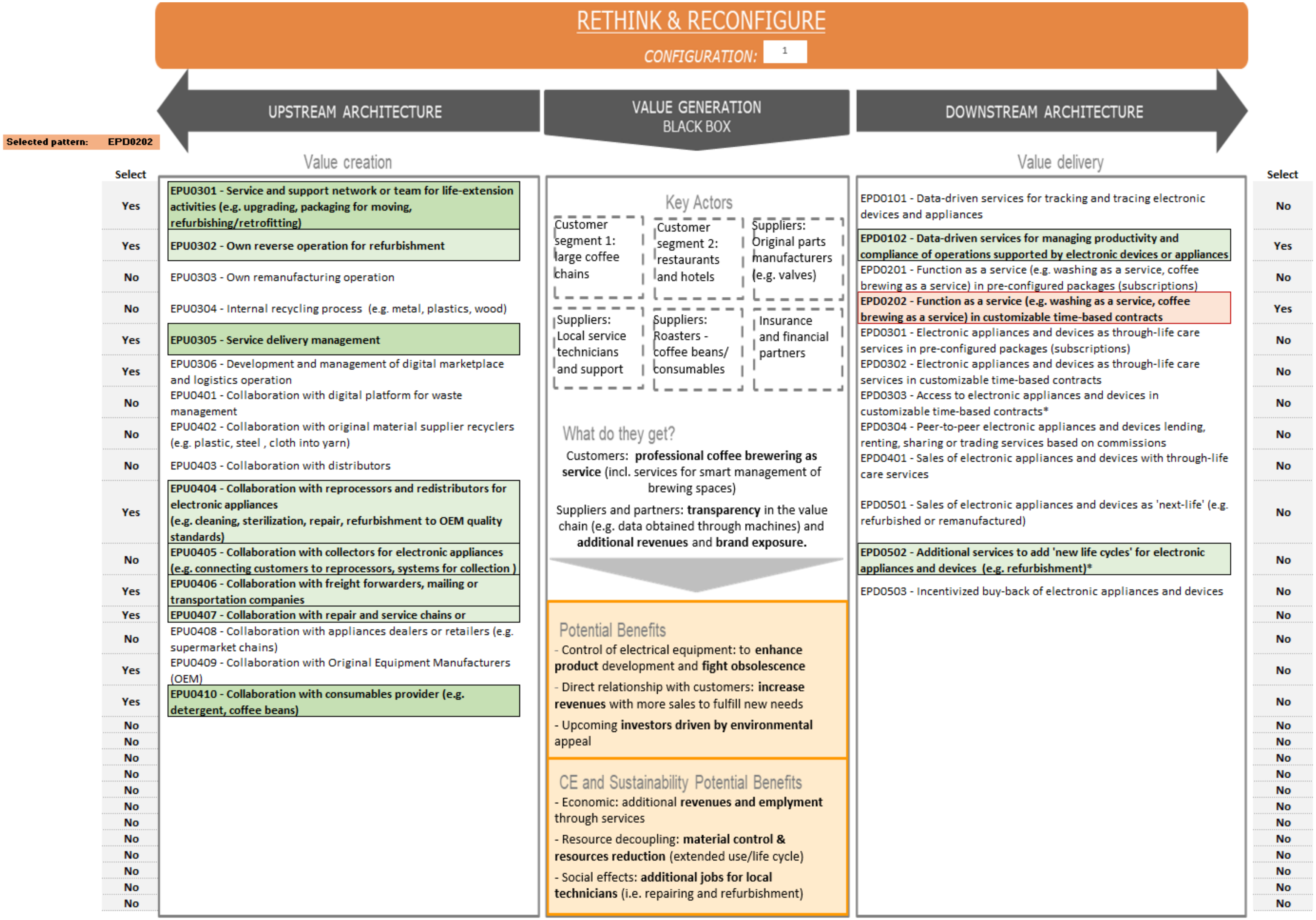



Figure 5 – Example of results for Module 2.

## 3.3. Module 3- Configuring detailed CEBMs

Module 3 enables the configuration of detailed CEBMs. As output, companies receive suggestions of configuration options for all elements of the CEBM. This module comprises one step:

### 3.3.1. Step 4 – Configure detailed CEBM alternatives

At the front-end, Step 4 comprises two functionalities:

F4.1 A *BM framework that enables documentation of the ideation process for checking the viability and detailing of the CEBMs.* The BM framework comprises 12 elements, which were previously described in section 3.1.1.

F4.2 *Advice on potential configuration options (COs)* for each CEBM element. COs are the available alternatives for shaping the 12 elements of a CEBM (Amshoff et al., 2015).

At the back-end, Module 3 also relies on case-based reasoning (Liao, 2005). A *matrix relating the selected combination of CEBM patterns (from Step 3) to correspondent common practice COs present in CEBM cases* enables the advices. The *complete list of COs* is available in the databases level. Both the matrix and knowledge base of COs were also developed as explained in section 2.1 and documented in Pieroni et al. (2020).

Figure 6 illustrates partial results presented in the CEBMES after the completion of Module 3 by the previously mentioned electrical equipment manufacturer. The CEBMES suggested two Cos of ‘Revenue Mechanisms’ (E08) for the chosen CEBM alternative based on the core pattern ‘Function as a service’ (EPD0202): (i) subscription with a pay per use fee (e.g. priced according to volume of brewed coffee); or (ii) subscription with a monthly/annual fee (e.g. priced according to duration). The recommended COs are not intended to be the final COs adopted by companies because adaptations to each organisational context are required. Instead, they are meant to remind/inspire companies about minimum required capabilities to implement CEBMs (e.g. reprocessing infrastructure and procedures; service level formalised in contracts). The additional lines (empty on Figure 6) on each block allow users to include or modify COs.

**Business Model Concept/ Configuration: 3**

**Key pattern:** Function as a service (e.g. washing as a service, coffee brewing as a service) in customizable time-based contracts

**Meaning:**
- Electronic devicesand appliancesmanufacturers offer services based on functionalities of the product (e.g. washing, coffee brewing).
- They charge accordingly to the use with a monthly/yearly rate agreed in customizable contractsand provide a comprehensive solution (e.g. including

**E10 - Value creation**
- Transportation and sorting processes for products
- Service and support network or team for life-extension activities (e.g. upgrading, packaging for moving,
- Retrofit products with sensors
- Reprocessing (or refurishment) infrastructure and procedures (e.g. checked, tested, cleaned, repaired,
- IoT and Web Service management
- Establish collaborations to aquire consumables (e.g. coffee beans, milk foam, detergents)
- Establish collaborations for collection, reprocessing and redistributions
- Develop and manage marketplace
- Design for simplicity, reparability, upgradability, and emotional and technical durability in design
- Design for manufacture, assembly, disassembly and end-of-life processing
- Design for efficiency
- Colelction or take back
- Attraction and maintenance of critical mass of participants
- Asset and inventory management procedures and skills
- -

**E11 - Partnerships or collaborations**
- Transport hub
- Reprocessors and redistirbutors for electornic Ppliances
- Repair and service chains or technicians
- Original Equipment Manufacturers (OEM)
- Logistics and transportation companies with overcPacity (E.g.: post)
- Consumables provider (e.g. detergent, coffee beans)
- -

**Overall Benefits for CE/Sustainability**

**E01 - Economic benefits**
- Direct increase in revenue (e.g. new services, increase in market share, new markets)
- -

**E02 - Environmental benefits**
- Reduction of resource consumption
- Reduction of energy consumption
- Avoid generation of waste
- -

**E04 - Target customers**
- B2C - Households and buildings
- B2B - Companies and offices
- -

**E09 - Value delivery**
- Take back formalized in contract
- System and interface to access tracking information
- Short-term customizable contracts
- Phone and call center support
- Long-term customizable contracts (e.g. 36 months, 60 months)
- Deposit
- Dedicated support account manager
- Manage service agreements
- -

**E07 - Service offerings**
- Support with marketing campaigns for stores
- Quantification of sustainability benefits and reporting (e.g. environmental and social
- On-site repair or replacement (i.e. swP in case of breakdowns)
- On-going maintenance (i.e. routine or preventive maintenance)
- Off-site repair
- Management of resources or consumables for electronic Ppliances operations (e.g.
- Maintenance products and instructions
- Lifetime guarantee
- Installation
- Delivery
- Collection or take-back
- -

**E12 - Benefits for partners**
- New sources of revenue, additional turnover and improved return on
- Environmental or social friendly solution
- Branding or visibility
- -

**E0 - Value Proposition**

Professional coffee brewering as service (incl. services for smart management of brewing spaces)

**E05 - Benefits for customers**
- Quality, expertise, durability
- Predictability in budgeting
- Environmental or social friendly solution
- Efficiency or performance
- Convenience
- Affordability - lower upfront investment

**E08 - Revenue mechanisms**
- Subscription model with pay-per-use fee
- Subscription model with monthly or annual fixed fee
- -

**E06 - Product offerings**
- Spare parts
- Refurbished or remanufactured electronic Ppliances and devices
- Modular products
- Equiped with monitoring devices
- Coffee beans or consumables (e.g.: coffee cups, detergent)
- -

BM elements adapted from: strategyzer.com

Figure 6 - Example of advice for possible COs provided in Module 3.

### 3.4. Module 4- Evaluating the potential of CEBMs

Module 4 focuses on the preliminary assessment of the economic, resource decoupling and customer value potential for CEBMs. As output, users receive calculations of indicators and comparative frameworks of scenarios to guide decision-making. The module comprises three steps (5/6/7):

#### 3.4.1. Step 5 – Evaluate the economic potential of CEBM alternatives

One core functionality (F5.1) is presented at the front-end: *support to the evaluation of the economic potential of CEBMs based on cost-benefit analysis with a dynamic business case framework.* The recommended indicators to calculate the business case vary according to the specific CEBMs proposed in Step 4. Indicators in five categories are recommended:

a) Financial factors - e.g. corporate income tax; depreciation, interest rates;
b) Market/demand assumptions – e.g. sales forecast, use cycles;
c) Revenue sources – e.g. pricing;
d) Development costs – e.g. refurbishment hubs, tracking/tracing devices;
e) Operational costs – e.g. average maintenance/repair interventions per contract;
f) Intangible benefits – e.g. price growth from improved reputation with customers, brand value.

To enable presentation of results and comparison among CEBMs, five composite indicators are calculated:

(i) Return on investment;
(ii) Net present value;
(iii) Payback;
(iv) Gross margin;
(v) Cash flow (graph format).

The back-end of Module 4 also relies on rule-based reasoning. In Step 5, *a matrix relating CEBM configurations (e.g. combination of CEBM patterns) and economic indicators* enables the advice on a dynamic business case structure. Moreover, the back-end hosts the calculation rationale for the composite indicators. The databases level hosts the *database of economic indicators to assess CEBMs*.

The indicators and their calculation rationale were obtained from state-of-the-art SLRs about indicators to assess CE initiatives available in literature (Kravchenko et al., 2019; Rodrigues et al., 2017). They were complemented by insights from the application of the CEBMn process with seven companies (A-G in Table 2).

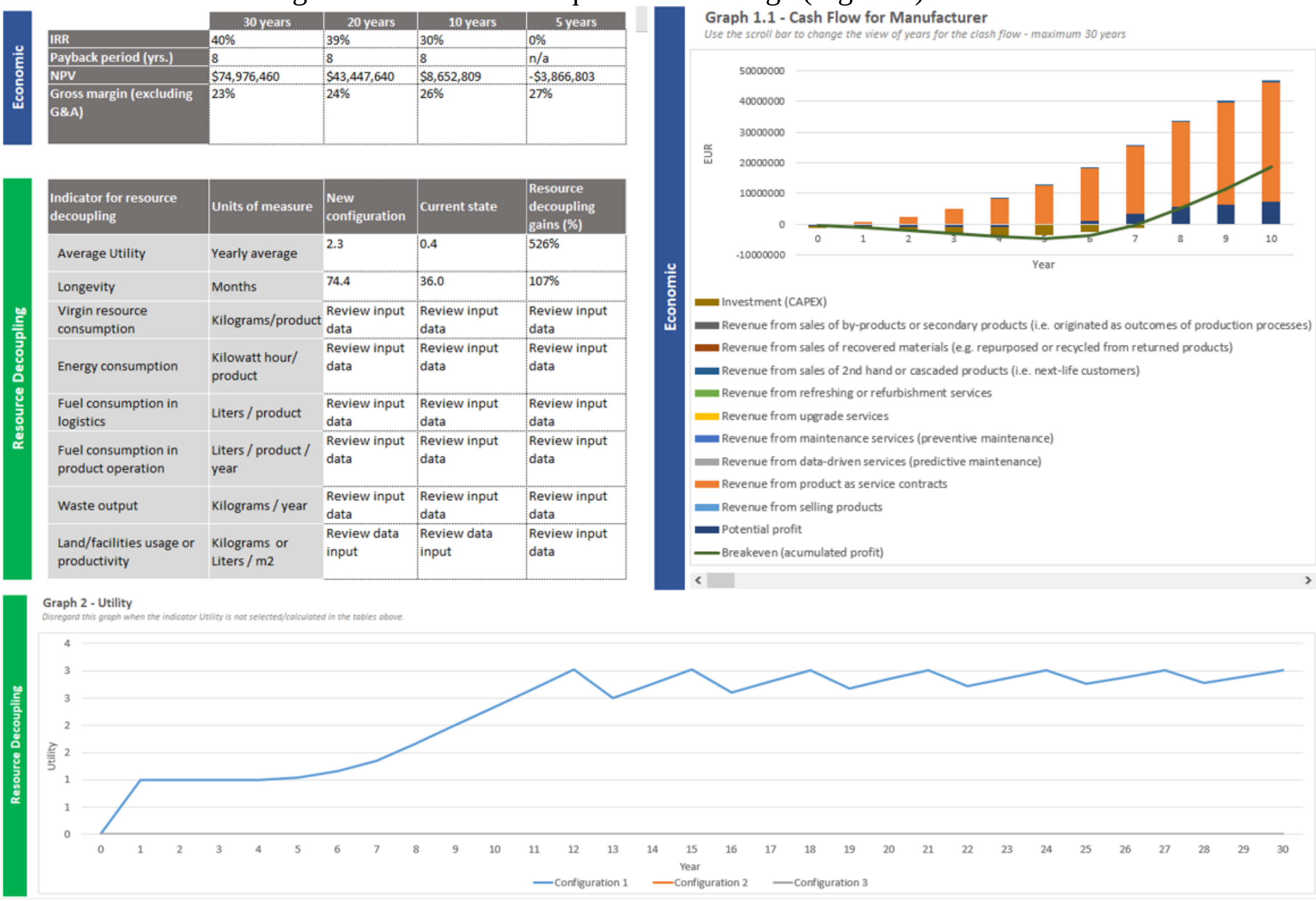
#### 3.4.2. Step 6 – Evaluate the resource decoupling potential of CEBM alternatives

At the front-end, Step 6 has one core functionality (F6.1), i.e. *support to the evaluation of the resource decoupling potential of CEBMs based on eight indicators*:

(i) Average utility (also in format of graph);
(ii) Longevity;
(iii) Virgin resource consumption;
(iv) Energy consumption;
(v) Fuel consumption in logistics;
(vi) Fuel consumption in product operation;
(vii) Waste output;
(viii) Land/facilities usage/productivity.

The CEBMES suggests the adequate indicators from the overall pool depending on the CEBM configurations proposed in Step 4. To establish a reference point for comparisons among different CEBMs, information of existing BM from the company or competitors is requested. Based on that, results about improvement/regression in resource decoupling of each CEBM compared to the existing scenario can be presented.

At the back-end, the rules are recorded in a *matrix relating CEBM configurations (e.g. combinations of CEBM patterns) with adequate indicators from the pool*. The correlations in this matrix were based on advices for evaluating resource decoupling in BMs by Kjær et al. (2019). The *resource decoupling indicators* hosted on the databases level were selected from Kravchenko et al. (2019). Only eight indicators were selected to enable the high level assessment required at this stage (Figure 7).



| Economic | 30 years | 20 years | 10 years | 5 years |
|---|---|---|---|---|
| IRR | 40% | 39% | 30% | 0% |
| Payback period (yrs.) | 8 | 8 | 8 | n/a |
| NPV | $74,976,460 | $43,447,640 | $8,652,809 | -$3,866,803 |
| Gross margin (excluding G&A) | 23% | 24% | 26% | 27% |

| Indicator for resource decoupling | Units of measure | New configuration | Current state | Resource decoupling gains (%) |
|---|---|---|---|---|
| Average Utility | Yearly average | 2.3 | 0.4 | 526% |
| Longevity | Months | 74.4 | 36.0 | 107% |
| Virgin resource consumption | Kilograms/product | Review input data | Review input data | Review input data |
| Energy consumption | Kilowatt hour/ product | Review input data | Review input data | Review input data |
| Fuel consumption in logistics | Liters / product | Review input data | Review input data | Review input data |
| Fuel consumption in product operation | Liters / product / year | Review input data | Review input data | Review input data |
| Waste output | Kilograms / year | Review input data | Review input data | Review input data |
| Land/facilities usage or productivity | Kilograms or Liters / m2 | Review data input | Review data input | Review input data |



Figure 7 - Example of results for Module 4/Step 7A.

### 3.4.3. Step 7 – Compare overall value creation potential

Step 7 comprises only the front-end, which contains 3 functionalities that were developed as responses to practical requirements (Table 1):

F7.1 A *framework that enables comparing the composite indicators for economic and resource decoupling potential* of up to three CEBM alternatives;

F7.2 A framework to support:

- Consolidation of the economic and resource decoupling quantitative indicators with *complementary qualitative indicators to provide an overview of the overall value creation potential criteria for CEBMs*. The qualitative indicators enable assessing the CEBM potential regarding (Figure 8):
  - (i) Superior customer value: based on the fulfilment level of customer benefits and the market potential/volume;
  - (ii) Economic growth: based on the composite indicators (Step 6), analysis of required investments and scaling-up conditions;
  - (iii) Resource decoupling: based on net reduction analysis through indicators; burden shifting mitigation possibilities, and rebound effects.

- *Indication of targets/thresholds for the evaluation criteria* to enable interpretation of results according to each company.

F7.3 Space for *documentation of mitigation and action plans to optimise and improve CEBMs* (Figure 8).

| | | Requirement is fulfilled when... | | | |
|---|---|---|---|---|---|
| **Circular Economy Targets** | **Requirement** | **Conditions for the company** | **Value for the bold condition on the left** | **Scenario 1.1** | **Mitigation plan** |
| Superior customer value | Perceived added benefits >= perceived added sacrifices | Minimum margin for customers >= **current margin for customers**<br><br>**Tip:** use the learnings from the exercise with the Customer Journey Map to identify at least one critical requirement for customers, in the example, the customers, which is a business, expected to maintain the margins they had when buying the previous offering (product instead of service). | 50% | | Verify whther disposal costs are considered in |
| | Market potential (representativeness/volume) | Expected market share for the German market is achieved in... **years** | 10 | | |
| Economic growth | Positive net profit | Gross margin of created business models>= **long-term gross margin of current business model (in 10 years)** | 65% | | Review channels and pricing considerations. |
| | Available investment options | Payback period of ... **years** is acceptable | 3 | | |
| | | External financing options are necessary and available (e.g. bank loan, investment groups, subsides/ funded public projects/ grants) | No | | |
| | Favourable upscaling conditions | Volume of returning products justifies pay-off investments, i.e., **ROI of at least...is expected after 5 years** | 100.00% | | |
| Resource decoupling | Positive net resource reduction | Longevity >= **current longevity** | 1 | | |
| | | Utility >= **current utility** | N/A | N/A | |
| | Absent burden shifting between life cycles stages | Burden shift to manufacturing is avoided | Yes | | |
| | | Burden shift to end-of-life is avoided | Yes | | Consider material substitution for |
| | Mitigated rebound effects | Business model is **able to substitute for benchmark alternatives** (i.e. current options in the market) | Yes | | |
| | | Price of offering in for business model is >= **substitute price** | $39 | | |
| | | The difference in price from proposed and current business model poses **risks to shifting consumption** (e.g. incrasing consumption due to lower prices) | No | | n.a |
| Adherence of scenario to Circular Economy Targets: | | | | 69% | |

Figure 8 - Example of results for Module 4/Step7B.

Figure 7 and Figure 8 exemplify part of the results presented in the CEBMES after the completion of Module 4.

As indicated in Figure 7, only two resource decoupling indicators (i.e. average utility and longevity) were selected for the electrical equipment manufacturer's case. Based on the cash flow graph (top-right on Figure 7), the manufacturer was able to foresee required investments for scaling-up the CEBM. These would be associated mainly with the manufacturing of machines and installation of infrastructure to enable connectivity for remote monitoring and management of maintenance. Based on these estimations, the company was able to attract investors to co-finance the scale-up of their CEBM. Moreover, the graph for products' utility, enabled identifying when refurbishment operations would be required in a more expressive volume, triggering discussions about the possibility of partnering with existing subcontractors to deal with refurbishment until enough volume is reached to justify investments in internal infrastructure.

Figure 8 illustrates the overall framework for evaluation/improvement of a CEBM potential, based on the case of a medical devices' manufacturer. Their proposed CEBM would offer immobilisation solutions as services for clinics/hospitals, which would enable reuse of medical devices by multiple patients before disposal. Even though this CEBM presented a promising resource decoupling potential (see green checkmarks on Figure 8), the economic benefits for the company and their customers (i.e. clinics/hospitals) were not satisfactory when compared to the existing model. This triggered the company to review channels and pricing considerations.

### 3.5. Application procedure

The recommended application procedures are described on the steps' interfaces. Moreover, a detailed guideline for practitioners was developed to explain the application of the CEBMES to support CEBMn process in parallel to other tools (e.g. interactive frameworks), which are available at DTU's repository (https://orbit.dtu.dk/en/publications/circular-economy-business-modelling-circit-workbook-2).

## 4. Evaluation of the CEBMES

This section provides an overview of the perceived usefulness of the CEBMES (4.1), insights about its applicability according to contextual aspects (4.2), and improvement opportunities (4.3).

### 4.1. Overall evaluation of applicability and usefulness

Figure 9 illustrates how participants within manufacturing companies (H-P in Table 2) evaluated the overall applicability and usefulness of the CEBMES.

For most participants, the CEBMES provided a logic sequence of steps that helped designing and maturing CEBMs (Pc47 and Pc48). However, most companies could only complete Steps 1-4, which they perceived as relatively easy to use. Three companies that completed all steps, perceived difficulties in Steps 5-7 related to a detailed level of information and extensive requirements for quantitative data (e.g. to estimate economic/resource decoupling potentials). These observations pointed out to a potential variability in applicability of different modules of the CEBMES depending on how advanced companies are in respect to the CEBMs' design stages. The complete evaluation of the CEBMES is available in Appendix B.

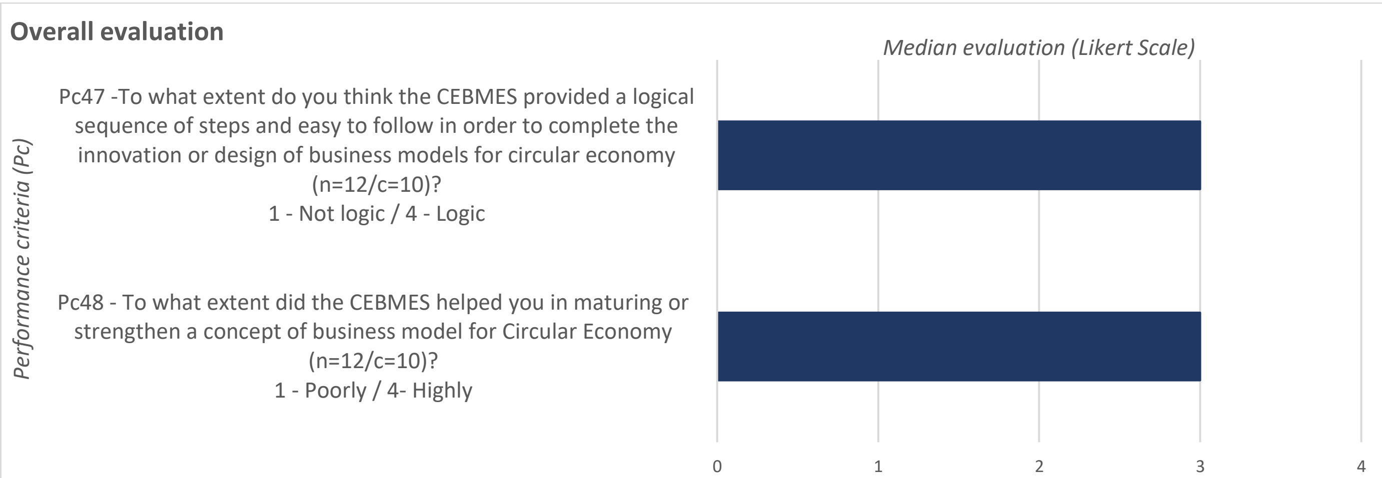



Figure 9 - CEBMES evaluation by manufacturing companies (Legend: n=number of respondents/c= number of companies).

### 4.2. Contextual aspects and implications for CEBMES applicability

Statiscal analyses enabled exploring contextual conditions that favoured/disfavoured the application or perception of the CEBMES performance. The initial set of perceived performance criteria (Pc) for Module 1 (Appendix A) included 11 variables (e.g. comprehensiveness for recommending solutions for CE problems). A process of reduction of variables was required to describe the perceived CEBMES evaluation with fewer non-redundant criteria. Spearman's correlation among the variables demonstrated that some Pcs were correlated to a certain extent, although not enough to be considered as fully overlapping (no correlation coefficient exceeded 0.8). Hence, Principal Component Analysis (PCA) was applied to build a reduced number of fully independent Pcs based on Principal Components (PCs). PCs showing an eigenvalue larger than 1 were considered further, as a common rule of thumb, and interpreted based on the most (positively/negatively) impacting initial variables. Four PCs, were achieved and interpreted based on the positive/negative contributions (with absolute value greater than 0.3) of the initial variables:

- **PC1: Functionality**, i.e. the degree to which the CEBMES performs its expected function of suggesting proper solutions for CE challenges, steering CE-thinking and supporting decision-making throughout the CEBMn process in the perspective of implementing actions targeting CE in a practical/informative way.
- **PC2: Need for detail**, i.e. the degree to which the advices provided by the CEBMES were perceived necessary and useful, although limited to guide users.
- **PC3: Good Black Box-alike**, i.e. the degree to which the CEBMES was perceived as effective to support decision-making, despite the presence of an unclear logic (to the user) behind its functioning.
- **PC4: Supporting newness**, i.e. the degree to which the CEBMES is capable of guiding the user towards solutions or actions that were unimaginable and perceivably creative.

This process considered all initial variables (Pcs) at least once in the interpretation process (Figure 10).

| | **Principal Components (PC)** | | | |
|---|---|---|---|---|
| **Initial performance criteria (Pc) extracted from the CEBMES evaluation**<br>*Detailed explanation of performance criteria available in Appendix A* | **PC1** | **PC2** | **PC3** | **PC4** |
| Pc01 - To what extent has Step 1 helped characterisation of CE problems and identification of opportunities? | | | -0.525 | |
| Pc02 - To what extent were the recommended ideas (i.e. CEBM solution patterns) in Step 2 comprehensive? | 0.466 | | | |
| Pc03 - To what extent could the recommended ideas in Step 2 address the CE problems and opportunities? | 0.397 | | | |
| Pc04 - To what extent were the recommended ideas in Step 2 applicable to your company's context? | | 0.477 | | |
| Pc05 - To what extent did recommended ideas in Step 2 require effort for adaptation? | | 0.514 | | |
| Pc06 -To what extent was the description of CEBM solution patterns provided in Step 2 enough? | | -0.342 | 0.327 | 0.625 |
| Pc07 -To what extent was it necessary to consult the Patterns' Database or the Cases' Database in Step 2? | | 0.438 | 0.301 | |
| Pc08 -To what extent was the information available in Step 2 within Patterns/Cases' Databases enough? | 0.346 | | | |
| Pc09 - To what extent did the graph in Step 2 supported the selection of ideas? | 0.376 | | 0.446 | |
| Pc10 - To what extent was the exploration of ideas in Step 2 straight forward (i.e. practical)? | 0.323 | | | |
| Pc11 - To what extent could you discover new ideas for CE that you had not seen/heard/thought about before? | | | | 0.540 |

Figure 10 - Determination of Principal Components (PC) for CEBMES evaluation aggregated based on impact coefficients ascribable to initial performance criteria (Pc).

Regressions were subsequently used to identify possible correlations among the four PCs and six contextual aspects of application (i.e. *being a large/SME company; sector; declared experience in CE; declared experience in BM innovation (BMI); and declared time of application*), in addition to the decision to progress with subsequent modules within the CEBMES (leveraged as a dummy variable). Three types of relationships were identified: (i) no correlations ($p>0.1$); (ii) quasi-significant correlation ($0.05<p<0.1$); and (iii) significant correlation ($p<0.05$).

(i) No correlation

- <u>Sectors or size of companies</u> did not affect the perceived performance of CEBMES. *This observation enables inferring a broad applicability and flexibility of the CEBMES for varied organisational contexts, indicating the potential ability of the CEBMES to be generalisable within the specific manufacturing sectors that it was developed/tested for (i.e. outdoor goods, furniture, heavy machinery, electrical/electronic equipment/devices).*

(ii) Quasi-significant correlation

- The use-time resulted in a quasi-significant positive relationship with the perception of companies regarding functionality and ability to support newness. The more time the companies used the CEBMES, the better their impression regarding its functionality and ability to support ideation. *This result was already expected and provided evidence about estimated time required to use the CEBMES, which were incorporated in the CEBMES' instructions.*
- The CEBMES' functionality motivated the users to advance from Modules 1 to 2. Even though some companies could not fully understand the logic behind Module 1 (i.e. CE characterisation vs. suggestions of solutions), they demonstrated motivation to move forward and appreciated the advices. The same company that mentioned that "*sometimes it is difficult to understand how the CEBMES comes from Steps 1 to 2 examples*", also mentioned that they *"followed the process as a recipe, as far as possible, and it was very helpful to structure the CEBMn approach!"*

(iii) Significant correlation

- The company's experience in BMI resulted in a significant positive relationship with the perception of effectiveness and clarity/logic to support decision-making. Companies with experience in BMI encountered logic in the selection of CEBM patterns to tackle CE problems instead of perceiving it as an effective 'black-box'. *This might be related to two aspects. Companies that were acquainted with activities related to strategic thinking felt more comfortable with the logic of advices, because this step is related to abstract discussions to transform a vision into ideas. Moreover, these companies might have specific functions and organisational structure that allows creativity and empowerment/autonomy of participants to try to change the status-quo.*

4.3. Improvement opportunities

The following improvement opportunities were identified based on replies to questionnaires and comments from interviews with companies (detailed in section 2.6):

- Consideration of additional criteria (e.g. customer segment specifications, scope of CEBMI) to refine the logic of advices for CEBM patterns according to the companies' contexts and improve the adherence of the graph in Step 1;
- Review of CEBM patterns for specific sectors (i.e. agriculture and food) (Steps 2/3);
- Additional explanations about sensitivity analysis for the economic potential assessments (Step 5);
- Clearer guidelines for each step with examples;
- More precision in definitions/terminology.

## 5. Discussions and final remarks

This section presents discussions and final remarks about the applicability and limitations of the CEBMES (5.1), contributions to literature and practice, and future research possibilities (5.2).

5.1. Applicability and limitations

Satisfactory use of the CEBMES by varied organisations points towards the applicability of this research to different manufacturing companies' sizes and sectors. Beyond the influencing contextual aspects explored in Section 4.2 (i.e. degree of experience in BMI and time of application), recurrent characteristics that favoured the CEBMES applicability were (Khan et al., 2020; Ünal et al., 2019a):

- Users were usually business developers, sustainability managers and product managers;
- Companies/users were willing to be trained to use the CEBMES independently;
- Companies/users were willing to steer a change of mindset towards CE-thinking within their organisations by engaging multifunctional teams;

- Companies had a pre-existing scope (e.g. a selected product or initial CEBM ideas) for which they wished to strengthen proposals of CEBMs.

Despite the positive uptake by companies, the research presents limitations. Even though the evaluation of the CEBMES was solid compared to other tools in the field (i.e. assessing varied Pcs with quantitative analysis), the results are restricted to four manufacturing sectors. Further testing is required to confirm applicability to other sectors (e.g. textile, agriculture).

Moreover, further testing with more companies within a single sector completing all modules could strengthen the analyses of correlations of CEBMES' applicability regarding contextual aspects.

Lastly, the knowledge databases within the CEBMES (e.g. CEBM patterns, cases, indicators) require a procedure for frequent updates to guarantee that the provided advices reflect innovations in the field.

### 5.2. Contributions to practice, literature, and future research

This research contributes to CEBMI literature by systematising practices and knowledge for action in the format of suggestions to guide the CEBMn process within manufacturing companies. The systematised practices and the process followed to develop the CEBMES go beyond available publications and fulfil expectations for holistic approaches for the strategic management of CEBMI and CE implementation (Khan et al., 2020; Ünal et al., 2019a).

The CEBMES was proposed based on a comprehensive evaluation methodology involving (i) development and testing with multiple practitioners (12 users within 10 companies); (ii) structured evaluation of its performance with multiple criteria (>40); and (iii) detailed analysis based on qualitative and quantitative (i.e. histograms, PCA, regressions) approaches. Available CEBMI works in literature tend to be limited to qualitative evaluations, based on unstructured approaches (i.e. observations/interviews), and with single or few case studies (<5) (Bocken et al., 2019; Pieroni et al., 2019a). Although a straight comparison of approaches is not possible due to significant differences in the level of evaluations or considered Pca, a reference checklist for CEBMI tool development (Bocken et al., 2019) confirms the solidity and value added by this research and the proposed CEBMES to literature, as explained in Figure 11.

Regarding practical contributions, this research can support facilitators or process champions within manufacturing companies to trigger a change of mindset towards CE-thinking within their organisations. The CEBMES can support manufacturing companies to strengthen proposals of CEBMs before seeking for funding or sponsorship for their implementation. The CEBMES will benefit its users by:

- Inspiring best practices on CEBMn;
- Confirming assumptions with a structured framework;
- Offering a logic structure that prompts decision-making;
- Helping keep an accounting of decisions.

The CEBMES can function as a 'side consultant', providing information that can be used to populate interactive frameworks that are suitable for group discussions and flexible to 'live changes'.

The work presented in this paper sheds light on three research avenues. First, implementing the identified improvement opportunities could improve the CEBMES usefulness. Even though the evaluation was not focused on usability due to the CEBMES stage of the development (i.e. high-fidelity prototype), participants saw potential and provided feedback about how interfaces/transitions could become more flexible in a web-based format. In association with this format, an automated procedure grounded on artificial intelligence could be developed for updating the databases in the CEBMES by sourcing knowledge from external/open-source CE expert platforms. Second, exploration of how companies beyond manufacturing (e.g. raw materials extraction, services, construction) deal with CEBMn could enable expanding the CEBMES' scope (e.g. allowing multiple companies with different positions within/across value chains to collaborate and work on simultaneous solutions of how their own CEBMs can converge for closing loops). Third, the integration of this research with works that investigate dynamic capabilities to boost CEBM innovation performance/maturity (Khan et al., 2020) could advance knowledge on how to overcome barriers for the implementation/scale-up of CEBMs.

| Checklist of criteria | Fulfilment | Comments and testimonials |
|---|---|---|
| 1. The tool is purpose-made for CEBMI<br>2. The tool is rigorously developed from both literature and practice insights<br>3. The tool is iteratively developed and tested with potential users | +++ | The development of the CEBMES comprised:<br>• Systematisation of conceptual requirements for CEBMn from systematic literature reviews (section 2.2);<br>• Collection of practical requirements for CEBMn and knowledge foundations for the CEBMES were based on empirically developed frameworks with 7 manufacturing companies (A-G in section 2.1 and Table 2 of section 2.2). |
| 4. The tool integrates relevant knowledge from different disciplines | +++ | • The systematic literature reviews from which conceptual requirements for the CEBMES were extracted comprised knowledge from CE, sustainability, and management disciplines (section 2.2).<br>• Practitioners from different functional areas and related to different disciplines were engaged in the collection of practical requirements or testing of the CEBMES (e.g. marketing and sales, procurement, operations, services excellence, digital technologies, business innovation, corporate social responsibility) (section 2.1). |
| 5. The final tool version has then been used by practitioners, preferably multiple times, and an evaluation of this process is done to assess tool use and usefulness | +++ | • The CEBMES was tested with 10 companies in case studies (H-P in Table 2).<br>• The evaluation comprised qualitative (i.e. clustering of feedback, benchmarking with checklist for CEBMI tool development described in section 4.3) and quantitative analyses (i.e. histograms, PCA, regressions described in sections 4.1 and 4.2). |
| 6. The tool provides a transparent procedure and guidance for its application | ++ | • The CEBMES contains instructions inside the prototypical tool. Moreover, users were trained with a webinar and received a manual – e.g. "Training and materials were good."<br>• The fact that companies were able to apply it independently corroborates with a positive evaluation for this criteria. One company mentioned that they "tried to follow the process as a recipe as much as possible, and it was very helpful to structure [their] approach!."<br>• Nevertheless, improvement opportunities in the instructions were identified, which indicates that this criteria was fulfilled, but could be improved – e.g. "A concise user-guide could be useful, for example, I was reluctant to rewatch the webinar."; "It is too much to consume. I think a process were you can start in a basic level and then dig deeper if you like [would be better]"; "Add small examples in the tool [how to fill it in]." |
| 7. CE or broader sustainability objectives and impact are firmly integrated into the tool and safeguarded when tool application is facilitated by others than the tool developer | +++ | • The CEBMES recommends CEBM patterns that rely on best practices for CE (section 3).<br>• Moreover, the CEBMES' Module 4 enables evaluating the resource decoupling potential of the proposed CEBMs. This aims to support the users in refining or guaranteeing the achievement of CE objectives and impact (section 3). |
| 8. The tool is simple and not too time-consuming | + | • According to the evaluation (section 4.1 and Appendix B), the CEBMES was considered simple in Modules 1, 2 and 3. However, companies faced difficulties in applying Module 4, which focused on quantitative assessment of CEBMs – e.g. "It feels a little bit complex and difficult to use for the first time". This was expected due to the nature of the tasks.<br>• Overall, the CEBMES requires significant effort for application (2h-4h for Modules 1 and 2, 1h for Module 3, and 3h for Module 4, summing up to 8h on average). However, this was expected because, differently than other available tools (Bocken et al., 2019; Pieroni et al., 2019a), its objective is to guide the CEBMn holistically and not solely with individual tasks of ideation. Moreover, only one company reported time as a restriction to the use of the CEBMES – e.g. "Comprehensive and impressive tool which is also holistic. Might overwhelm companies in how much time they need to spend". In general the number of companies being able to use the CEBMES up until the Module 3 (i.e. detailing the CEBMs) indicates acceptance of the effort required. Companies that could not apply Module 4 associated it with: (i) lack of readiness to pursue this module (i.e., they still needed more iterations in the previous modules), (ii) lack of access to data; or (iii) lack of priority by sponsors. |
| 9. The tool inspires or triggers (business) change | +++ | Different companies reported that the CEBMES brought an element of newness, providing ideas that can trigger change of companies' status quo (section 4.2). Examples of testimonies were:<br>• "Helpful to reflect upon what the company does today in relation to the CE-concept, also to reflect upon what may be further possibilities in the enhancement of CE-practice."<br>• "We had not considered offering a product or group of products in rented, leased, or subscription based packages. We found this to be a very interesting example for the company as there are many opportunities to offer packages for certain categories of products demanded in seasonal activities."<br>• "The CEBMES provided the company with ideas that they had not considered, e.g. to rent out/lease a package of products from different product categories." |
| 10. The tool is adaptable to different (business) contexts | +++ | • The broadness of companies participating in the validation (Table 2) points out to the flexibility of the CEBMES to adapt to different contexts (i.e. sizes, sectors), within the scope that it was developed for (i.e. specific manufacturing sectors).<br>• The PCA showed that the positive performance of the tool was not affected by size or sectors, which corroborates with this criterion (section 4.2). |

Figure 11 - CEBMES evaluation according to CEBMI tool development criteria (Bocken et al., 2019) (Legend: +++ = very strongly; ++ = strongly; + = moderately; 0 = doesn't meet criterion or only marginally).

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**Marina P. P. Pieroni:** Conceptualisation, Data Curation, Formal analysis, Investigation, Methodology, Visualisation, Writing - Original Draft; **Tim C. McAloone:** Conceptualisation, Funding acquisition, Project administration, Resources, Supervision, and Writing - Review & Editing; **Yuri Borgianni and Loranzo Maccioni:** Data Curation and formal analysis for the quantitative evaluation of results, and Writing - Review & Editing; **Daniela C.A. Pigosso:** Conceptualisation, Funding acquisition, Methodology, Supervision, and Writing - Review & Editing.

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## Appendix A – Performance criteria for evaluation of the CEBMES

Tables A1, A2, A3, A4 and A5 present the complete performance criteria evaluated in each module of the CEBMES.

Table A1 – Company-/user-related aspects

| Aspect | Question | Evaluation options (Likert Scale) |
|---|---|---|
| Sector | A1 - What is the industry sector of your company? | Open |
| Size | A2 - What is the size of your company (i.e. number of full time employees)? | 1 -Fewer than 10; 2 - 10 to 49; 3 - 50 to 249; 4 -250 or more |
| Revenue | A3 - What is the turnover or annual revenue of your company? | |
| Ownership structure | A4 - What is the ownership structure? | 1 - The first contact with the topic was in this project<br>4 - Very experienced (i.e. with several successful projects or previous experience) |
| Organisational experience in CE/sustainability | A5 - How experienced do you judge your organisation with circular economy or sustainability implementation initiatives? | |
| User's experience in CE/sustainability | A6 - How experienced do you feel about circular economy or sustainability implementation initiatives? | |
| Organisational experience in business model innovation | A7 - How experienced do you judge your company with business model innovation? | |
| User's experience in business model innovation | A8 - How experienced do you feel about business model innovation? | |

Table A2 - Performance criteria (Pc) for Module 1 of the CEBMES.

| Performance criteria (Pc) | Question to respondents about performance criteria | Evaluation options (Likert Scale) |
|---|---|---|
| Sufficiency to characterise CE problems and opportunities | Pc01 - To what extent has Step 1 helped characterisation of CE problems and identification of opportunities? | 1- Not sufficient<br>4 - Sufficient |
| Comprehensiveness for recommending solutions for CE problems | Pc02 - To what extent were the recommended ideas (i.e. CEBM solution patterns) in Step 2 comprehensive? | 1 - Not Comprehensive<br>4 - Very Comprehensive |
| Precision of advices (i.e., ability to steer companies towards CE-thinking) | Pc03 - To what extent could the recommended ideas in Step 2 address the CE problems and opportunities? | 1 - Poorly<br>4 - Highly |
| Usefulness (i.e. ability to recommended applicable solutions to CEBMs for the context and potential for implementation) | Pc04 - To what extent were the recommended ideas in Step 2 applicable to your company's context? | 1 - Poorly<br>4 - Highly |
| Effort for adaptation (i.e. easiness of customisation of CEBMs solutions) | Pc05 - To what extent did recommended ideas in Step 2 require effort for adaptation? | 1 - High effort<br>4 - Low effort |
| Clarity<br>Definition: clear and descriptive CEBM patterns | P06 -To what extent was the description of CEBM solution patterns provided in Step 2 enough? | 1 - Poorly<br>4 - Highly |
| Need for more information fulfilment, i.e., ability to fulfil the need for detailed level of information by companies | Pc07 -To what extent was it necessary to consult the Patterns' Database or the Cases' Database in Step 2? | 1 - Not necessary<br>4 - Fundamental |
| Clarity<br>Definition: clear and descriptive CEBM patterns | Pc08 -To what extent was the information available in Step 2 within Patterns/Cases' Databases enough? | 1- Not clear<br>4 - Very clear |
| Usefulness of the graph for visualisation | Pc09 - To what extent did the graph in Step 2 supported the selection of ideas? | 1 - Not useful<br>4 - Very useful and added value to the discussion or selection of patterns |
| Subjective grade of simplicity<br>Definition: variety, organisation and format of information available help exploration (i.e. informed decision-making) | Pc10 - To what extent was the exploration of ideas in Step 2 straight forward (i.e. practical)? | 1 - Not useful<br>4 - Very useful and added value to the discussion or selection of patterns |
| Subjective grade of novelty<br>Definition: ideas suggested by the method are recognised as new knowledge, bringing an element of 'discovery' to the users (i.e. "Wow, I did not know that" feeling) | Pc11 - To what extent could you discover new ideas for CE that you had not seen/heard/thought about before? | 1 - All ideas were known before by the users<br>4 - Many ideas suggested by the tool represent new knowledge, bringing an element of 'discovery' to the users (i.e. "Wow, I did not know that" feeling)) |

Table A3 - Performance criteria (Pc) for Module 2 of the CEBMES.

| Performance criteria (Pc) | Question to respondents about performance criteria | Evaluation options (Likert Scale) |
|---|---|---|
| Coherence | Pc12 - To what extent does the suggested combination of patterns (indicated by the green boxes in step 3) make sense? | 1 - Not coherent<br>4 - The combinations make sense and are possible<br>(i.e. no technical impediments) |
| Broadness (i.e. comprehensive knowledge for CBM) | Pc13 - To what extent do you think that the visualisation in step 3 supported articulation/communication and alignment/ mutual understanding among the group of participants in the discussion, supporting consensus? | 1 - The recommended patterns do not seem to address the problems identified in Step 1<br>4 - The recommended patterns provide satisfactory solutions for the perceived problems for CE in the company |
| Usefulness | Pc14 - To what extent do you agree that the possibility of analysing multiple scenarios in | 1 - Disagree<br>4 - Strongly agree |

| | | |
|---|---|---|
| | parallel for the CEBM was useful (i.e. enriched discussions)? | |
| Usability | Pc15 - To what extent to you think that the open field in step 3 for creating an initial CEBM based on the combinations (i.e. defining the key actors, value proposition, key benefits for CE/Sustainability and actors) enabled the contextualisation of the CEBMs to you company's reality? | 1 - Poorly<br>4- Highly |
| Subjective degree of consideration of collaborations | Pc16 - To what extent did the solution patterns contributed to identification of collaborations? | 1 - Poorly<br>4- Highly |
| Subjective degree of relevance of collaborations | Pc17 - To what extent do you think those collaborations are relevant for the implementation of the CEBMs? | 1 - Not relevant<br>4 - Fundamental |

Table A4- Performance criteria (Pc) for Module 3 of the CEBMES.

| Performance criteria (Pc) | Question to respondents about performance criteria | Evaluation options (Likert Scale) |
|---|---|---|
| Visibility of viability | Pc18 - To what extent did the recommendation of elements of the business model in step 4 enabled visibility of the viability of the CEBMs? | 1 - No visibility or clarity of what is required to make a new business model viable<br>4 - High visibility that helped synthesis, taking conclusions and decision-making for configuring new business models for circular economy |
| Broadness (comprehensive knowledge for CBM) | Pc19 - To what extent are the elements of the business model suggested by the tool in step 4 comprehensive (i.e. a large variety is present and you do not think that there is something missing)? | 1 - Not comprehensive<br>4 - Very comprehensive |
| Confidence level | Pc20 - To what extent did the provision of values (i.e. qualitative or additional quantitative benchmarking information) in step 2 and step 3 support your decision or selection of ideas? | 1 - Poorly<br>4- Highly |
| 'Subjective degree of usability<br><br>Definition of usability: enabled or helped the free ideation and contextualisation to the company's own reality. | Pc21 - To what extent to you think that the open fields (i.e. in grey) in step 4 for creating the detailed business model enabled the contextualisation of the CEBMs to you company's reality? | 1 - It did not help with contextualisation<br>4 - It enabled contextualisation to the company's own reality and helped ideation about expected benefits, engaged actors and value proposition |
| Subjective degree of difficulty<br>Definition of difficulty: effort required | Pc22 - To what extent do you think it was difficult to generate the value proposition? | 1 - Difficult<br>4 - Easy |
| Confidence level | Pc23 - How confident are you with the result in steps 2 and 3? | 1 - Not confident<br>4 - Confident |
| Changes in the value proposition occurred from step 3 to step 4 | Pc24 - To what extent did the suggestions of offerings, overall benefits or benefits for customer and partners contributed or required modification of the value proposition? | 1 -No modifications<br>4 - Several modifications |
| Flexibility to simulate and change advices in steps 2,3,4: | Pc25 - To what extent did you change the selected solution patterns (step 2) or combinations of those (step 3) with iterations (i.e. several attempts)? | 1 -No modifications<br>4 - Several modifications |
| Subjective degree of difficulty<br>Definition of difficulty: effort required | Pc26 - To what extent was it difficult to perform the iterations? | 1 - Difficult<br>4 - Easy |
| Degree of understanding of CEBMs in a collaborative space (i.e. group discussion, validations) | Pc27 - To what extent do you think that the sequence of visualisations (steps 2, 3 and 4) support the company and participants in gradually improving the level of understanding about the future potential of CEBMs? | 1 - Poorly<br>4- Highly |

Table A5 - Performance criteria (Pc) for Module 4 of the CEBMES.

| Performance criteria (Pc) | Question to respondents about performance criteria | Evaluation options (Likert Scale) |
|---|---|---|
| Subjective degree of usefulness<br>Definition of visibility: access to organised data that can help synthesis and decision-making | Pc28 - To what extent did the evaluation support to a business case enabled visibility and useful considerations about the feasibility of the CEBMs? | 1 - No visibility<br>4 - High visibility |
| Subjective degree of sufficiency<br>Definition of sufficiency: enough and the right ones for calculation. | Pc29 - To what extent are the indicators for the economic evaluation sufficient (i.e. enough and the right ones for the purpose)? | 1 - Not sufficient<br>4- Sufficient |
| Subjective degree of sufficiency<br>Definition of sufficiency: enough and the right ones for calculation. | Pc30 - To what extent did the evaluation support to a business case enabled visibility and useful considerations about resource decoupling potential of the CEBMs? | 1 - No visibility<br>4 - High visibility |
| Subjective degree of sufficiency (i.e. enough and the right ones for calculation) | Pc31 - To what extent are the indicators for the resource decoupling evaluation sufficient (i.e. enough/ right ones for the purpose)? | 1 - Not sufficient<br>4- Sufficient |

| | | |
|---|---|---|
| Subjective grade of confidence<br>Definition of confidence: results allow or motivate the company to move forward with investigations (e.g. experiment to test assumptions, refine simulations, approve solutions with the board or attract funding) | Pc32 - To what extent the collection of evidence (i.e. information and visualisations about economic, resource decoupling, customer value potential) enabled by the tool supported the company in moving forward with the implementation of the CEBMs (e.g. experimenting to verify assumptions, approving the business case in the company´s governance)? | 1 - Poorly<br>4- Highly |
| Subjective grade of confidence<br>Definition of confidence: results allow or motivate the company to move forward with investigations (e.g. experiment to test assumptions, refine simulations, approve solutions with the board or attract funding) | Pc33 - To what extent the considerations about action plans (i.e. to tackle trade-offs or rebound effects) enabled by the tool supports the company's argumentation in moving forward with the implementation of the CEBMs (e.g. experimenting to verify assumptions, approving the business case in the company´s governance, obtaining findings)? | 1 - Poorly<br>4- Highly |
| Subjective measure of satisfaction with trainings<br>Definition of satisfaction: added clarity and enabled independent use by the facilitator | Pc34 - To what extent were you satisfied with the trainings including webinar and material (i.e. they were clear and enabled independent use of the tool by you)? | 1 - Not satisfied<br>4 - Very satisfied |
| Subjective degree of difficulty<br>Definition of difficulty: effort required | Pc35 - To what extent were these tools easy to use? | 1 - Difficult<br>4 - Easy |
| Subjective degree of difficulty<br>Definition of difficulty: effort required | Pc36 - To what extent did they add value? | 1 - None<br>4 - Highly |
| Subjective grade of engagement<br>Engagement: actively involved in the decisions and discussions promoted by the tool | Pc37 - To what extent were decision makers from the companies actively engaged (i.e. involved in the discussions and decisions) during the use of the tool (process)? To what extent there were a steering group or sponsor engaged with the project? | 1 - None<br>4 - Highly |
| Subjective grade of resistance<br>Resistance: difficulties to explore different ideas; difficulties to think out of the linear logic | Pc38 - To what extent did you identify resistance to change form participants engaged in the process of BM innovation/design? | 1 - None<br>4 - Highly |
| Subjective degree of difficulty<br>Definition of difficulty: effort required | Pc39 - To what extent do you think it was difficult to use the tool? | 1 - Difficult<br>4 - Easy |
| Subjective degree of difficulty<br>Definition of difficulty: effort required | Pc40 - To what extent was STEP 1 difficult to use? | 1 - Difficult<br>4 - Easy |
| Subjective degree of difficulty<br>Definition of difficulty: effort required | Pc41 - To what extent was STEP 2 difficult to use? | 1 - Difficult<br>4 - Easy |
| Subjective degree of difficulty<br>Definition of difficulty: effort required | Pc42 - To what extent was STEP 3 difficult to use? | 1 - Difficult<br>4 - Easy |
| Subjective degree of difficulty<br>Definition of difficulty: effort required | Pc43 -To what extent was STEP 4 difficult to use? | 1 - Difficult<br>4 - Easy |
| Subjective degree of difficulty<br>Definition of difficulty: effort required | Pc44 -To what extent was STEP 5 difficult to use? | 1 - Difficult<br>4 - Easy |
| Subjective degree of difficulty<br>Definition of difficulty: effort required | Pc45 -To what extent was STEP 6 difficult to use? | 1 - Difficult<br>4 - Easy |
| Subjective degree of difficulty<br>Definition of difficulty: effort required | Pc46 -To what extent was STEP 7 difficult to use? | 1 - Difficult<br>4 - Easy |
| Subjective degree of clarity<br>Definition of clarity: logical sequence of steps and easy to follow | Pc47 -To what extent do you think the tool provided a logical sequence of steps and easy to follow to complete the innovation or design of business models for circular economy? | 1 - Not logic<br>4 - Logic |
| Subjective degree of usefulness<br>Definition of visibility: helped in maturing or strengthening CEBMs | Pc48 - To what extent did the CE- Driven Business Model Configurator helped you in maturing or strengthen CEBMs? | 1 - Poorly<br>4- Highly |

## Appendix B – Evaluation of CEBMES in each module

Figures B1, B2 and B3 presents the results of the evaluations across the CEBM modules.

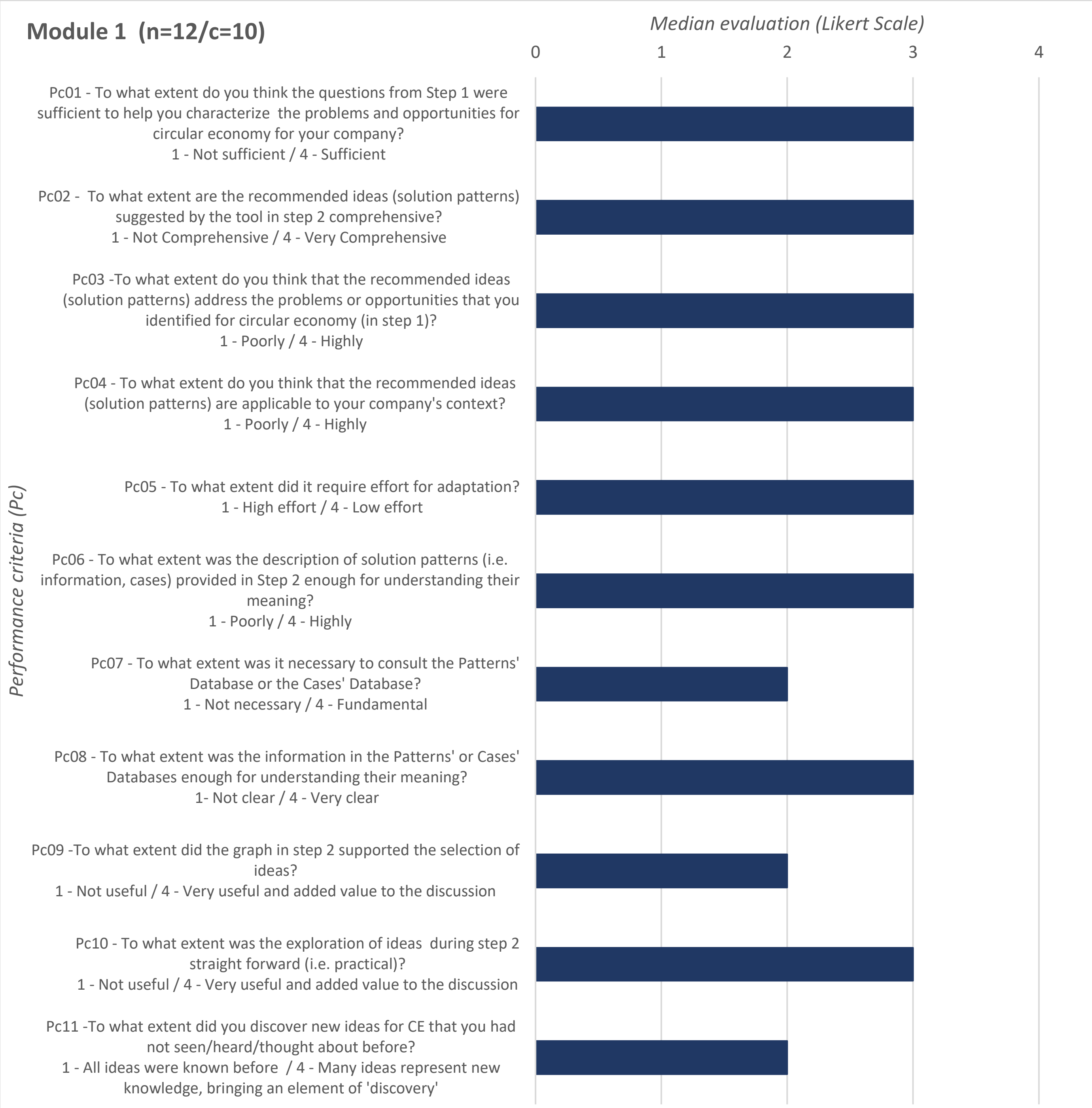


Figure B1 – Evaluation of Module 1 (Legend: n=number of respondents/c= number of companies).

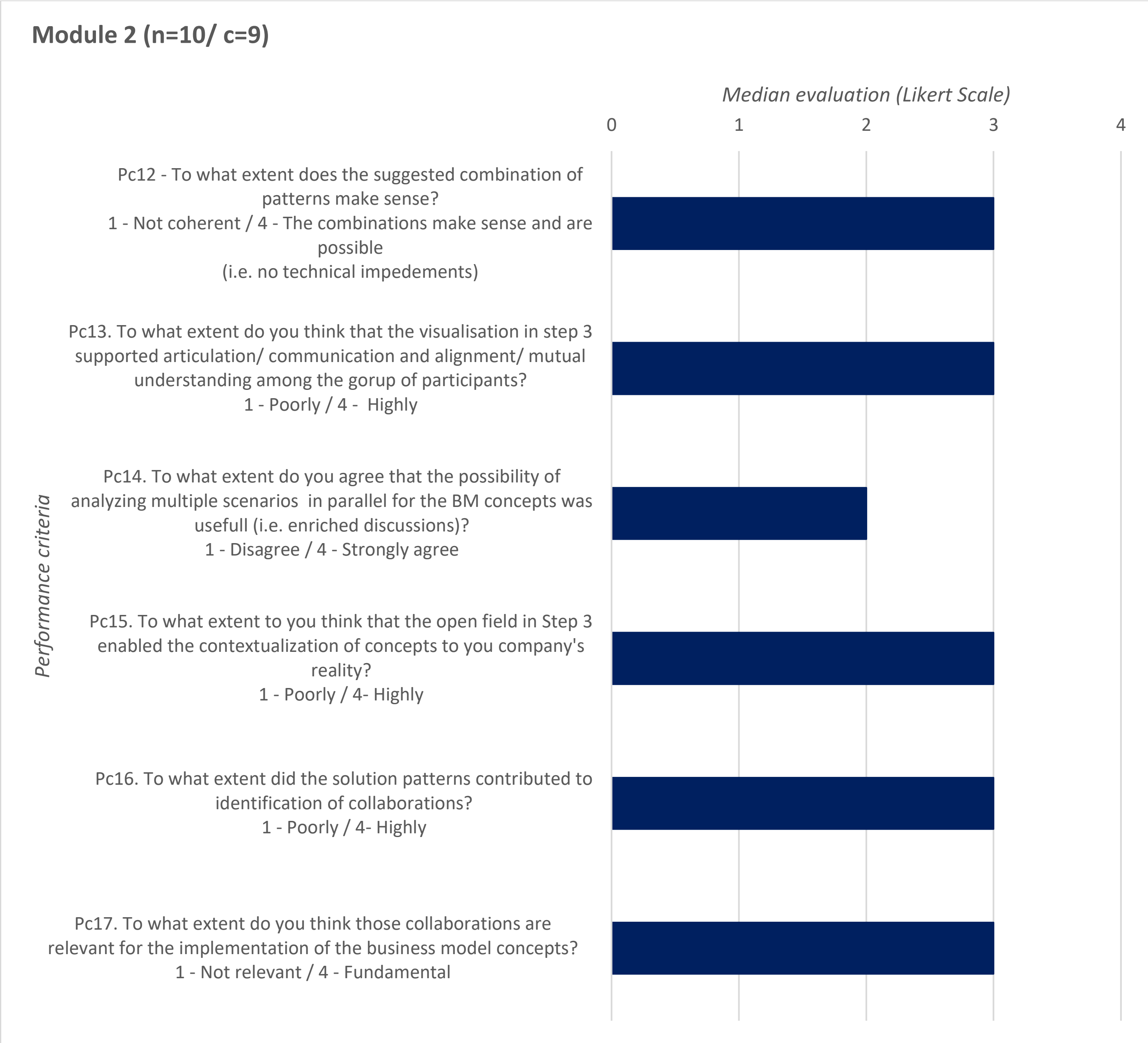


Figure B2 – Evaluation of Module 2 (Legend: n=number of respondents/c= number of companies).

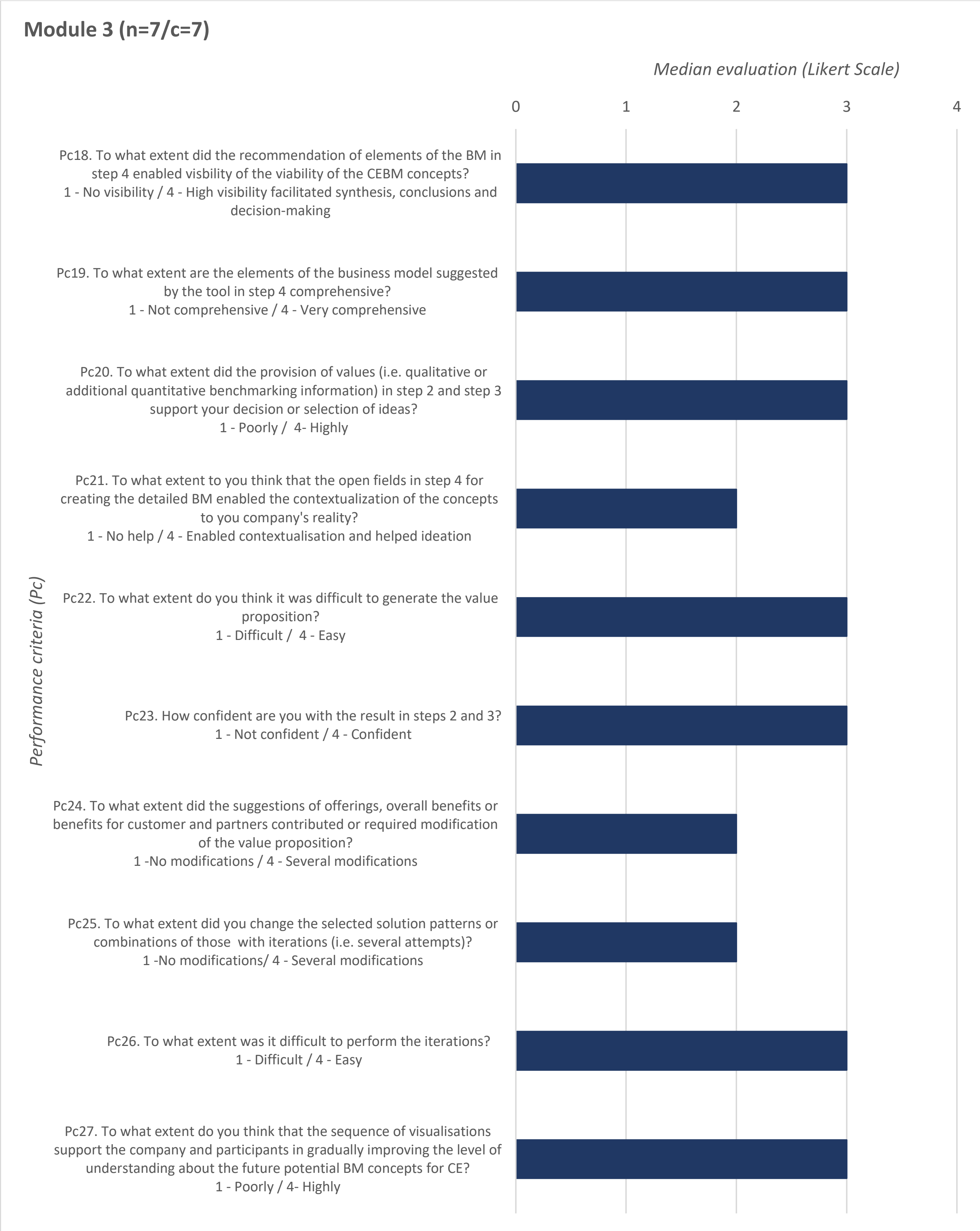


Figure B3 – Evaluation of Module 3 (Legend: n=number of respondents/c= number of companies).

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