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Research article

Making the transition to a Circular Economy within manufacturing companies: the development and implementation of a self-assessment readiness tool ☆

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ABSTRACT

Circular Economy (CE) is a key approach to supporting a transition towards sustainable growth. However, due to the lack of understanding of readiness for the CE transition, manufacturing companies still face a number of challenges in successfully implementing CE. This paper describes the development of a CE readiness self-assessment tool, *MATChE* (MAking the Transition to a Circular Economy), following iterative cycles of theoretical development and empirical co-development with potential users. The resulting web-based platform enables a self-assessment of manufacturing companies' readiness to transition to CE. In addition to allowing the understanding of strengths and gaps for CE implementation across eight key dimensions (e.g. strategy and business model innovation), the tool enables internal and external benchmarking studies (at the company or business unit levels); the prioritisation of focus areas based on strategic drivers; and the development of transition paths with support of CE-related tools, methods and approaches. The MATChE tool is, at the time of writing, supporting over 330 manufacturing companies (incl. 900+ users), spread across 16 manufacturing sectors and 38 countries. Future research is ongoing to minimise the limitations of the tool and expand its scope beyond manufacturing companies, in a number of different directions (e.g. service providers and waste management companies).

1. Introduction

The increasing recognition of the need to mitigate the effects of population growth, wealth increase and human consumption is currently leading several international organisations, such as the European Union (EU) (European Commission, 2019), the Organisation for Economic Co-operation and Development (OECD) (Steffen et al., 2015; OECD 2018, 2019) and the United Nations (UN) (UN, 2020), to consensually highlight the need for a significant change in our economic system, in order to respect the planetary boundaries (Steffen and Stafford Smith, 2013; Häyhä et al., 2016). In this context, Circular Economy (CE) has emerged as a key approach to support sustainability transition and enhance industry competitiveness, towards sustainable growth (European Commission, 2020). CE is defined as "an economy that provides multiple value creation mechanisms, which are decoupled from the consumption of finite resources" (Ellen MacArthur Foundation, 2015b), which is particularly relevant within the context of manufacturing companies (Pieroni et al., 2021a; Lieder and Rashid, 2016). A successful transition to CE requires a systemic change in the way companies understand and do business, with sustainability as a strong foundation (Kravchenko et al., 2019; Millar et al., 2019).

Currently, industry is faced with a duality of opportunities and challenges (Hopkinson et al., 2018), as described in the following. The potential sustainability and business benefits from adopting a circularity mindset in industry are significant. In Europe alone, the business benefits linked with CE are estimated to be ca. 1.8 trillion Euro per year up until 2030 (Ellen MacArthur Foundation, 2015b). Nevertheless, despite the increased interest in CE implementation and the large amount of research and governmental incentives (van den Bergh, 2020), companies still face challenges in successfully implementing CE (Bocken et al., 2016). Once having decided to implement CE, the key challenges faced by manufacturing companies are connected to:

- Systemic nature: creating a CE requires fundamental changes throughout the value chain (Bressanelli et al., 2020), from new business model innovation (Galvão et al., 2020), product/service design (Blomsma et al., 2018; Pigosso et al., 2014) and production processes all the way to consumption patterns

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(Geissdoerfer et al., 2020) and end-of-life scenarios (EEA, 2016; Hopkinson et al., 2020).
- High complexity: new uses of existing material flows increases the boundaries and the complexity of CE systems (Korhonen et al., 2018). Furthermore, the evaluation of the sustainability performance of CE systems presents high complexity (Kjaer et al., 2019; Rodrigues et al., 2017).
- High risks: the systemic nature and high complexity of CE also leads to high risks in the implementation of CE businesses (Trigkas et al., 2020). Furthermore, a number of risks associated with managing hazardous substances in a circular system exist (Bodar et al., 2018).
- Multi- and inter- disciplinarity: the complexity and novelty of CE requires the combination of a number of disciplines, such as natural sciences, engineering, business, economics and management (Sauvé et al., 2016), which takes extra effort to orchestrate.
- Lack of knowledge: a successful CE implementation in companies requires new knowledge, capabilities and skills (e.g. ranging from material composition to social behaviour) (De los Rios and Charnley, 2017; Kalar et al., 2021).

The aforementioned challenges are mostly experienced by companies that have already decided to investigate the potential of transitioning for a CE, which correspond to the main scope of this research. Nevertheless, it is important to highlight that the existence of other business-oriented challenges (e.g. economic barriers, value chain barriers, legal barriers, risk barriers (Rizos et al., 2016)), as well as theoretical challenges (e.g. as the lack of a consistent CE definition (Kirchherr et al., 2017), incl. social and cultural definitions of waste (Korhonen et al., 2018)), also play an important role in hindering the transition to CE.

Manufacturing companies play a key role in CE implementation, due to their strong contribution to the economy and significant influence in creating, delivering and capturing value from new products and services across the entire value chain (Pieroni et al., 2021b). It is estimated that only 2-5% of companies have currently successfully implemented circular business models (OECD, 2018). The *circularity gap* (measured in terms of the share of virgin materials in relation to the total material consumption, based on the System of Environmental-Economic Accounting) is currently growing (de Wit et al., 2020), indicating that CE is still insufficiently implemented worldwide.

Momete states that the limited implementation of CE might be linked to a lack of analytical diagnosis tools, which could offer the big picture about the readiness of companies and economies to migrate from an unstainable linear model to a sustainable circular one (Momete, 2020) On the one hand, the lack of understanding of the companyś readiness before starting out on the journey towards CE leads to a higher chance of failure during the implementation (Zhang et al., 2020). On the other hand, the assessment of readiness before heavily investing resources into the necessary change process is known to increase the probability of success of initiatives (Rodgers et al., 2021) and ensure a more effective implementation of complex changes (Weiner, 2009).

To address these challenges and enhance the potential success of CE implementation in manufacturing companies, this paper describes the development of a CE readiness self-assessment tool, *MATChE* (MAking the Transition to a Circular Economy), which aims to deliver four elements of support for CE transition within manufacturing companies:

(i) understanding strengths and gaps for CE implementation.
(ii) perform internal and external benchmarking.
(iii) prioritise focus areas.
(iv) plan transition paths with support of CE-related tools, methods and approaches.

The next section (Section 2, Literature review) describes the theoretical foundation for readiness assessment, highlighting existing studies tackling CE readiness at different levels of analysis. It is followed by a detailed description of the scientific approach employed for the development of the tool (Section 3, Methods), including the theoretical development based on state-of-the-art review within readiness assessment approaches, as well as strong stakeholder engagement for the empirical co-development through action research and case studies, aimed at enhancing the tool's usefulness and usability. Section 4, Results, presents the final version of the tool, its key features and the key steps taken for its application. The key findings are further discussed in Section 5, Discussion. Finally, the key limitations and potential future research are highlighted in Section 6, Conclusion.

2. Literature review

The concept of organisational readiness for change is explored by a number of different disciplines, such as management, health, information technology and engineering (Weiner, 2009). Organisational readiness is defined as a comprehensive attitude that is influenced by four main areas: the content of the change (i.e. 'what'); the change process (i.e. 'how'); the context of the change (i.e. 'where'); and the individuals involved in the change (i.e. 'who') (Holt et al., 2007). In that sense, the readiness concept refers to "the state of being both psychologically and behaviourally prepared to take action (i.e., willing and able)" (Weiner, 2009).

Readiness assessments aim to provide a systematic analysis of an organisation's ability to change and transition to a new desired state (Jöhnk et al., 2021), with an indication of opportunities, gaps and potential challenges (Pirola et al., 2019). The readiness assessment can be performed through qualitative (i.e. interviews and observation) or quantitative (i.e. surveys and questionnaires) approaches, and special emphasis should be given to the reliability and validity of the results (Holt et al., 2007). By assessing the readiness level, companies can get a situational analysis of current readiness, as a starting point for prioritising action. The current readiness can also be used as a benchmark for comparison, to support the transition process (Pirola et al., 2019). Studies have also demonstrated the relevance of readiness assessments within complex changes, involving one or more organisations (Blackman et al., 2013), as a precondition for innovation (Halpern et al., 2021), and as the best early indicator of how organisations will respond to introducing new business systems (Ochurub et al., 2012).

Within the broad CE literature, initial studies focused on readiness assessment on numerous levels, including: at a country level (Momete, 2020; Garcia and Cayzer, 2019); at a sectorial level (Siew, 2019); at an ecosystem level (Parida et al., 2019); at the regional level (Pigosso et al., 2018); and at the level of individual readiness of employees (Singh et al., 2018), as following described.

In 2019, Garcia and Cayzer (2019) proposed the assessment of CE transition readiness at a national level, demonstrated in a Colombian case. The framework contains a combination of top-down (i.e. policy and legislation, supportive infrastructure and awareness) and bottom-up enablers (Information and communications technology (ICT) and Business models Design & Supply Chain) (Garcia and Cayzer, 2019). One year after, Momete (2020) proposed a unified framework for assessing the readiness of European Union economies to migrate to a circular modelling, based on the evaluation of the three sustainability pillars (i.e. economic, social and environmental). In addition to enabling benchmarking at a country level, the framework also supported the identification of systemic interventions needed by the EU in the path towards circularity.

Siew (2019) evaluated the readiness for CE in the construction sector in Malasya based on a survey questionnaire with 100+ respondents. The survey measured the CE readiness in the sectorial

level based on the evaluation of five indicators (i.e. input in the production process, utility during the use phase, destination after use, efficiency of recycling and complementary risk indicators), following a Likert scale ranging from 1 (not ready) to 5 (extremely ready) (Siew, 2019). At an ecosystem level, Parida et al. (2019) developed a two-stage transformation model for orchestrating industrial ecosystems in CE. The ecosystem readiness assessment evaluates trends and regulatory trends across three areas: (i) the external environment, (ii) business model, and (iii) ecosystem partner (Parida et al., 2019).

At the regional level, Pigosso et al. (2018) propose the evaluation of the readiness for industrial symbiosis collaborations across co-located companies in a given region , actively supported by the involved municipalities. The readiness is evaluated using a 10-point Likert scale across ten different areas: resource minimisation potential, reuse/recycle potential, change of raw materials potential, waste commercialisation potential, potential for business model innovation, investment potential, readiness to cooperate and communicate, readiness for knowledge sharing and experience in managing trade-offs. Finally, at the level of the individual employees, Singh et al. (2018), developed an extended theory of planned behaviour model considering attitude, social pressure, perceived behavioural control, environmental commitment and green economic incentives (Singh et al., 2018).

Despite the range of existing readiness approaches listed here, no readiness approaches address the company organisational level, which is fundamental for supporting the transition to a CE. Furthermore, none of the approaches identified follow a life cycle perspective, and none of them provide the possibility to perform a benchmark with other (internal or external) business units, nor do they couple these to advice regarding how to make a transition to CE, based on their identified readiness.

3. Methods

Assisting companies within the manufacturing sector to assess their readiness to transition to CE must take point of departure in the relevant knowledge within the field, to the context of a typical manufacturing company. For this reason, the development of the MATChE CE readiness self-assessment tool was carried out based on a strong methodological approach, in order to ensure: (i) the inclusion of relevant dimensions to the industry branch; (ii) the inclusion of state-of-the-art science-based knowledge from literature, following the systematic literature review method (Biolchini et al., 2005); (iii) a transparent, verified and validated process to the development of the tool based on action research (Coughlan and Coghlan, 2009) and case studies (Yin, 2006) methodology; and (iv) a repeatable and updatable tool design, allowing for later adaptations, to other industry fields than the manufacturing industry.

To ensure the above quality dimensions in the design and development of the MATChE self-assessment readiness tool, three development cycles were applied before launch (Fig. 1).

3.1. Cycle 1: theoretical development

The first step in the MATChE tool development process was to carry out a literature review, to firstly ascertain important success factors, drivers and barriers for company transition to CE. As the field of CE is relatively young, related studies regarding the adoption of sustainability strategies in general were also studied in the literature review. Two main enquiries were developed in the literature review, to enable the first iteration of the readiness assessment tool, namely: (i) literature regarding readiness assessment approaches, to inform the definition of readiness steps (Section 3.1.1); and (ii) literature regarding necessary dimensions for manufacturing companies to master, when working with CE (Section 3.1.2).

3.1.1. Developing a readiness scale

To elicit literature regarding readiness assessment approaches, an iterative process was applied to develop the following search string in Scopus: *TITLE (readiness) AND TITLE-ABS-KEY ((transition OR "change management") AND (organi?ation*) AND (scale OR measure OR evolution OR likert))*. The search in Scopus resulted in 28 relevant papers, which were further evaluated in relation to the following inclusion criterion *"papers should include the definition of a scale for measuring organisational readiness"*, resulting in nine papers being finally selected. A common characteristic of the majority of the identified studies was that they used a five-point Likert-scale (e.g. ranging from 1 (strongly disagree) to 5 (strongly agree) (Haffar et al., 2014; La Lopa and Day, 2011; Zephir et al., 2007), adapted to their specific aims (e.g. the ability of performing a given task; from not being able to perform a task to being able to support others to perform a task) (Wijnen-Meijer et al., 2012). On the basis of the scales derived from the literature study, the generic five-point Likert scale was decided, spanning: "1 – Not ready; 2 – Low readiness; 3 – Medium readiness; 4 – High readiness; and 5 – Ready". A frequent challenge with generic Likert scales is that they can be subject to multiple and inconsistent interpretations, thus essentially rendering them unusable, not least if they are to be used for benchmarking. For this reason, the readiness scale was customised for the CE self-assessment, as described in Section 4.1.

3.1.2. Developing readiness dimensions and aspects

Gaining an understanding of the necessary dimensions of importance for CE transition was a more involved process, taking point of departure in a comprehensive review of literature to identify circular economy dimensions and aspects reported in the literature. Given that the field was subject to significant scientific and societal (grey literature) attention at the time of development of the readiness self-assessment tool, key systematic literature reviews (Lieder and Rashid, 2016; Tukker, 2013; Ghisellini et al., 2016; de Jesus et al., 2016; Heshmati, 2017; Masi et al., 2017; Liu et al., 2017) on circular economy formed the basis of the review of the scientific literature, whereas material (white papers, reports) from the European Union (European Commission, 2015), Ellen MacArthur Foundation (Ellen MacArthur Foundation 2015b; Webster, 2015; Ellen MacArthur Foundation 2015a, 2012, 2013b, 2013a) and SITRA (SITRA, 2016), the key organisation behind the World Circular Economy Forum, formed the point of departure for the grey literature. The following search string was used in Scopus as a starting point for the literature review, to elicit CE dimensions and aspects of importance to consider for industry, when transitioning to CE: *TITLE (("circular economy" OR circular?) AND (implementation OR transition OR change OR practice OR business OR application OR pursuit OR deployment OR execution))*, resulting in 82 documents. From these, the papers which presented business processes or life cycle areas of relevance and particular activities, achievements, or initiatives were selected; resulting in 61 relevant articles.

3.2. Cycle 2: low-definition prototype for expert testing

On the basis of the 61 identified articles in the literature review, five initial CE dimensions were identified, covering: organisational readiness; business model readiness; market readiness; (product and service) offerings readiness; and operations readiness. Each of the five CE readiness dimensions were detailed according to five CE aspects, summing up to 25 formulated CE readiness questions for the first prototype of the readiness assessment tool.

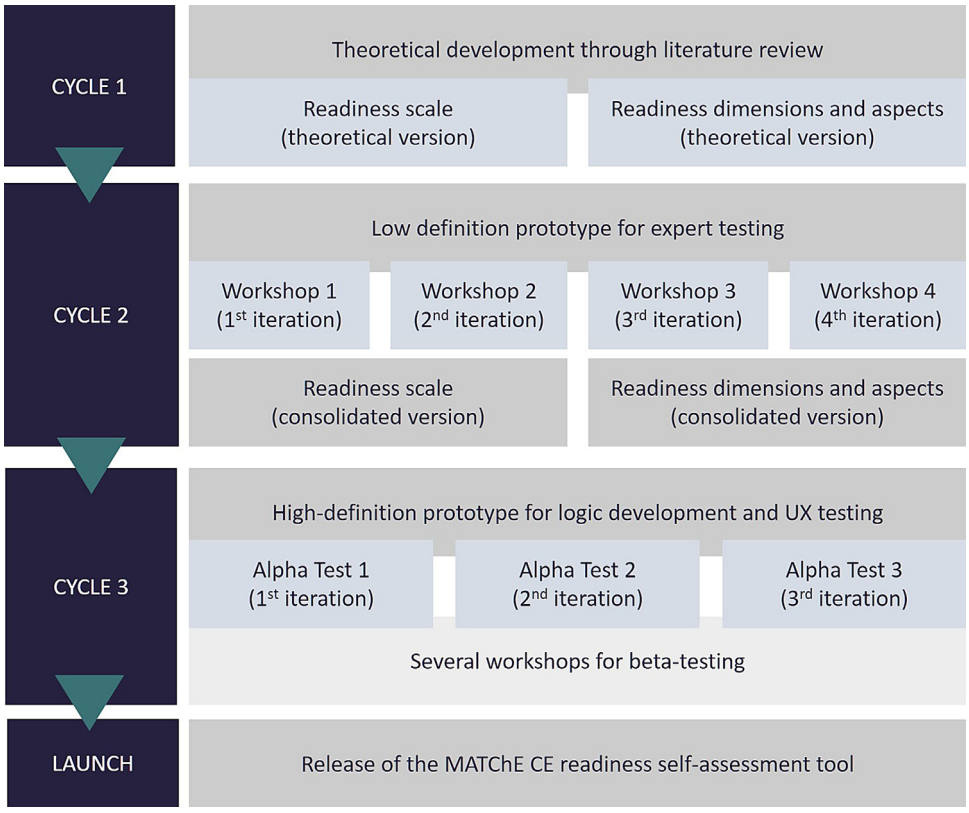


Fig. 1. Overview of the main cycles and steps carried out for the development of the MATChE CE readiness tool.

Fig. 2. (a) First low-definition (paper-based) prototype of MATChE CE readiness assessment tool; (b) workshop 2 with 35 environmental directors from Danish industry.

The low-definition prototype of the CE readiness tool was prepared as a paper-based prototype, with the intention of testing among experts (Fig. 2a). A paper-based prototype was purposely chosen to ensure focus on the contents and logic of the self-assessment tool, and not the user interface or functionality, which were not in focus here.

The low-definition prototype was subjected to four iterations, based on expert feedback in four controlled workshop environments. In total, 75 potential users of the tool were involved in the workshops, as further described. The participants could freely choose what would be the input context for the self-assessment (e.g. the entire company or a specific business unit), to allow for a

broader test of the tool. In all workshops, data regarding the readiness assessments performed by the participants were not shared with the researchers, as the workshop process was designed to collect feedback regarding the dimensions, questions, and the readiness scale (and not the readiness results). Furthermore, the involved participants were fully aware of the stage of the research, and the inherent limitations in relation to the quality of the output data to support decision-making. The low-definition prototype was enhanced from one workshop to the next, enabling an iterative development and test of new features and elements (i.e. the final workshop corresponded the test of the third iteration of the low-definition prototype which was enhanced after the first workshop (1st iteration), second workshop (2nd iteration) and third workshop (3rd iteration) – resulting in the development final 4th iteration.

The first workshop aimed to test the low-definition prototype amongst 15 Life Cycle Assessment (LCA) and ecodesign experts from Danish companies, all operating at the 'specialist' level in their respective companies (including ARLA, Novo Nordisk, Coloplast, Danfoss, Grundfos, LEGO Group, etc.). This workshop reaped very detailed feedback on the readiness scale, the aspects presented and highlighted key gaps in the dimensions and aspects, leading to a new version of the prototype, with adjusted dimensions and aspects. The test population within the workshop were an important reference for the process, as they were members of a closely collaborating open industry interest group, within which the authors were also a member, leading to high trust and therefore direct and honest feedback. The respondents represented mostly the tactical and operational layers of their respective companies.

The second workshop enabled the test amongst 35 sustainability and environmental managers and directors from 35 Danish companies, as part of the Confederation of Danish Industry's Director Forum for Environmental Affairs (Fig. 2b). This workshop, presenting the second iteration of the tool, brought new insights into the necessary iteration of the tool development, due to: (i) it's presentation to potential users at the tactical (management) and strategic (director) levels of companies; and (ii) a broader reach to companies from numerous sectors (heavy industry, electronics, butchers, medico, construction, fast moving consumer goods, etc.). The feedback gained from this workshop uncovered the need to include a more market-oriented view, a consideration of policy drivers and barriers, and a more astute focus on the organisational aspects of CE transition.

In the third workshop, the CE readiness self-assessment prototype was tested amongst 25 sustainable product development researchers, within the authors' own research network. This workshop ensured an expert-critical view on particularly the aspects and dimensions of the CE readiness assessment tool, questioning of the need for an equal amount of aspects covered under each dimension, and pointing out gaps and overlaps between some aspects. A thorough re-work of the dimensions and aspects was the main outcome of this workshop.

Finally, the fourth workshop involved a new test amongst the 15 LCA and ecodesign specialists from Danish companies (same group as workshop 1), in order to verify and validate changes and developments applied since the first iteration. This workshop saw the last iteration of the paper-based prototype, which gained positive feedback regarding the new organisation of dimensions and aspects, but added a further dimension of 'Technology and Data', to capture the importance of the Internet of Things (IoT) and data-driven solutions to CE. The low-definition prototype resulted in an extensively iterated and validated concept for the CE readiness assessment tool, with a total of eight CE dimensions and 30 aspects (questions) and further described in Section 4.1.In addition to enabling the consolidation of a robust and industry-relevant set of dimensions and aspects, Cycle 2 also supported the definition of key features for the development of the MAThE tool:

(i) Assessment of CE readiness at different levels in the organisation (i.e. both at the company and the business unit levels): this feature is especially relevant for large organisations with different readiness across different business units.
(ii) Company-wide assessment, enabled by the possibility of engaging colleagues from different functions, covering a diverse skill set: this feature has been deemed relevant due to the need for cross-functional collaboration, avoiding the bias of just one representative within each company providing an often narrower view of the company's readiness.
(iii) Benchmark within the organisation, both internally (across different business units) and externally (with companies from similar sectors, regions and/or sizes): this feature is relevant to create the sense of urgency and alignment required for the CE transition.
(iv) Support for the development of transition paths, so to support companies in the prioritisation of the most relevant dimensions/aspects and the identification of the most relevant tools and methods to support the transition.

The aforementioned features were transformed into a requirements list and served as a key input for the development of the high-definition prototype, in Cycle 3.

3.3. Cycle 3: high-definition prototype for logic development and UX testing

On the basis of the identified requirements for the CE readiness self-assessment tool, the second prototype of the tool was built as a digital *'works-like, looks-like'* prototype. The tool was programmed from the bottom-up as PHP-based web-platform, on a secure server, to ensure data security for the later development of the final tool.

The web-based prototype of the MAThE CE readiness self-assessment tool consisted of a fully operational version of the tool, which included not just the contents of the CE dimensions and aspects, but also the logic behind the scoring of individual readiness levels and combined readiness levels of multiple contributors from the same organisation.

The logical flow development behind the tool was designed to encourage high quality and robust data from the users, in order to: (i) provide a transparent and trustworthy presentation of the readiness score for the company or the business unit being assessed; and (ii) ensure good conditions for the analysis of the delivered data through the resulting tool.

In preparation for the development of the web-based prototype of the tool, a study of the user experience (UX) design was carried out, by following a User Centred Design methodology (Abras et al., 2004), and entailing extensive user-journey mapping (Patton and Economy, 2014), storyboarding and user interface design (Saffer, 2013). This element of the development of the tool will not be detailed or discussed in any further detail, within this paper. The high-definition prototype was subjected to iterations in alpha-version and beta-versions (King et al., 2017). The three iterations of the alpha-version of the tool entailed the following test procedures:

- Test 1: Initial testing of the tool with 22 internal research colleagues (professors, researchers, PhD students, admin staff), to ascertain the reliability, usability and user journey experience of the tool. This test revealed many implicit shortcomings of the tool that were based on the authors having taken certain usability aspects for granted, which other colleagues did not quite catch.

- Test 2: Volume testing among three classes, ranging from 40-70 masters students, in order to: 'stress-test' the tool, regarding its usability within given scenarios; test its ability to act as an aggregator of multiple inputs; and test the integrity of the server, when receiving multiple responses. These tests gave many insights into the need for a more simplified user journey, and significant improvements in the registration and identification process, which posed teething troubles in the start. Tests within this group were repeated multiple times, on a voluntary basis by the students.
- Test 3: Alpha testing within the 15 LCA and ecodesign specialists (same group from 'low-definition' workshops 1 and 4), to ascertain feedback, regarding the digitisation of the tool, based on their earlier experiences and advice. The feedback from these trusted colleagues was invaluable, due to their extended prior investment into the testing of the tool. The tool was also released to these colleagues for test and feedback with their respective companies, either as facilitators themselves, or in collaboration with the authors.

On the basis of the three iterations in alpha-version, the project moved to the development of a beta-version, for own-use when facilitating workshops with single or multiple companies present.

The beta-testing of the tool was achieved through 20 workshops, in numerous constellations, ranging from single-company workshops (with between 15-80 delegates), to branch organisation workshops (often around 30 delegates from 30 companies), and many other setups, in between. The main learnings, at this stage, were about the reliability of the software platform for the tool, which needed to be upgraded to a dedicated server, in order to be able to cope with numerous simultaneous users, without experiencing server time-outs. After various iterations – and around 300 registered users on the tool's web platform – a full release of the tool (for standalone usage) was announced.

The detailed self-assessment approach for CE readiness is further described in the Section 4.1, which contains the step-by-step approach for the CE readiness self-assessment and key features, as well as the detailed description of the final dimensions and questions. The application in a real world setting by users is exemplified in Section 4.2, which described the current user status of the tool and provides as exemplary demonstration.

4. Results

The resulting 'MATChE CE readiness self-assessment tool', from the research, assessment, prototyping and co-development process, is a stand-alone tool that can help manufacturing companies to carry out a self-assessment of its readiness to transition to CE.

4.1. Step-by-step approach for the CE readiness self-assessment and key features

The MATChE CE readiness self-assessment tool supports a ten-step approach, which starts with the identification of the current readiness profile and evolves towards planning the implementation and CE transition process (Fig. 3):

Step 1 starts when the user creates a user profile in the MATChE tool (www.matche.dk). The tool works by recognising the domain of a user's email address (e.g. "@companyname.com") as the identifier for the company to which the user belongs. The first time a new domain name is registered by a user, the 'parent user' will be asked to provide basic details of the company, such as a company name, primary sector, market type (business-to-business (B2B), business-to-consumer (B2C), business-to-government (B2G)), size, country, etc. These data are subsequently verified by the research team maintaining the tool, who further enhances the company profile by applying a specific company sector code, according to the Danish industrial classifications code "Dansk Branchekode 2007 (DB07)" (Statistikbanken, 2020), which is the national classification system based on the "Statistical Classification of Economic Activities in the European Union: NACE rev. 2" (Eurostat, 2008). All subsequent users with the same email domain will be associated with the same company, to enable them to contribute to the same readiness assessment(s). Clustering of multiple domains (i.e. for large holding companies with many sub-brands) is also possible, but from the tool administrator side, only.

It is important to highlight that not all users on the MATChE tool are within the intended scope of 'manufacturing companies'; in fact, at the time of writing about 1/3 of all users belong to 'out-of-scope' organisations, i.e. non-manufacturing companies, service companies, consultancies, universities, government agencies, etc. Whilst it is important, from a research perspective, to keep the data in the platform used for benchmarking and statics 'clean', the authors also recognised that the readiness assessment tool and its related tools would be of high interest to 'out-of-scope' users. It was therefore decided to make the tool available to out-of-scope users, but to: (i) exclude the data entered by an 'out-of-scope' user from the statistics calculations; and (ii) disable an out-of-scope user from carrying out an external benchmark from among the 'in-scope' companies on the tool.

Step 2 involves the selection of the scope for the readiness self-assessment (i.e. the entire company or a specific business unit). By default, the CE readiness assessment tool establishes a 'company level' readiness profile. Based on the recognition, however, of the fact that a given company might have numerous business units, which might have differing levels of CE readiness, the tool allows for the unlimited creation of business units by the user, where all company participants on the tool can contribute to one or more business unit and/or the 'company level' readiness assessment. The MATChE tool aggregates the readiness scores from business units up to the company level readiness score, whilst also maintaining a readiness score on the basis of each business unit.

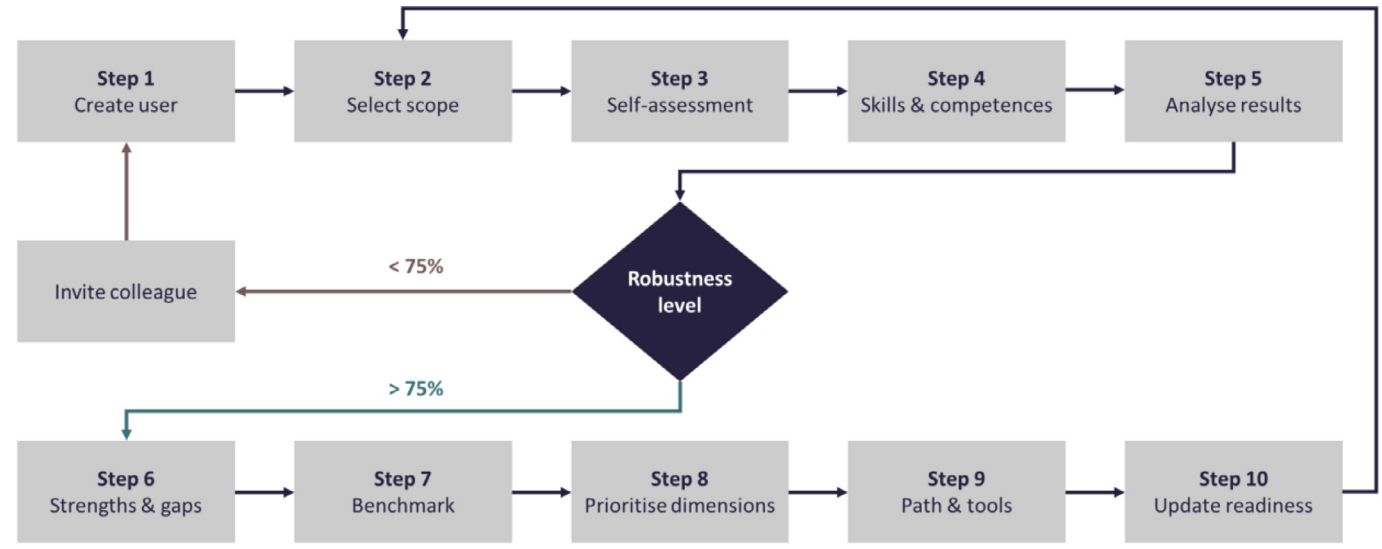
The user then answers the 30 readiness questions, across the eight CE readiness dimensions (Step 3), using the readiness scale designed according to the Likert system, with descriptors that enable a uniform answer from each respondent: 1: Understanding the potential; 2: Planning pilot implementation; 3: Piloting initiatives; 4: Planning scale up; and 5: Scaling up initiatives. The MATChE CE readiness self-assessment tool comprises a total of 8 CE dimensions and 30 aspects (questions), following combined business process and life cycle perspective (Table 1).

In Step 4, the user is required to define their skills and expertise areas, which will be used for calculating the robustness of the self-assessment. The tool has an in-built feature of recording expertise areas of each user. The expertise areas that the user can rate themselves on are: Maintenance and after-sales; Sales and marketing; Supply chain management and operations; Sustainability; Product and service innovation; Change management; Market intelligence & business development; Reverse logistics and waste management; Compliance, standardisation and lobbying. By rating themselves on a 1-5 Likert scale for each of these nine areas, the user contributes to painting an overall picture of 'skills coverage' for their company's readiness assessment profile, which in turn encourages the invitation of sufficient colleagues to complete the CE readiness assessment, thus increasing the trustworthiness of the data. At the same time, these expertise areas tell a story, for the data analysis, of the types of users that are using the tool.

The analysis of the consolidated readiness results for the selected scope is performed in Step 5. To provide an overview to the user, of how much the current readiness score can be trusted, five indicators are included in the results view of the readiness as-

Table 1
CE readiness dimensions and aspects (questions).

	**Organisation**
	Readiness of 'Organisation' measures the internal business capabilities of your company to be able to implement new concepts, such as the Circular Economy
	How far is your business in developing a clear business case (i.e. calculating the business benefits) for CE new initiatives?
	How far is your business in establishing processes (e.g. take-back) and tools (e.g. circularity assessments) to support CE implementation?
	How far is your business in taking risks and investing in Circular Economy initiatives?
	To what extent has your business developed training programmes to enhance knowledge and skills regarding CE?
	**Strategy & Business Model Innovation**
	Readiness of 'Strategy & Business Model Innovation' measures the capabilities to enable a long-term strategy to be developed, which is linked to the development of new business models that can effectively deliver enhanced competitiveness and growth
	To what extent is Circular Economy being embraced in your company's long-term strategy?
	To what extent have company management committed themselves to Circular Economy initiatives and allocated resources?
	To what extent has your business identified new potential value propositions across the product life cycle?
	How far is yourbusiness in communicating the value of new offerings to the market?
	How far is your business in defining new revenue streams and financial models (e.g. resell the product)?
	**Product & Service Innovation**
	Readiness of 'Product & Service Innovation' measures the capabilities necessary to develop new solutions (incl. products and services) that are suitable in a Circular Economy context
	To what extent is your business developing and delivering Product/Service-Systems (e.g. additional services, subscriptions, sharing solutions)?
	How far is your business in developing products and services considering extended lifetime (design for maintenance, modularity, etc)?
	How far is your business in developing products and services considering End-of-Life (e.g. design for remanufacturing, recycling?
	How far is your business in developing products and services that can be shared with other users (e.g. car/bike sharing)?
	**Manufacturing & Value Chain**
	Readiness of 'Manufacturing & Value Chain' measures the capabilities that will help you to create new value chain engagements and partnerships, aimed at maximum value creation from finite resources
	To what extent has your business established new partnerships in the value chain to enable a circular business?
	To what extent is your business collaborating with and/or influencing suppliers to encourage circular initiatives?
	To what extent is your business using recycled/renewable/biodegradable materials in manufacturing processes?
	How far is your value chain and manufacturing in entering industrial symbiosis (e.g. using waste streams as raw material)?
	**Technology & Data**
	Readiness of 'Technology & Data' measures your capabilities for the creation of value, through enhanced data management and sharing of the provided solutions
	How far is your business in applying technology for product monitoring during the use phase (e.g. sensors, Internet of Things)?
	How far is your business in applying technology to support the products for extended lifetime (e.g. spare parts, easy repair, upgradability)?
	**Use, Support & Maintenance**
	Readiness of 'Use, Support & Maintenance' measures the capabilities need to provide enhanced maintenance and repair services, aiming at an extended value creation from the provided solutions
	How far is yourbusiness in supporting and servicing the product during the use phase (e.g. maintenance, advice)?
	How far is your business in repairing products so to extend their lifetime?
	How far is your business in establishing sharing platforms which can encourage shared product use and access?
	**Takeback & End-of-Life Strategies**
	Readiness of 'Takeback and End-of-Life Strategies' measures the capabilities that will ensure maximised value of end-of-life products
	How far is your business in establishing takeback systems for products after their use (i.e. reverse logistics)?
	How far is your business in disassembling and remanufacturing products, so they can be sold to other customers?
	How far is your business in recovering the value out of products at End-of-Life (e.g. through material recovery)?
	**Policy & Market**
	Readiness of 'Policy & Market' measures the external readiness of the legislative frameworks and markets for the development and provision of circular solutions
	How far is your business in influencing the market readiness for 2nd-life products (e.g. remanufactured or recycled products)?
	How far is your business in influencing the market readiness for new business models (e.g. leasing instead of selling)?
	How far is your business in co-developing new circular solutions with key value chain stakeholders (e.g. recyclers, service providers, logistic)?
	How far is your business in influencing the sectorial legislative frameworks related to the implementation of CE initiatives?
	How far is your business in influencing the national and international legislative framework related to the CE implementation?



Value added to the user

Step 1: Domain-based user registration enables consolidated company profile based on the input of several users from the same company
Step 2: Scope and context (i.e. entire company or a specific business unit) are defined by the user, ensuring a targeted assessment
Step 3: Order of dimensions to be answered is fully defined by the user, ensuring flexibility and agility to the users
Step 4: Overview of skills and competences enables the user to have a quick overview of missing areas with potential to invite new colleagues
Step 5: Indicators of the readiness assessments enables the user to quickly check the robustness and reliability of the readiness results
Step 6: Overview of key challenges and opportunities for CE implementation, including a description of the current status and recommendations
Step 7: Internal and external benchmark allow the users to further prioritise the dimensions to be focused in the CE transition
Step 8: Focus of resources in the dimensions with the highest potential to decouple value creation from resource consumption
Step 9: Effective selection of tools and methods based on the strategic prioritization and current readiness, enabling a higher success chance
Step 10: Flexibility for the continuous update of the readiness assessment, providing a clear dashboard for measuring readiness over time

Fig. 3. Step-by-step approach for the use of the MATChE CE self-assessment tool, with an indication of the value added to the user in each step.

sessment (see also the examples in Fig. 4). 'Total readiness score' is a count of the aggregated readiness score of 150, considering that there are 30 aspects (questions) with a maximum possible score of '5' per aspect. The total score is, in itself, not entirely comparable, from business unit to business unit, but it nevertheless gives an indication of how far on the path that particular company/business unit is. 'Assessments' provides a count of the amount of assessments carried out for a particular company or business unit (i.e. number of different users submitting an assessment). 'Agreement' is a measure (low-medium-high) of the agreement level of the responses to the assessment for the particular company/business unit, calculated by measuring the standard deviation between them. 'Skill coverage' shows the level of coverage of the nine above-mentioned expertise areas. Finally, 'Robustness' is a measure of how much the user can trust the results on a given readiness assessment, which is the product of the number of assessments, standard deviation between the assessments and skill coverage.

If the robustness is low (calculated based on the number of assessments, agreement level and skills coverage), the user is encouraged to invite other colleagues from different functions to enhance the robustness of the results – an indication of missing skills is provided by the MATChE tool. Enabled by the allocation and domain-based company registration, the MATChE tool allows any user to invite a colleague within the same email domain, borrowing a principle from 'viral sharing' (Hoffman et al., 2020) to encourage as many colleagues as possible from the same company to contribute to the readiness assessment and thus building as true-to-reality a picture as possible, of the current readiness of the company to transition to CE. The more trustworthy the data within the tool, the more value it has. One important way to ensure trustworthiness of the data is to ensure multiple data entries per entity (company) registered on the platform. Therefore, the tool is encouraged to be used by as many colleagues as possible, within each participating company.

When the robustness is high, Step 6 involves the identification of strengths and improvement opportunities, based on an overview of the eight CE dimensions. Depending on the resulting consolidated CE readiness score for a given company and its business units, a summary is provided, aspect-by-aspect, dimension-by-dimension, of the current readiness, plus context-specific recommendations about how to increase the readiness for a particular CE aspect. Furthermore, an auto-generated PDF report can be created, summarising the particular business unit or company view, regarding current readiness and improvement recommendations.

Step 7 enables companies to benchmark the results internally (i.e. across different business units) and/or externally (e.g. companies from the same size, sector, region or business type). After having completed at least one readiness assessment, a user is able to carry out an internal benchmark between other business units and the company level within the company. The tool provides a list of comparative strengths and gaps and creates a report for the user to download. In addition, it is possible to carry out an external benchmark with all other companies on the MATChE tool. Furthermore, four filters make it possible for the user to benchmark external companies according to: primary sector; company type (B2B,

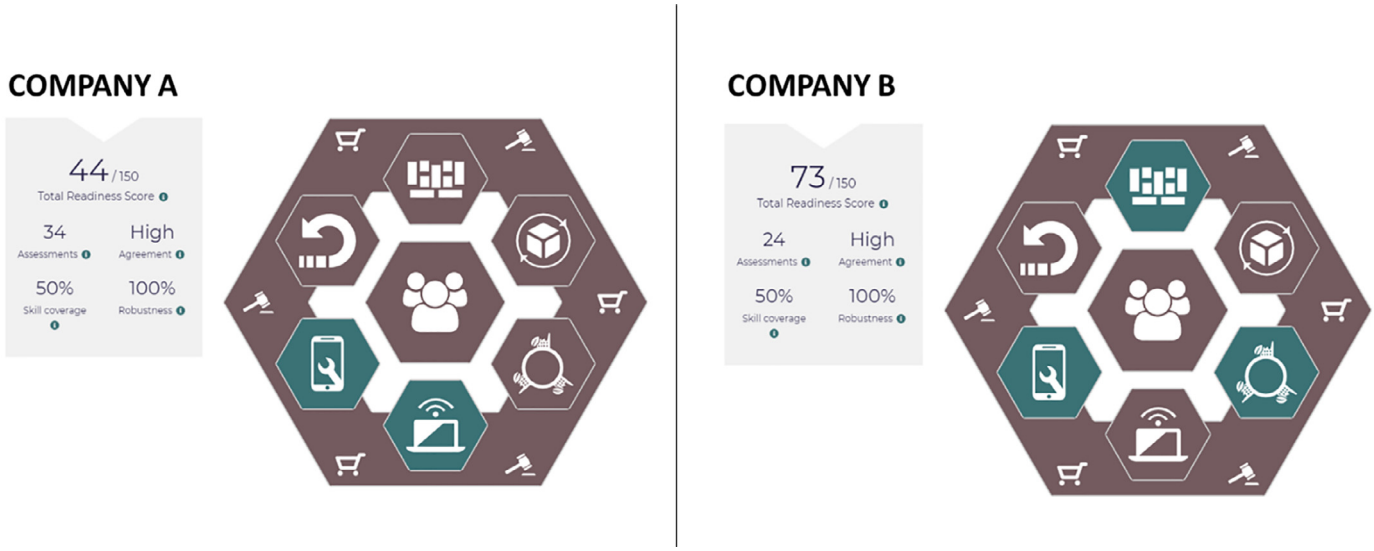


Fig. 4. CE readiness profile of companies A and B, with an overview of the readiness indicators and an indication of key strengths (represented in green) and improvement opportunities (represented in grey).

B2C, B2G); country; and company size. These filters *only* function if they capture a minimum of five external companies with the same characteristics as the filter, in order to preserve the anonymity of the data.

The prioritisation of the key CE dimensions for enhanced readiness based on their importance (low, medium and high) and timeframe (now, near and far) is performed in Step 8. A prioritisation of eight CE dimensions is possible to make, through a feature of the MATChE tool, in terms of 'importance' versus time to implement. By prioritising the dimensions to work with, a so-called 'transition path' can be charted, with recommendations for a transition process. Step 8 is followed by the selection of the implementation path and the best tools to support readiness enhancement, on the basis of current readiness and on the prioritised CE readiness dimensions (Step 9). The MATChE tool is equipped with a number of CE methods and tools (101 at the time of writing). These tools are categorised, with respect to their fit to: readiness dimensions; readiness levels; transition path status; organisational level the tool is suitable for (strategic, tactical, operational); and whether the tool is targeted at single users or teams. In addition, the tools are made available for download by the user. Depending on the readiness status of the user's company or business unit, the tools are 'promoted' as suggestions, to aid the transition process.

The readiness can be re-evaluated at a frequent basis, to support the identification of new improvement opportunities for the implementation of new CE initiatives (Step 10). It is possible for the user to go in at any time and perform an update of the data for a readiness assessment. The idea of this feature is to allow updated readiness assessments, after an improvement action, pilot project, competency lift, or similar has been carried out within the company and/or business unit in question. It also allows for the documentation of the evolution of the companyś CE readiness over time, which can be used for internal and external communication.

The final noteworthy feature of the CE readiness assessment tool – and in many ways, perhaps the most fundamental – is data security. The project responsible for creating the MATChE tool is under the strictest of regulations within its university, regarding data security, both with regards to GDPR and in terms of good data management practice. Expired or abandoned user data and company are purged on a regular basis. The MATChE tool is resident on a dedicated and encrypted secure server, with no other shared users. And with respect to the integrity of user logins, generic email domains (such as @gmail.com, @hotmail.com) are excluded from being able to register on the platform, as are known spoof mail domains (a blacklist is maintained). This measure ensures that the data on the tool are both kept safe from unwelcomed and unauthorised users, as well as kept as 'clean' as possible, to allow for optimal benchmarking and analytics.

4.2. User status and exemplary demonstration

The MATChE tool is, at the time of writing, supporting over 330 manufacturing companies (incl. 900+ users), spread across 16 manufacturing sectors and 38 countries. The key professional/job functions represented in the tool are: (i) Sustainability; (ii) Research & Development; (iii) Product Design and Development; and (iv) Strategic Planning. B2B and B2C companies are well represented, but B2G companies are less so.

To exemplify the use of the MATChE tool in a real-life context, the CE readiness of two companies from different sectors are described in this section. Company A is a large global manufacturing company, providing consumer electronic devices (i.e. B2C), with headquarters in Europe. Company A has defined Circular Economy as part of their overall sustainability strategy, and wanted to explore how to enhance the circularity of their business. In total, 34 different employees from the company engaged in the CE readiness self-assessment (steps 1-5), which was focused on the entire company as a whole (i.e. no specific business units were selected) (step 3). Company B is a global manufacturing company providing wood products in a B2B context, with headquarters in North America. Company B has been working with sustainability for many years, and engaged in the development of Circular Economy initiatives in order to explore new business opportunities for decoupling value creation from resource consumption. In total, 24 employees from Company B engaged in the CE readiness assessment, which focused on one specific business unit, which had the higher potential for new circular business models.

The consolidated readiness results for both companies (step 6) are presented in Fig. 4, with an overview of the key readiness indicators and an indication of strengths and improvement opportunities. Despite having a skill coverage of 50%, both companies managed to have a high amount of assessments (34 and 24, respec-

tively) and a high agreement level (i.e. low standard deviation), which resulted in a high robustness of the results.

The total readiness score of Company A is 44 (out of 150), with key strengths in two dimensions: Ťechnology & Data; and Úse, Support & Maintenance. Company A is planning scale-up of products monitoring during use and repair services, and has already full implementation of service support provision systems. The key improvement opportunities within the other six dimensions are related to:

- Organisation: calculating the business case for CE and structuring the right process and tools.
- Strategy & Business Model: developing a long-term strategy for CE and communicating the overall value proposition to customer.
- Product & Service Innovation: developing product/service-systems, with products designed for end-of-life and sharing schemes.
- Manufacturing & Value chain: establishing new partnerships to enable circular solutions and identifying opportunities for industrial symbiosis.
- Takeback & End-of-Life Strategies: designing takeback systems, remanufacturing products and recycling materials.
- Policy & Market: exploring the market for second hand products and influencing legislation towards higher circularity within the electronic sector.

Company B has a total readiness score of 73 (out of 150). Śtrategy & Business Model; Ḿanufacturing & Value Chain; and Úse, Support & Maintenance´are the key strengths of Company B in terms of strengths. The company is actively implementing circularity in their key business strategy, and is piloting a number of new circular business models to explore their market potential. Furthermore, the company is active in the establishment of new partnerships across the value chain, which are also focused on the investigation of materials with a higher circularity. Company B is also scaling-up service support platforms and repair services to extend the product life.

The key improvement opportunities within the other five dimensions are related to:

- Organisation: being able to take risks and invest for the implementation of new concepts and initiatives.
- Product & Service Innovation: designing for life extension and designing sharing systems.
- Technology & Data: exploring new technologies to allow extended product use.
- Takeback & End-of-Life Strategies: remanufacturing products and recycling materials.
- Policy & Market: exploring the market for second hand products.

On the basis of the readiness profile, Companies A and B performed an external benchmarking (step 7), which supported the prioritisation of the dimensions to focus (step 8). While Company A decided to focus on Śtrategy & Business Model´and Ṕroduct & Service Innovation´(two of the identified improvement opportunities), Company B decided to continue focusing on their strengths (e.g. Śtrategy & Business Modeĺ) in addition to selecting two additional improvement areas (i.e. Órganisation´and Ṕroduct & Service Innovation´dimensions). At the time of writing, both companies are implementing a number of initiatives within the selected dimensions, supported by a number of tools proposed from the MATChE tool and complemented with other tools that are connected to their key business processes (step 9). Once finalised, it is expected that the companies will perform a new readiness assessment (step 10), to be able to measure the readiness enhancement and to plan the next steps in their journey towards Circular Economy.

5. Discussion

The successful implementation of circular initiatives demands a thorough understanding of the companyś readiness profile (incl. a deep understanding of key strengths and gaps) and a tailored approach for the development of transition paths for CE implementation, which respects and builds upon the identified existing readiness. Hence, understanding how CE readiness and CE implementation relate to each other increases the probability of successful CE implementation and is essential to leverage CE potential towards sustainable growth.

The application of the MATChE readiness tool with the identification of strengths and improvement opportunities for CE, as well as the internal and external benchmarking, increase the degree to which the involved employees perceived the urgency for the transition to CE which is one of the key success factors for the CE transition. In addition, the application of the MATChE tool supports a higher alignment within the organisation in relation to on-going initiatives and the priorities for CE implementation. Combined with the extensive database of methods and tools, which are pre-selected according to the current readiness and prioritised areas, the tool enables the development of a feasible transition path which can enhance the success rate of CE initiatives, and ensure the evolution from pilot projects to scale-up and full implementation.

Given the amount and granularity of data that the tool is able to collect and analyse, the MATChE CE readiness self-assessment tool has been designed so as to provide valuable research insights into the readiness of the industry with respect to CE transition. These insights can be created on the basis of many different dimensions, which are of potential use to not only the companies that the tool's main interface is designed for, but also researchers, policy-makers and strategic funding agencies. In this context, there is a potential of using the MATChE tool to continuously provide a dashboard with anonymised data of CE readiness in different sectors, regions, company sizes and types to support further research and policy-making within CE implementation.

In addition to the practical contribution to the manufacturing industry, the MATChE tool also contributes to the state-of-the-art in the CE literature, enabling the understanding of the key dimensions and aspects to evaluate CE readiness at an organisational level. MATChE complements existing similar CE readiness tools with different analysis levels: country level (Momete, 2020; Garcia and Cayzer, 2019); sectorial level (Siew, 2019); ecosystem level (Parida et al., 2019); regional level (Pigosso et al., 2018); and individual employee level (Singh et al., 2018), as described in Section 2, Literature review. In relation to the scope (i.e. circularity evaluation at the company level), the most similar approach to the MATChE tool is Circulytics®, launched by the Ellen MacArthur Foundation in 2019. Despite not being developed to evaluate the CE readiness and not having been published in academic literature, the Circulytics® tool (Ellen MacArthur Foundation, 2020) presents a number of similarities to the MATChE platform, which are worth discussing. The key characteristics of the MATChE CE readiness self-assessment tool and its comparison to Circulytics® are summarised in Table 2.

Despite the similarities between MATChE and Circulytics® in contributing with the overall understanding of CE implementation at a company context, each tool has different overall goals and approaches. In future studies, it might be interesting to explore the potential synergies of both approaches, to enable companies in their CE transition, when applied in a combined fashion. It would furthermore be interesting to compare the results of companies that have engaged in both initiatives to understand whether there is a correlation between the CE readiness score (MATChE) and the CE circularity index (Circulytics®).

Table 2
Comparative tool of the MATChE platform and the Circulytics® tool (* corresponds to estimations by the authors).

Characteristic	MATChE	CIRCULYTICS®
Main goal	Measure and enhance readiness for CE transition, based on a customised transition path	Measure the circularity level of companies
Score calculation	30 aspects, divided across 8 dimensions	18 indicators, divided across 11 themes
CE dimensions measured	Organisation; Strategy & Business Model; Product & Service Innovation; Manufacturing & Value Chain; Technology & Data; Use, Support & Maintenance; Takeback & End-of-life; Policy & Market	Strategy and planning; People and skills; Innovation; Operations; External engagement; Product & Materials; Services; Assets; Water; Energy; Finance
Data input	Qualitative	Mix of qualitative, semi-quantitative and quantitative data
Level of depth	High-level	High-level
Scope	Company level Business unit level	Company level only
No. of users involved in assessment	Min. 1, max. ∞ In-built consolidation feature of readiness profile	One representative per company
Reliability of results	Robustness function, calculated based on the agreement level (standard deviation), skill coverage and number of assessments	Reliability is solely based on the input/output data from the user, and not evaluated within the tool
Advice after completing	Readiness dashboard Full report with current status and recommendations CE transition paths, based on 99+ tools and supporting cases	Scorecard Communications toolkit
Benchmarking possibilities	Internal benchmarking External benchmarking	Indirectly, through annual data insights
Availability	Online, 24/7	Registration-based, based on a 3rd part software
Time to complete	Circa 1 hour per person for the self-assessment, can be completed as a workshop	Data collection: weeks-months* Questionnaire: 2-3 hours*

6. Conclusions

The MATChE tool was developed based on the identification of the eight key dimensions that are necessary for manufacturing companies in making the transition to CE: (1) Organisation; (2) Strategy and Business Model Innovation; (3) Product & Service Innovation; (4) Manufacturing & Value Chain; (5) Technology & Data; (6) Use, Support & Maintenance; (7) Takeback & End-of-Life Strategies; and (8) Policy & Market. In total, 30 aspects were identified to support the identification of the companies´readiness in each one of these dimensions, which are used for a self-assessment by manufacturing companies. By analysing a number of contextual factors (e.g. organisational culture; policies and procedures; past experience; organisational resources and organisational structure), the CE readiness self-assessment tool provides important guidance to support the successful transition towards of manufacturing companies in a CE, which has the potential to support minimising the currently observed circularity gap. The CE readiness profile enhances the understanding of strengths and gaps for CE implementation within an organisation, based on a cross-functional effort within a company. In addition to that, the MATChE tool also allows companies to perform internal and external benchmarking studies to support the prioritisation of key CE focus areas and dimensions; and to plan relevant transition paths with support of CE-related tools, methods and approaches.

At the same time, the MATChE tool has clear limitations. Firstly, the scope of the tool is currently limited to manufacturing companies. This delimitation was chosen in order to be fully applicable to the main focus group for the research and to be as specifically useful as possible to this sector. Future directions from this initial scoping could go a level deeper and more specific (e.g. electronic equipment manufacturing, packaging manufacturing), or broadly to other sectors (e.g. maritime branch, agro-food sector, service industry). Such an expansion of the scoping for the tool (which the authors are currently planning), should be carried out with the intention of retaining as many of the current dimensions and aspects as possible, to preserve comparability, whilst obviously having to change some dimensions and aspects, to be more relevant for the new scope. The second limitation of the tool is that it provides a consensual starting point to measure readiness in a company, but does not attempt to provide any quantitative goals or targets, as such. This was, again, a conscious choice, when developing the MATChE tool, in order to retain focus on creating an initial baseline for companies to build on. One development, in the future, could be to build quantifiable indicators, to lead the change, also in relation to specific performance targets – but such an addition to the tool would clearly require more granularity of multiple scopes, within each sector. The third main limitation of the tool is that it does not consider material and energy flows as an indicator for the calculation of the CE readiness profile, nor for the prioritisation of the CE focus areas. While the understanding of the organisational readiness remains as the main goal of the tool, it might be relevant to support the prioritisation process of focus areas by combining the readiness profile (i.e. the results of the MATChE tool) with the circularity potential of different business units/CE dimensions, by using existing metrics for circularity assessment at company level (e.g. Circulytics®). In that case, the evaluation should be done based on quantitative data, which will most likely be provided by one representative from the company and/or business unit.

Finally, there has been an increased interest in the use of the CE readiness approach by other types of stakeholders than only manufacturing companies. Future research is ongoing for the expansion of the scope of the MATChE tool in a number of different directions (e.g. value chain, sectors, types of companies).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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