Assessing the readiness of manufacturing companies for the Circular Economy: an analysis and an initial proposal

Bressanelli G.*, Perona M.*, Saccani N.*

** Dipartimento di Ingegneria Meccanica e Industriale, University of Brescia, Via Branze, 38 25123 – Brescia – Italy (gianmarco.bressanelli@unibs.it)*

Abstract: Nowadays manufacturing companies are struggling with the transition towards a Circular Economy focused on sustainable production and consumption. The transition from linear business models to a Circular Economy is a great opportunity for industrial organizations to gain competitive advantage while decoupling economic growth from resource extraction and waste generation. However, manufacturing companies frequently fail in understanding where to start in approaching such a systemic transition, as fundamental changes are needed in the design of products, production processes, business models and supply chains. Moreover, scientific literature has only recently started to discuss Circular Economy extensively, still giving little support in understanding how it can be introduced in industrial organizations. To provide a first attempt into filling this gap, this paper proposes a model to assess the readiness of manufacturing companies for the Circular Economy paradigm. A review and a critical comparison of existing tools is carried out. Based on this review, a readiness assessment model is then proposed. The model provides an improved understanding of Circular Economy for manufacturing firms, supporting them in assessing their potential and giving insights on where to start to address such transition.

Keywords: Circular Economy; Manufacturing; Readiness assessment; Maturity model; Sustainability

1. Introduction

Manufacturing companies are nowadays struggling with the transition towards Circular Economy, to address environmental issues related to natural resources depletion and waste generation. Moving towards Circular Economy is a great opportunity for industrial organizations and manufacturing companies (Elia et al., 2020). Despite such premises, manufacturing companies frequently fail in understanding where to start in approaching such a systemic transition. Fundamental changes are in fact needed in the design of products, production processes, business models and supply chains (Bressanelli et al., 2019). In addition, scientific literature has only recently started to discuss Circular Economy extensively, thus still giving little support in understanding how Circular Economy can be introduced in industrial organizations. With the aim to provide a first attempt into filling this gap, this paper proposes an initial model to assess the readiness of manufacturing companies for the Circular Economy paradigm. Despite the relevance of assessing Circular Economy at the micro and meso levels (Roos Lindgreen et al., 2020; Walker et al., 2021), previous works investigated Circular Economy readiness assessment for manufacturing organizations in a scattered way. Prieto-Sandoval et al. (2018) established a list of key elements needed for assessing the level of Circular Economy implementation under the three categories of circular fields of action, industrial symbiosis and environmental certifications. Camacho-Otero and Ordoñez (2017) developed a conceptual framework to define the key elements that a company circularity assessment should include, based on expert interviews. Cherrafi et al. (2021) presented a self-assessment model to evaluate the readiness level of an organization in implementing green and lean initiatives, concluding that future research should extend assessment models to the supply chain context. Saidani et al. (2017) provided an overview of three methods to evaluate the product performance in the light of Circular Economy principles. Garza-Reyes et al. (2018) proposed a toolkit to enable the assessment of the Circular Economy degree in manufacturing enterprises, based on a literature review. Despite these attempts, there is still a general disagreement on what evaluating elements and circularity criteria should be used for assessing the readiness of manufacturing organizations for the Circular Economy (Camacho-Otero and Ordoñez, 2017; Vinante et al., 2021). Moreover, the complexity of the Circular Economy paradigm is still far from being fully considered in existing tools (Saidani et al., 2017). In this paper, a review and a critical comparison of existing tools for the evaluation of the Circular Economy readiness of manufacturing organizations is carried out. First, we provide in Section 2 the background on Circular Economy needed for manufacturing companies to embrace such a transition. Then, four tools to evaluate manufacturing companies' readiness to Circular Economy are presented, described and analysed in Section 3. We studied, for each tool, its specific objective, the evaluation elements adopted, and the input data required, as well as the results. Based on the combination of the background analysis on Circular Economy with the specific analysis of the previous tools, we then propose a comprehensive readiness assessment model in Section 4. Lastly, concluding

remarks, limitations and suggestions for future research are presented in Section 5.

2. Background: Circular Economy for manufacturing companies

Circular Economy emerged as a sustainable alternative to the traditional production and consumption paradigm developed during the last century, and based on the *take-make-dispose* principle (Ellen MacArthur Foundation, 2012). Circular Economy aims to overcome the limitations of linear economy, since it decouples economic growth from natural resources exploitation, from the emissions of climate change gases and from waste generation (Corona et al., 2019). Practically speaking, Circular Economy eliminates the end-of-life concept of products through the exploitation of a series of closed-loop cycles of reduce, reuse, remanufacture and recycle activities (Bressanelli et al., 2020). Manufacturing companies and organizations who want starting the transition towards Circular Economy can leverage on a series of actions, that should pursued in a systemic way to create circular value creation (Hansen and Revellio, 2020). First, the design of products should be modified to increase the characteristics of durability, standardization and modularity, as well as to encourage the adoption of recycled materials in the production of new products. The purpose of circular product design is to facilitate the management of the various end-of-life phases, from the disassembly of the components to the separation of the various materials sent for recycling. Second, production processes should be redesigned, by adopting cleaner production practices as well as by exploiting the opportunities of industrial symbiosis for the exchange of by-products within eco-industrial districts (Fraccascia and Yazan, 2018). Third, a rethinking of business models towards servitization and product-service systems like leasing, pay-per-use and sharing is needed. In fact, products designed to last are incompatible with traditional revenue mechanisms based on buying and selling. Thanks to these business models, it is possible to satisfy the demand from more people with the same number of resources. Moreover, in servitized business models, product ownership remains with the supplier, who is therefore naturally incentivized to design products to last, to offer maintenance and repair services as well as to collect products at the end-of-life. Fourth, a reconfiguration of the supply chain is needed, to optimize the sourcing of materials and the distribution of products, as well as by developing new forms of collaboration with all the players of a Circular ecosystem (González-Sánchez et al., 2020; Konietzko et al., 2020). Fifth, manufacturing companies are called to implement reverse logistics and manage the end-of-life of products, to reuse products, remanufacture components and recycle materials (Garza-Reyes et al., 2019). Lastly, company general green habits can be set for facilitating the implementation of Circular Economy, such as raising awareness and green marketing and communication (Gusmerotti et al., 2019).

3. Overview of Readiness Assessment tools

Several tools have been proposed for assessing the readiness of Circular Economy at the micro and meso levels. An overview of them is presented in the following, alongside with a critical discussion of each one of them.

3.1 Circular Economy toolkit

The Circular Economy Toolkit (Evans and Bocken, 2014) is an assessment tool created by the scholars Jamie Evans and Nancy Bocken. The tool supports a circularity assessment of the products and services offered by a company, with the aim of indicating the potential areas for improvement. The Circular Economy toolkit is thus an interactive tool that provides opinions on 7 areas for improvement of a company, through the study of 33 evaluation elements divided into specific groups of questions. Each evaluation element studied by the tool allows to provide a structured answer on a three-level scale (low-, middle- and high-level).

The first group of questions assesses the design, manufacture and distribution phases of the product under assessment, evaluating elements such as the amount of material wasted during production, the biodegradability of materials, the use of recycled inputs, the use of scarce input materials, the use of eco-efficient inputs, the use of toxic inputs, and the use of waste as input to new processes. The second group of questions assesses the usage phase of the product under assessment, evaluating elements such as the presence of faults during usage, the durability of the lifespan of the product, and the waste of energy during usage. The third group of questions assesses the repair and maintenance activities related to the product under assessment, evaluating the elements regarding the costs of such activities, the presence of maintenance and/or repair services, the availability of spare parts, technical support and warranty services, the ease of access to internal mechanisms, the standardization of components, and the difficulties in finding faults and defects. The fourth group of questions is related to the closed-loop activities of Circular Economy, covering reuse and redistribution of products. The main evaluation elements are related to the presence of markets for second-hand products, the offering of second-hand sales of the product, and the shelf-life of the product. The fifth group of questions is related to the refurbishment and remanufacturing activities of products and parts in a Circular Economy. In this area, the evaluating elements cover the incidence of costs for reconditioning or remanufacturing products, the collection costs of end-of-life products, the share of products subject to reconditioning and/or remanufacturing, the difficulty in disassembly the product, the possibility to damage the product during disassembly, the ease of identification of disassembled parts, the adoption of a modular design, the ability to upgrade parts and components, the number of mechanical connections, and the number of tools needed for disassembly. The sixth group of questions is related to the 'product-as-a-service' opportunity related to the product under assessment. In this area, two evaluation elements are considered. The first one is related to the presence of product-as-a-service markets, while the latter is related to the offering of products as services in general terms. Lastly, the seventh group of questions is related to product recycling and end-of-life. It covers evaluation elements regarding the diversity and number of different

materials included in the product, and the ease of separation of materials for recycling.

Overall, the Circular Economy Toolkit has the advantage of being user-friendly, even for non-expert users about Circular Economy, and at the same time being effective in providing a first list of areas to improve. The assessment is however limited to a single product. Moreover, supply chain aspects of Circular Economy are neglected by this tool. In fact, among the seven areas of analysis, there is no one dedicated to a circular supply chain analysis. Lastly, the tool can be considered too superficial to understand the actual complexity of the Circular Economy, in the perspective in which this toolkit provides an evaluation with a questionnaire based on a ternary scale, in which the user has the habit of putting the cursor in the middle (by nature). Furthermore, some questions could lead to different and subjective interpretations from user to user.

3.2 LifeGate light assessment

The LifeGate light assessment tool (LifeGate, 2020), created by LifeGate, is an online tool that allows companies to receive an initial assessment of their socio-environmental performance, helping them in defining a first level of awareness on the sustainability of their business. The result of the tool is numerical (differently from the Circular Economy toolbox), since it computes a percentage index (ranging from 0 to 100%) that evaluates the company performance in different areas. Another peculiarity of the LifeGate light assessment tool is the peculiarity that, instead of analysing the circularity of a single product, it focuses its attention on the study of the sustainability of an entire organization. The object of the analysis in this case is therefore the entire company, also paying attention to the selection of suppliers and customers to ensure a circular supply chain collaboration based on the alignment of sustainable objectives (overlooked by the Circular Economy toolkit). The tool provides a sustainability index (in percentages) on five areas by analysing the responses to 22 evaluation elements. The rating scale of the responses to the elements is a five-level scale, ranging from 0 (nothing has been done about the *i-th* element) to 4 (the *i-th* element has been fully implemented).

The first area of assessment is related to the organization of the company, and it assesses the presence of guidelines and objectives about sustainability, as well as the presence of a code of ethics for employees, to ensure that they act in an ethical and responsible manner. The second area of evaluation is related to the stakeholder management. It covers elements regarding the communication towards stakeholders, assessing whether the company interacts and communicates in a clear, transparent and collaborative manner with its stakeholders, and whether the company develops institutional reporting on sustainability issues. It also assesses the presence of employee training programs, of welfare initiatives, and the awareness of employees on sustainability issues. The third area of analysis is related to the environmental impact of the company. It covers evaluating elements regarding the presence of a management, monitoring and improvement system, the presence of environmental certifications, the presence of an environmental impact assessment (e.g., a carbon footprint based one), and whether the company optimizes its logistics to reduce emissions associated with transport. The fourth area of assessment covers the supply chain dimension (overlooked by the Circular Economy toolkit). It evaluates the selection and monitoring of suppliers based on environmental criteria, the external communication of the company sustainable development strategies, the usage of energy from renewable sources, and the presence of green purchasing policies. The fifth evaluation area is focused on marketing and communication, and it assesses whether the company evaluate the environmental impacts of its products, the offering of sustainable products, the communication of sustainability values, and the involvement of stakeholders in the external communication of the sustainable value proposition of the company.

Overall, the LifeGate light assessment tool uses a wider and more precise evaluation scale compared to the Circular Economy toolkit (the values belong to a five-level scale, and range from 0 to 4), rather than using a ternary one. Rather than considering a purely Circular Economy evaluation of a single product, this tool focuses on a more general concept of sustainability extended to the entire organization. It focuses mostly on the importance of training and raising awareness on all the stakeholders involved in a circular supply chain. However, it does not focus on the main Circular Economy approaches regarding the reuse or remanufacturing of products, as well as the adoption of servitized business models.

3.3 Circular Economy Indicator Prototype (CEIP)

The Circular Economy Indicators Prototype (CEIP) is a tool created by Cayzer et al. (2017) in order to provide an overall assessment of the circularity of a product, diversifying the analysis into the general five phases of its life cycle, namely Design/Redesign; Production; Marketing; Use; End of life. The CEIP uses a points-based questionnaire to compute a simple final numerical result with minimum and maximum limits. The obtained overall score is representative of the circularity performance of the product. In addition, the tool offers the possibility to consult a spider diagram showing the performance in the different areas of the product life cycle.

The questionnaire is composed of fifteen questions, divided into the five phases of the life cycle of the analysed product. The first area assesses the design / redesign phase of the product. It evaluates the characteristics of the product in terms of recycled content, lightness of components and the presence of a complete product bill of materials. The secondo area evaluates the production process, assessing the presence of a complete energy bill for manufacturing processes to identify the energy used in production, and assessing the presence of a complete list of solid waste generated during production processes. The third area is related to marketing activities, evaluating what type of packaging is used, the presence of product warranty, and the availability of rental options for the product. The fourth area evaluates the usage phase. It assesses the possibility to repair or reuse the product to extend its useful life, as well as the potential for reducing waste during the product usage. The last area is related to the end of life management, assessing the type of waste collection scheme

for product recovery, the ease of separation of the product from other end-of-life products, and the methods through which the product can be returned to the supply chain. The main CEIP advantage is the fact that, in addition to providing as a result a unique indicator representative of the generic circularity of a product, it provides an easy to interpret table and spider diagram detailing the circularity performance score for each area of the product lifecycle. On the other hand, some crucial aspects of Circular Economy are quite overlooked. In fact, various features such as modularity, design for disassembly, upgrade or the use of new digital technologies are not taken into consideration by the CEIP tool.

3.4 MAThE Readiness Assessment

The MAThE Readiness Assessment is a tool developed by Pigosso and McAloone (2021) under the MAThE (Making the Transition to Circular Economy) programme, carried out by the Technical University of Denmark. It is intended to be a free assessment tool, able to help interested companies in kickstart their transition towards Circular Economy. The tool assesses the readiness of a manufacturing company for implementing circularity. It is also developed for the purpose to help in creating awareness inside the organization and develop a shared language around Circular Economy. The assessment is based on 30 questions grouped into 8 dimensions for the Circular Economy. Each question is rated on a five-level scale, ranging from 1 (not ready) to 5 (ready), encompassing the intermediate levels of planning pilot, piloting the initiative, and planning the scale-up. After answering to the 30 questions, the tool provides a total readiness score, where the maximum is 150 points. The tool allows to combine the compilation from multiple users (e.g., different employees from the same company), and compute a total score by mixing answers based on the declared expertise of each person.

The first readiness dimension is related to the organization, and it measures the internal capabilities of the company in developing a business case for the Circular Economy, establishing processes and tools, taking risks and investing in circularity as well as developing training programs to enhance skills and knowledge about Circular Economy. The second readiness dimension is focused on Strategy and Business Model innovation, and it aims to measure the capabilities that are needed to enable long-term Circular Economy strategy and the development of new business models. It assesses to what extent Circular Economy has been embraced in the company long-term strategy, as well as the company commitment, the identification of new potential value propositions, the right communication of the value offerings to the market and the proper definition of new revenue streams and financial models. The third dimension covers the innovation of product and service. It measures the capabilities needed to develop new solutions suitable for the Circular Economy, such as the design and delivery of product-service systems, the extension of product lifetime, product sharing and services related to end-of-life such as remanufacturing and recycling. The fourth dimension is related to manufacturing and the value chain, and it measures the ability to create partnership and engagement throughout the value chain. More specifically, it assesses the creation of partnership along the value chain to enable new circular business, the engagement of suppliers towards sustainability, the use of recycled, renewable, or biodegradable materials in production processes, and the exploitation of industrial symbiosis. The fifth dimension focuses on technology and data, and it measures the capabilities needed for creating value from data management and digital technologies. It assesses two elements. The first one is focused on the readiness in applying digital technologies (such IoT) for product monitoring during usage, while the latter aims to evaluate the application of technologies for supporting the extension of product life, e.g., through an easy repair and upgradability. The sixth dimension is related to the use, support, and maintenance of the product. It assesses the readiness of the company in providing supporting services such as maintenance and repair, as well as the ability of the company in establishing sharing platforms to encourage the sharing of products. The seventh dimension focuses on takeback and end-of-life strategies, aiming at evaluating the presence of takeback systems based on reverse logistics, the readiness of remanufacturing processes or recycling activities for a proper material recovery. Finally, the last dimension is about policy and market, and it measures the ability of the company in influencing the marked readiness for second-hand products or for leasing services, as well as the ability to influence the sectorial, national or international legislative framework regarding the implementation of Circular Economy. Overall, the MAThE tool emerged as one of the most comprehensive tools for assessing the readiness of manufacturing companies to Circular Economy. However, the role of digital technologies in enabling such a transition is overlooked also by this tool.

4. The C-Readiness tool: an initial proposal

In this Section we propose an initial structure for a Circular Economy readiness assessment tool for manufacturing companies, leveraging on the strengths of current tools and overcoming their main limitations, while following the main elements needed for the transition towards Circular Economy provided in the background (Section 2). We decided to frame the list of C-Readiness dimensions (i.e., key elements for evaluating the readiness towards Circular Economy) into six main circular areas (Table 1).

4.1. Product Design and Structure

The first circular area aims to assess the circularity of a company in the very first phase of the product life cycle it offers. We suggest considering the following evaluation elements, many of them covering the dimension of circular product design: (1.1) the use of biodegradable, recyclable or recycled materials, where the higher is the share of these materials in the design of products, the higher is the score assigned to this element; (1.2) the non-use of toxic raw materials in the design of products, where the lower is the share of these materials, the higher is the score assigned to this element; (1.3) the use of critical raw materials in terms of supply availability and resources scarcity, where the lower is the share of such materials, the higher is the score assigned to this element; (1.4) the presence of product

labels and certifications from an environmental point of view, such as Cradle-to-Cradle, Environmental Product Declarations and so forth; (1.5) to what extent products are designed with circularity in mind, i.e., to facilitate the recycling of materials and the remanufacturing of components or product life extension.

4.2. Production processes

The second circular area aims to evaluate the circularity of a company in the second stage of the life cycle of the products it provides, i.e., manufacturing processes. We suggest considering the following evaluation elements: (2.1) the incidence of scraps and production waste compared to the total volumes produced, since one of the main objectives of the circular economy is to move towards a zero-waste system; (2.2) the presence of a system for monitoring the consumption of resources (such as energy, water, compressed air, etc.) consumed during production processes, since monitoring is the first step towards waste reduction; (2.3) the use of energy from renewable sources during production; (2.4) the adoption of industrial symbiosis systems for trading production by-products; (2.5) the presence in the company of an environmental management system, such as the ISO 14001 based one.

4.3. Business model

The third circular area does not directly represent a specific phase of the product life cycle. However, the way in which vale is created and products are offered affects the circularity of the company. Consequently, we suggest considering the following evaluation elements: (3.1) the offering of a second-hand regenerated products line; (3.2) the presence of an alternative offering proposal to the sale of products, such as product leasing or pay-per-use product-service systems; (3.3) the offering of sharing the product among multiple users (sharing product-service system); (3.4) the use of cloud-based trading platforms for scraps and waste; (3.5) the collaboration with suppliers and value chain partners in the co-design of products and processes following a Circular Economy perspective.

4.4. Supply Chain

The fourth circular area aims to assess the circularity of a company in the third phase of a product's life cycle, which relates to its distribution. We thus suggest considering the following elements during the C-Readiness evaluation: (4.1) the availability of suppliers' selection criteria based on green and environmental performances; (4.2) the type of materials used for packaging, in order to avoid the usage of e.g. single-use packaging; (4.3) the optimization of the distribution network to minimize its environmental impacts, e.g., by trying to saturate transportation means in order to limit the number of trips needed for delivering products to customers; (4.4) the use of environmental-friendly transport carriers, such as the use of rail transport instead of road transportation, where applicable; (4.5) the traceability of products, components and materials along the supply chain to certify their green characteristics and, at the same time, to avoid their dispersion into the environment. In this context, the use of sensors, IoT, RFID and blockchain technology may help.

4.5. Reverse Logistics, Regeneration and End of Life

The fifth circular area aims to evaluate the circularity of a company when its products reach the end-of-life. We therefore look at the presence of a Reverse Logistics structure, which takes care of collecting end-of-life products as well as the presence of activities aimed at reuse or remanufacturing. We thus suggest considering the following evaluation elements: (5.1) the existence of take-back initiatives organized by the company, such as end-of-life recovery of products; (5.2) the management and control of reverse logistics activities. In this case it is better to evaluate whether, in addition to organizing reverse logistics, the company also directly controls such activity, e.g., by effectively setting up an infrastructure dedicated to it; (5.3) the existence of initiatives (in this case also external to the company) for the reuse of products; (5.4) the existence of initiatives (in this case also external to the company) for the remanufacturing of components; (5.5) the existence of advanced material recycling initiatives; (5.6) the share of the products that ends up as waste in landfills at the end of their life. This last element, from a Circular Economy point of view, should be minimized.

4.6. Company green culture and habits

The sixth and last circular area does not evaluate a specific phase of the product life cycle, but instead, it aims to analyse the company green approach adopted for addressing the general issues of environmental sustainability, with a particular reference to the single-use plastics-free movement (which was overlooked by previous tools). We suggest considering the following elements: (6.1) the presence of actions aimed at eliminating single-use plastics inside offices and factories; (6.2) the non-usage of single-use plastics for drinking water; (6.3) the non-usage of single-use plastics in drinking coffee; (6.4) the non-usage of single-use plastics in the company canteen areas; (6.5) the degree of application of separate waste collection inside company offices and factories; (6.6) the presence of actions taken to promote the sustainable mobility of company employees; (6.7) the external communication of the company environmental performance through marketing and promotion strategy.

Table 1: C-Readiness areas and dimensions

Area	ID	C-Readiness Dimension
1. Product Structure	1.1	Use of biodegradable, recyclable or recycled materials
	1.2	Use of toxic materials (e.g., REACH Directive)
	1.3	Use of critical raw materials (in short supply)
	1.4	Presence of product green labels (e.g., Cradle-2-Cradle)
	1.5	Application of Circular Design strategies (e.g., modularity)
2. Production Processes	2.1	Incidence of scraps and waste during production
	2.2	Presence of a resource monitoring system
	2.3	Share of energy coming from renewable sources
	2.4	Industrial symbiosis (by-products exchange)

	2.5	Presence of an environmental mgmt. system (e.g., ISO 14001)
3. Business Model	3.1	Offering of second-hand or regenerated products
	3.2	Offering of a product-service systems solution (e.g., leasing)
	3.3	Offering of a sharing solution
	3.4	Usage of platform for trade waste and by-products
	3.5	Collaboration with partners in the design of circular solutions
4. Supply Chain	4.1	Product monitoring and tracking (e.g., through IoT)
	4.2	Supplier selection based on environmental criteria
	4.3	Use of sustainable materials for packaging
	4.4	Optimization of the distribution network to reduce transport
	4.5	Use of environmental-friendly transport carriers
5. Reverse Logistics, Regeneration and EoL	5.1	Presence of take-back initiatives carried out by the company
	5.2	Presence and control of Reverse Logistics
	5.3	Existence of product reuse initiatives (direct or indirect)
	5.4	Existence of remanufacturing initiatives (direct or indirect)
	5.5	Existence of recycling initiatives (direct or indirect)
	5.6	Share of the product that goes to landfill at the EoL
6. Company green culture and habits	6.1	Actions to eliminate single-use plastics in the company
	6.2	Use of plastics in providing drinking water to employees
	6.3	Use of plastics in providing coffee to employees
	6.4	Use of plastics in the canteen area of the company
	6.5	Degree of application of separate waste collection
	6.6	Actions to guarantee employees' sustainable mobility
	6.7	Company environmental footprint communication

4.7. C-Readiness score

We then suggest considering a three-level readiness scale for each evaluating element, where we suggest assigning: (i.) Low Readiness = 0 Readiness points; (ii.) Middle Readiness = 0.5 Readiness points; (iii.) High Readiness = 1 Readiness point; (iv.) Not Applicable = 0 Readiness points (and the evaluating element is excluded from the computation of the Readiness score). Consequently, the Circular Economy readiness of each j-th area can be computed by considering the points assigned to each i-th evaluating element, as of Eq. 1:

$$C_{R_{j-th\ Area}}[\%] = \frac{\sum_i P_i}{|i|} \qquad (Eq.1)$$

In addition to the computation of the C-Readiness of each area, we suggest combining the score of each area into a total, comprehensive circularity index. This can be easily done by making a weighted average of the individual scores, as of Eq. 2 (where W_{Rj} is the weight of the j-th area):

$$C_{Readiness}[\%] = \sum_j C_{R_j} \times W_{R_j} \qquad (Eq.2)$$

The expected results can be finally easily plotted into a spider-diagram, as shown in Figure 1, to increase the visualization of the results.

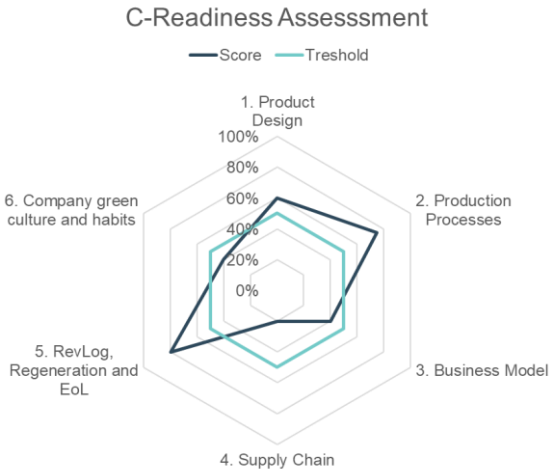

Figure 1: C-Readiness score (illustrative case)

5. Conclusion

This paper developed an initial proposal for a tool to assess the Circular Economy readiness of manufacturing companies, based on a background analysis on Circular Economy and on the analysis of current existing tools. While maturity models target to demonstrate which maturity level an organization is in, readiness models aim at clarifying whether an organization is ready – or not – to start a development process. The proposed C-readiness tool overcomes the limitations of previous assessment methods. Compared to other tools, it allows the assessment of an entire organization (the analysis is not limited to a single product), it considers a systemic vision and a supply chain perspective inside a single company evaluation, usually overlooked by previous tools, it provides numerical results, and it consider several elements not considered by previous tools, such as the limitation in the use of single-use plastics and the exploitation of digital technologies in enabling Circular Economy. The C-readiness tool is intended to evaluate the readiness of a manufacturing company for the Circular Economy in the early stages of development. It helps in creating the required awareness and shared language inside the company needed to embrace such a transition. The tool is also intended to allow companies to understand where they are – in terms of readiness – and what they need to do to improve their readiness performances. The next step of the research will involve the application of the model to manufacturing companies in different industries for testing and validation purposes, and the implementation of the tool into a

software platform to automate the collection of input data and the computation of the readiness results.

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References

Bressanelli, G., Perona, M. and Saccani, N. (2019), "Challenges in supply chain redesign for the Circular Economy: a literature review and a multiple case study", *International Journal of Production Research*, Taylor & Francis, Vol. 57 No. 23, pp. 7395–7422.

Bressanelli, G., Saccani, N., Pigosso, D.C.A. and Perona, M. (2020), "Circular Economy in the WEEE industry: a systematic literature review and a research agenda", *Sustainable Production and Consumption*, Elsevier B.V., Vol. 23, pp. 174–188.

Camacho-Otero, J. and Ordoñez, I. (2017), "Circularity assessment in companies: conceptual elements for developing assessment tools", *23rd International Sustainable Development Research Society Conference*.

Cayzer, S., Griffiths, P. and Beghetto, V. (2017), "Design of indicators for measuring product performance in the circular economy", *International Journal of Sustainable Engineering*, Vol. 10 No. 4–5, pp. 289–298.

Cherrafi, A., Garza-Reyes, J.A., Belhadi, A., Kamble, S.S. and Elbaz, J. (2021), "A readiness self-assessment model for implementing green lean initiatives", *Journal of Cleaner Production*, Elsevier Ltd, Vol. 309 No. January, p. 127401.

Corona, B., Shen, L., Reike, D., Rosales Carreón, J. and Worrell, E. (2019), "Towards sustainable development through the circular economy—A review and critical assessment on current circularity metrics", *Resources, Conservation and Recycling*, Elsevier, Vol. 151 No. September, p. 104498.

Elia, V., Gnoni, M.G. and Tornese, F. (2020), "Evaluating the adoption of circular economy practices in industrial supply chains: An empirical analysis", *Journal of Cleaner Production*, Elsevier Ltd, Vol. 273, p. 122966.

Ellen MacArthur Foundation. (2012), *Towards a Circular Economy - Economic and Business Rationale for an Accelerated Transition*.

Evans, J. and Bocken, N. (2014), "Developing a Tool for Manufacturers to Find Opportunity in the Circular Economy -", *KES Transactions on Sustainable Design and Manufacturing*, Vol. 2011 No. 1, pp. 303–320.

Fraccascia, L. and Yazan, D.M. (2018), "The role of online information-sharing platforms on the performance of industrial symbiosis networks", *Resources, Conservation and Recycling*, Elsevier, Vol. 136 No. December 2017, pp. 473–485.

Garza-Reyes, J.A., Kumar, V., Batista, L., Cherrafi, A. and Rocha-Lona, L. (2019), "From linear to circular manufacturing business models", *Journal of Manufacturing Technology Management*, Vol. 30 No. 3, pp. 554–560.

Garza-Reyes, J.A., Salomé Valls, A., Peter Nadeem, S., Anosike, A. and Kumar, V. (2018), "A circularity measurement toolkit for manufacturing SMEs", *International Journal of Production Research*, Vol. 7543, pp. 1–25.

González-Sánchez, R., Settembre-Blundo, D., Ferrari, A.M. and García-Muiña, F.E. (2020), "Main Dimensions in the Building of the Circular Supply Chain: A Literature Review", *Sustainability*, Vol. 12 No. 6, p. 2459.

Gusmerotti, N.M., Testa, F., Corsini, F., Pretner, G. and Iraldo, F. (2019), "Drivers and approaches to the circular economy in manufacturing firms", *Journal of Cleaner Production*, Elsevier Ltd, Vol. 230, pp. 314–327.

Hansen, E.G. and Revellio, F. (2020), "Circular value creation architectures: Make, ally, buy, or laissez-faire", *Journal of Industrial Ecology*, p. jiec.13016.

Konietzko, J., Bocken, N. and Hultink, E.J. (2020), "Circular ecosystem innovation: An initial set of principles", *Journal of Cleaner Production*, Elsevier Ltd, Vol. 253, p. 119942.

LifeGate. (2020), "LifeGate light assessment", available at: https://susy.whyinvestin.com/customers-form/lifegate/.

Pigosso, D.C.A. and McAloone, T.C. (2021), "Making the transition to a circular economy within manufacturing companies: the development and implementation of a self-assessment readiness tool", *Sustainable Production and Consumption*, Elsevier B.V., Vol. 28, pp. 346–358.

Prieto-Sandoval, V., Ormazabal, M., Jaca, C. and Viles, E. (2018), "Key elements in assessing circular economy implementation in small and medium-sized enterprises", *Business Strategy and the Environment*, pp. 1–10.

Roos Lindgreen, E., Salomone, R. and Reyes, T. (2020), "A Critical Review of Academic Approaches, Methods and Tools to Assess Circular Economy at the Micro Level", *Sustainability*, Vol. 12 No. 12, p. 4973.

Saidani, M., Yannou, B., Leroy, Y. and Cluzel, F. (2017), "How to Assess Product Performance in the Circular Economy? Proposed Requirements for the Design of a Circularity Measurement Framework", *Recycling*, Vol. 2 No. 1, p. 6.

Vinante, C., Sacco, P., Orzes, G. and Borgianni, Y. (2021), "Circular economy metrics: Literature review and company-level classification framework", *Journal of Cleaner Production*, Elsevier Ltd, Vol. 288, p. 125090.

Walker, A.M., Vermeulen, W.J.V., Simboli, A. and Raggi, A. (2021), "Sustainability assessment in circular inter-firm networks: An integrated framework of industrial ecology and circular supply chain management approaches", *Journal of Cleaner Production*, Elsevier Ltd, Vol. 286, p. 125457.