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Developing a qualitative maturity scale for circularity in manufacturing

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Abstract. Circular Economy (CE) is gaining momentum and its diffusion in manufacturing companies remains a key element to be addressed. Indeed, the principles and practice of circularity can enhance sustainability in the manufacturing sector, but changes are required in organizations in order to fully embrace this paradigm. Therefore, several assessment models have been proposed to quantitatively measure CE performance, yet covering niche aspects, whereas a holistic perspective is usually neglected. In addition, there is significant scope to improve the elements composing the big picture through delineating where possible improvements might occur and this can be provided through an evaluation of the current status of a manufacturing company in respect to the optimum or reference model. Therefore, the goal of this contribution is to create the building blocks for a maturity model assessment proposing a complete and exhaustive maturity scale supporting companies in clarifying strategic objectives towards circularity in manufacturing. This goal has been achieved through a review of the scientific literature review and a validation exercise performed through two workshops in which practitioners and researchers have been involved. This mixed-methodology allowed to strengthen the results obtained.

Keywords: Circular Economy; Maturity; Manufacturing.

1 Introduction

Nowadays more than ever, manufacturing companies are required to update and rethink traditional activities and operations, especially through the perspective of sustainability [1], and with a focus on limiting resource consumption and extending resource lifecycles. In this regard, calls for adopting circular economy (CE) principles have proliferated based on values and principles that are intended to increase sustainability in the manufacturing sector [2]. Indeed, the extant literature presents a plethora of research dealing with CE in terms of definition of the paradigm [3], description of the main principles [4], and possible circular business models adoptable by companies [5].

A common need identified across these calls is that of a reference model to enable companies to embrace CE through embarking on a structured transition, based on clear objectives. Different assessment models have been proposed, such as those to assess resource consumption and greenhouse gasses emissions [6]. Although these models often generate quantitative measures, their scope is limited usually to a specific process or a specific resource. They all tend to have either a firm-level or a network-level perspective, without providing a holistic picture. They also neglect the possibility to benchmark the current status assessed with better achievable levels. Indeed, each company requires varying time and efforts to undertake this path. Developing a qualitative maturity scale for circularity in manufacturing firms is therefore needed. The existing maturity models for circularity appear to focus on assessing structural and technical factors of manufacturing systems and tend to neglect organizational factors and the managerial practices, which indicates a limitation in the current approaches to circularity, since organization science underlines how the way in which things are done, i.e. the granularity in practices, is fundamental to understand and explain performance differentials [7]. Therefore, the goal of this contribution is to develop a qualitative maturity scale allowing to position manufacturing companies in the path towards circularity to support them in defining clear objectives to improve self-performance towards circularity.

The paper is structured as follows. Section 2 reports the methodology adopted. Section 3 reviews the literature on assessment models for CE. Section 4 presents the qualitative maturity scale developed based on the review. Section 5 reports on the workshops held to validate the scope and applicability of the scale, and finally Section 6 concludes the contribution with implications, limitations and future research directions.

2 Methodology

The present contribution aims to establish the basis and the building blocks to clarify the distinctive maturity levels in which a manufacturing company can be positioned concerning CE implementation. To achieve this goal, the extant literature was reviewed by querying Scopus with the following string: “circular economy” AND (“assessment” OR “maturity”) AND “model*” AND “manufacturing”). This led to an initial output of 79 to which 9 were added relying on suggestions from experts in the field. Then non-English written documents were excluded and the remaining sample was spanned to select eligible papers. Therefore, non-manufacturing specific papers, and papers not focused on models to assess circularity or circular aspects were discarded. The final sample of 44 papers (only partly reported in this paper) was reviewed in section 3.

This review enabled to define the maturity scale that then has been validated (see section 5) through two complementary workshops held in Italy and in Finland, involving a total of 20 European participants (10 in each workshop) from industry. The workshops took place online using *Mural* and *Miro* tools to actively engage participants in the collaborative validation of the scale and the discussion of its value and applicability.

3 Literature review: assessment models for CE

The extant literature on models assessing CE performances is quite vast [8], since each model developed tends to be focused on a specific aspect of CE [6]. This allows companies to immediately retrieve information about a distinctive aspect without instead having the overview on the company as a complex entity operating in an even more complex network. This limits the potential of CE in coping with the linear inefficiencies like unsustainable materials, and unexploited customer engagement [11].

These assessment methods may evaluate the greenhouse gasses emissions of productive activities [12], the resources consumption starting by considering the product design [13]. These measurements are sometimes grouped in the Life Cycle Assessment (LCA) to support for instance the decision-making process towards the design of new circular products or services [14]. Moreover, in addition to the environmental performance, these models are also extended to the evaluation of the economic benefits taking the name of Life Cycle Costing (LCC) to meet the companies' economic needs [15]. These models allow to monitor the undertaking of an initial path towards circularity focusing first on the consumption of limited resources, but offer only a partial view without fully capturing the range of the opportunities enabled by circularity. As a consequence, considering the network perspective characterizing CE, other models were developed such as those focused on the supplier selection process [16] or those supporting the engagement with the right partners in a reverse logistics network [17]. Following the same circular lifecycle perspective, maturity assessment models were developed to evaluate functional product requirements to ensure product circularity at the end of their lifecycle [18]. In line with these models, the LCA and the LCC were adopted also to monitor the environmental performances of an industrial symbiosis network [19] stressing the importance to engage with external stakeholders.

Although these existing models provide great tools to assess manufacturing companies' current circular performances on specific issues, they do not help them in understanding concretely where they are, to be able to put in place new actions to improve their conditions. This issue can be covered by an internal awareness generated through a thorough initial qualitative analysis concerning their general current achievements in terms of circularity, as proposed for SMEs [20]. This awareness is necessary also for larger companies requiring significant changes supported by clear plans, defined by managers, to be aligned with the external ecosystem [21]. Indeed, the strategic and the managerial indicators cover the most relevant roles in embracing CE [22].

In summary, the current approaches to measure circularity in isolation are insufficient to capture the multiple dimensions of practice that manufacturing companies need to embrace in their transitions towards improved levels of circularity. The existing measurements need to be grouped and analyzed together to provide companies with a holistic understanding of what different levels of circularity mean and require.

3.1 Maturity Frameworks

The evaluation of the status of a company in respect to the optimum is also known as "maturity". Maturity models typically consist of a sequence of maturity levels, usually five, representing a desired evolutionary path, in which the initial stages represent a limited set of capabilities in a domain, which progressively moves towards enhanced capabilities [21] and a stage of maturity. Maturity seen as a measure to evaluate the capabilities of an entity become popular since the Capability Maturity Model (CMM) was proposed and was proven in practice on Software Engineering domain [22], [23]. This was adopted in different areas especially when dealing with an innovative paradigm requiring drastic internal change for companies such as the challenges of digital transformation [24] that require a new set of skills [25]. Indeed, it has been considered a useful tool for the CE context too [26] even though still at an emergent stage regarding the building blocks characterizing CE. This is the gap this paper addresses.

Determining the capability levels of processes in organizations requires the definition of best practices in a reference model [27] that outlines a process lifecycle, objectives, outputs and relationships between them. These reference models are refined into activities and base practices which exemplify attributes and characteristics of firms' practices enabling to assess performances. The proposed qualitative maturity scale for circularity in manufacturing is intended to operate as a reference model, where the dimensions and categories of the activities and base practices operate as the key building blocks for a fully-fledged circularity maturity model. This contribution opens up the black box of maturity scale development, through reporting on the process of incorporating the needs of the intended users. It strengthens the transparency of the process through demonstrating how varying stakeholders were actively involved in collaboratively examining the applicability and what can be achieved through the use of the scale.

4 Qualitative Maturity Scale for Circular Economy

Further to the review of assessment models for CE reported in section 2, a clustering and systematization of circularity components into five distinct qualitative maturity levels is below proposed and illustrated in Fig. 2.

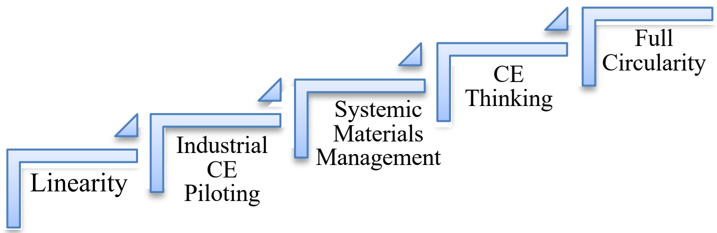

Fig. 1 Circular Economy Qualitative Maturity Scale

A manufacturing company classified in the *Linearity* level is still stuck into the traditional concept of make-take-dispose. The only sustainable/circular-oriented activities consist in legal responsibilities mainly related to waste management and limited usage of toxic substances. Therefore, the company performance is monitored only to mitigate additional costs rather than to find new opportunities in a circular scenario.

The second level of maturity, named *Industrial Circular Economy Piloting,* corresponds to a more advanced level, within which the company is interested in changing, at least partially, the current linear pattern. Indeed, some pilot experimentation takes place, pushing performance closer to resources sufficiency. Detailed analyses are performed to diagnose resource bottlenecks and to evaluate different processes parameters in terms of material and energy consumption. In addition, led by the strategic level, the experimentation goals and results are shared within the company boundaries across different hierarchical levels, from the top management to the more operative levels, to engage employees in this transition and create internal awareness.

The third achievable level, named *Systemic Material Management,* corresponds to the adoption of CE in a more extended perspective, i.e. to the whole company. Here the "R-cycles" characterizing CE have become a standard practice adopted by the company in order to systematically identify possibilities to reuse, refurbish, recycle, and remanufacture materials. To make this possible, the entire company is involved and the operative level is required to take an active role in this initiative. Every resource used by the company is internally analyzed to think about possible future reintroduction into (new) R-cycles. The LCA is implemented to keep the most critical processes under control. This is backed also by the monitoring of the circular performance, conducted by the local unit leaders, with an initial attempt to share the results with value chain partners and other stakeholders such as customers. Therefore, to do that, an initial adoption of information and communication technologies (ICT) to optimize material management and to make operations more sustainable is seen.

The fourth level of the scale is named *Circular Economy Thinking* since at this level the company is not only internally able to recirculate resources, but it has also understood the potential in defining stronger partnerships with external stakeholders to repurpose industrial materials. Therefore, industrial symbiosis networks, and an attempt to establish a closed-loop supply chain is observed at this level. To support these initiatives, ICT are used in a more integrated manner. Moreover, the LCA is performed as common practice on all the production processes and products developed internally.

The highest maturity level, from which continuous improvement follows, is named *Full Circularity*. At this level, the firm is fully immersed into the circularity paradigm and committed to achieving social, economic and environmental positive performances in all the products, processes and operations. This is achieved thanks to the exploitation of synergies among forward and reverse logistics, and among local value chains by sharing a mutual vision for sustaining full circularity leading to the co-creation of new value circles within manufacturing networks. ICT are highly integrated into operations to support these interactions. Strategic, tactical and operational levels of the company are aligned with a systematic and proactive follow-up of the circular transition.

5 Maturity Scale validation

The maturity scale developed for circularity in manufacturing it has been validated through two complementary workshops evaluating its applicability and value.

In the first workshop, the importance of clearly determining the positioning of a company in respect to the improved levels achievable in CE was highly emphasized. This would enable to facilitate the clarification of internal objectives extending the traditional ones of manufacturing operations. There was wide agreement with the need to first think about internal adaptation of traditional processes by starting with piloting experimentation focused mainly on material management. This creates the awareness to also look externally into other possible stakeholders that should be involved in alignment with the maturity scale proposed. Indeed, the higher levels of maturity require the involvement of external actors to make the recirculation of resource possible.

In the second workshop, participants acknowledged the usefulness of a maturity scale to address, on the one hand, capability gaps concerning CE know-how within companies and, on the other hand, the possibility to pace the transition, since the required changes for CE would be too massive to tackle at once. The workshop has also highlighted how participating companies understood the importance of an early identification of circularity potential across supply chain individual components, which requires a common reference architecture and the adoption of an ecosystem type of thinking for the effective sharing of material information and logistics optimization. This is reflected particularly in the Systemic Material Management level of the maturity scale.

Across both workshops, participants converged on their consideration of product as a key element to be updated and innovated to address circularity, underlining also the need to ensure consumer satisfaction in modifying products, and the engagement of the labor force through strengthening their competencies for undertaking this transition. Another crucial aspect raised by participants concerned the need to be aligned with other industrial actors, especially those operating in the same supply chain, which can be achieved through better data sharing capabilities. This indeed requires the introduction of integrated platforms allowing an easy exchange of relevant information and the establishment of type of data required to be shared and exchanged.

6 Conclusions

The present contribution aimed at developing a qualitative maturity scale for circularity in manufacturing. The maturity scale represents an extensive description of a possible stage within which a manufacturing company can be found during the transition from linear to circular manufacturing. It supports a diagnosis-oriented introspective qualitative analysis, by covering the distinctive actions that should be put in place to achieve higher levels of circularity starting from an initial update of internal practices.

Our contribution of a qualitative maturity scale is a fundamental step in the formulation of a circularity maturity model for manufacturing firms. The qualitative stages of the scale correspond to a matrix of practices and a first attempt at systematizing the sophistication and embeddedness of the proposed practices, with a view to developing a validated maturity model that enables manufacturing firms to position current practices against the maturity scale and optimize CE performance. The process presented here contributes to opening up the black-box of maturity models development, as it demonstrates how the needs of industry practitioners are reflected, how and why industry practitioners will seek to apply them, and who needs to be involved. Further developments should be focused on extending the maturity scale beyond a descriptive scope and outline a detailed range of prescriptive actions, giving manufacturing companies access to the more practical instruments and indicators they need to fully embrace circularity. In addition, considering the value of data sharing expressed during the workshops, further analysis in this direction will be performed.

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