# A Circularity Measurement Toolkit for Manufacturing SMEs

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# Circularity Measurement Toolkit for Manufacturing SMEs

**Abstract**

The development and adoption of the concept of circular economy in the last two decades have been remarkable. However, despite its widespread adoption, little progress has been made regarding its measurement, especially in manufacturing SMEs. This paper, therefore, proposes a Circularity Measurement Toolkit (CMT) which enables the assessment of the degree of circularity in manufacturing SMEs. A conceptual CMT framework, which provided the basis for the proposed tool and that defined the different types of circular practices and a classification or levels of circularity was developed from an extensive literature reviewed. To ensure the structure's accuracy of the proposed CMT in terms of requirements to be measured, the monitoring process and actions involved, the tool was verified through a Delphi-study. Furthermore, its practicality was validated through a case study approach in a manufacturing SME. This paper contributes by filling a gap in the CE measurement field through the proposal of the CMT. Besides providing an evaluation of the degree of circularity in the practices of manufacturing SMEs, companies can also employ the proposed CMT to identify corrective actions or future efforts for the adoption of CE practices.

**Keywords:** Circular economy; circularity; manufacturing SMEs; measurement, environmental.

## 1. Introduction

Technological advancement and fast-paced production/consumption with no clue for recycling (Su et al. 2013) are resulting in the fast depletion of natural resources (Nadeem et al. 2017) and causing serious damages to the environment. Besides various frameworks/models and efforts have been proposed and initiated to deal with this phenomena, the concept of Circular Economy (hereafter referred as CE) has emerged, over last two decades, as another potential alternative to tackle such challenges (Loon, Delagarde, and Van Wassenhove 2017). CE is believed to have sprouted from ecological and environmental economics (Ghisellini, Cialani, and Ulgiati 2016) and eco-industrial development that proposes the coexistence of a healthy economy and a healthy environment (Geng and Doberstein 2008). CE is an economic framework (Masi et al. 2017), based on the circular flows of products and materials, which promotes the replacement of the traditional linear flow of materials ending up into the landfill, with a new flow where waste becomes food (Webster 2015). CE is gaining momentum as it has now been widely used in the formulation of new strategies to overcome the aforementioned environmental problems (Masi et al. 2017; Ellen MacArthur Foundation 2013; World Economic Forum 2014).

CE is currently receiving increased attention and adaptation in different regions. For instance, the EU particularly promotes the practices of recycling and recovery of products (European Environment Agency 2016), the US focuses on related policy development (Heck 2006), and China has a national CE policy (Geng et al. 2012). However, despite this widespread appraisal and adaptation of the CE concept, there is still a lack of comprehensive frameworks (Masi et al. 2017) and measurement tools to assist companies in the evaluation of CE practices and performance (Elia, Gnoni, and Tornese 2017; Haas et al. 2015), especially SMEs. In the current published literature, scholars have proposed

eight measurement methods/tools, adhering to five requirements to be assessed (see Table 1). However, a thorough exploration of the published literature points to more necessary requirements, see Section 3.3, that must be incorporated to ensure a comprehensive measurement of circularity. Therefore, the aforementioned eight tools were found to be lacking of a comprehensive approach. Table 1 categorises the published literature, within the context of SMEs, which has focused on assessing and measuring CE practices/performance and exploring their scope under 12 measurement requirements as suggested by scholars (see Section 3.3). The 12 requirements for the measurement of circularity are introduced, further discussed and justified in Section 3.3.

Table 1. Published literature regarding CE measurement in SMEs

| | CE requirements to be measured | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Reducing environmental damage | Increasing internal awareness | Reducing input of materials | Reducing critical materials | Reducing non-renewable resources | Increasing durability of products | Increase external awareness | Increase value chain support | Increase green market | Increase longevity of products | Increase technologies | Increase legislation development |
| (Ellen MacArthur Foundation and Grata Design 2015) | | | ☑ | ☑ | ☑ | ☑ | | | | | | |
| (Di Maio and Rem 2015) | | | | | ☑ | | | | | | | |
| (Park and Chertow 2014) | | | | | ☑ | | | | | | | |
| (Li and Su 2012) | ☑ | | ☑ | ☑ | | | | | | | | |
| (Genovese et al. 2015) | ☑ | | ☑ | ☑ | ☑ | | | | | | | |
| (Wen and Meng 2015) | ☑ | | ☑ | | | | | | | | | |
| (Scheepens, Vogtlander, and Brezet 2016) | ☑ | | ☑ | | | | | | | | | |
| (Elia, Gnoni, and Tornese 2017) | ☑ | | ☑ | ☑ | ☑ | ☑ | | | | | | |
| This paper - | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ |

In the literature, the most complete assessment framework proposing a material circularity index (MCI) may be considered the one developed by the Ellen MacArthur Foundation and Grata Design (2015). This tool measures the minimisation of a linear and maximisation of a circular approach. Nevertheless, due to the complexity of this framework, its practical adaptation/applicability for SMEs may be challenging. On the other hand, the Circular Economy Index (CEI) proposed by Di Maio and Rem (2015) measures the ratio of actual recycled products compared to what was received for recycling. The Reuse Potential Indicator (RPI) proposed by Park and Chertow (2014) serves as a decision-making tool in recycling processes by identifying characteristics of materials as “resource like” and “waste like”. Li and Su (2012) introduced an index method for the Chinese chemical industry; with five categorisations that include economic development, ecological efficiency, pollution reduction, resource exploitation and development potential. Genovese et al. (2015) developed a tool combining life cycle analysis with an environmental input-output analysis to evaluate circular production systems in the food and chemical industry. Wen and Meng (2015) proposed a Resource Productivity Indicator to evaluate the impact of industrial symbiosis for CE. Scheepens, Vogtlander, and Brezet (2016) offered an indicator by incorporating cost-effectiveness, eco-costs, and market value to evaluate the implementation of CE in water recreation parks. Elia et al. (2017) introduced a framework and measurement tool implementable at

all levels, i.e. micro, meso and macro, proposing the requirements to measure, processes to monitor, and the actions involved. However, as mentioned earlier, this tool (discussed later in Section 3) does not fully envelop all necessary requirements to be measured as well as the processes to be monitored and action involved.

### *1.1 Problem statement and research scope*

Given the fact that the previously discussed measurement tools are not fully comprehensive, especially for SMEs, a practical full-scale assessment of CE practices, particularly for manufacturing SMEs, still remains incomplete. Therefore, the development of a tool for manufacturing SMEs is vital and much needed to measure circularity and promote its adaptation.

Based on the above research gap, this research proposes a Circularity Measurement Toolkit (hereafter referred to as CMT) and standard categorisation for different levels of circularity among manufacturing SMEs. The proposed CMT categorises/standardises different circularity degrees and measures the current circularity level of SMEs. This would help in formulating future strategies and interventions that can be implemented to reduce resource consumption, price volatility, waste generation, environmental damage, and at the same time, strengthen the supply chains of manufacturing SMEs.

Hereafter the paper is divided into six sections that include: Research methodology (Section 2), conceptual development of the framework for the proposed CMT (Section 3), its verification through a Delphi-study (Section 4), the updated CMT (Section 5) and, its validation using a case study approach (Section 6). The conclusions, limitations and future research directions derived from this work are included in Section 7.

## 2. Research methodology

This section presents an overview of the research methodology followed in this study to develop, verify and validate the proposed CMT (see Figure 1). The research was scoped and a systematic literature review carried out to identify and fulfil the gap as discussed in Section 1. Overall, the development of the proposed CMT consisted of three main stages, namely: (1) development of a conceptual framework for the proposed CMT, (2) its verification, and (3) its validation (see Figure 1). The conceptual development of the framework for the proposed CMT was based on published literature, used as a guidance of how researchers had previously measured and categorised specific CE practices. Additionally, previous academic work was adapted to facilitate the design and development of the framework for the proposed CMT (see Section 3).

### *2.1 Locating the studies*

The research utilised only peer-reviewed academic articles to ensure the rigour and reliability of the sourced information and authentic organisation's websites/publications. These articles were located by using search strings that included '*Circular Economy*', '*Circularity*', '*Measurement of Circularity*', '*SMEs*', and '*Environmental*'. The Boolean approach (i.e. and/or) was adopted to search for earlier mentioned search strings on following electronic databases: Science Direct (www.sciencedirect.com), Emerald Insight (www.emeraldinsight.com), Inderscience (www.inderscience.com), Springer (www.springer.com), Taylor & Francis (www.tandfonline.com), IEEE Xplore (ieeexplore.ieee.org/Xplore/home.jsp), Google Scholar (scholar.google.co.uk), websites of organisations working/promoting CE (e.g. www.ellenmacarthurfoundation.org).

Given the focus of the study being Circularity measurement, only eight articles/tools were found. These eight tools are discussed in Section 1 (see Table 1).

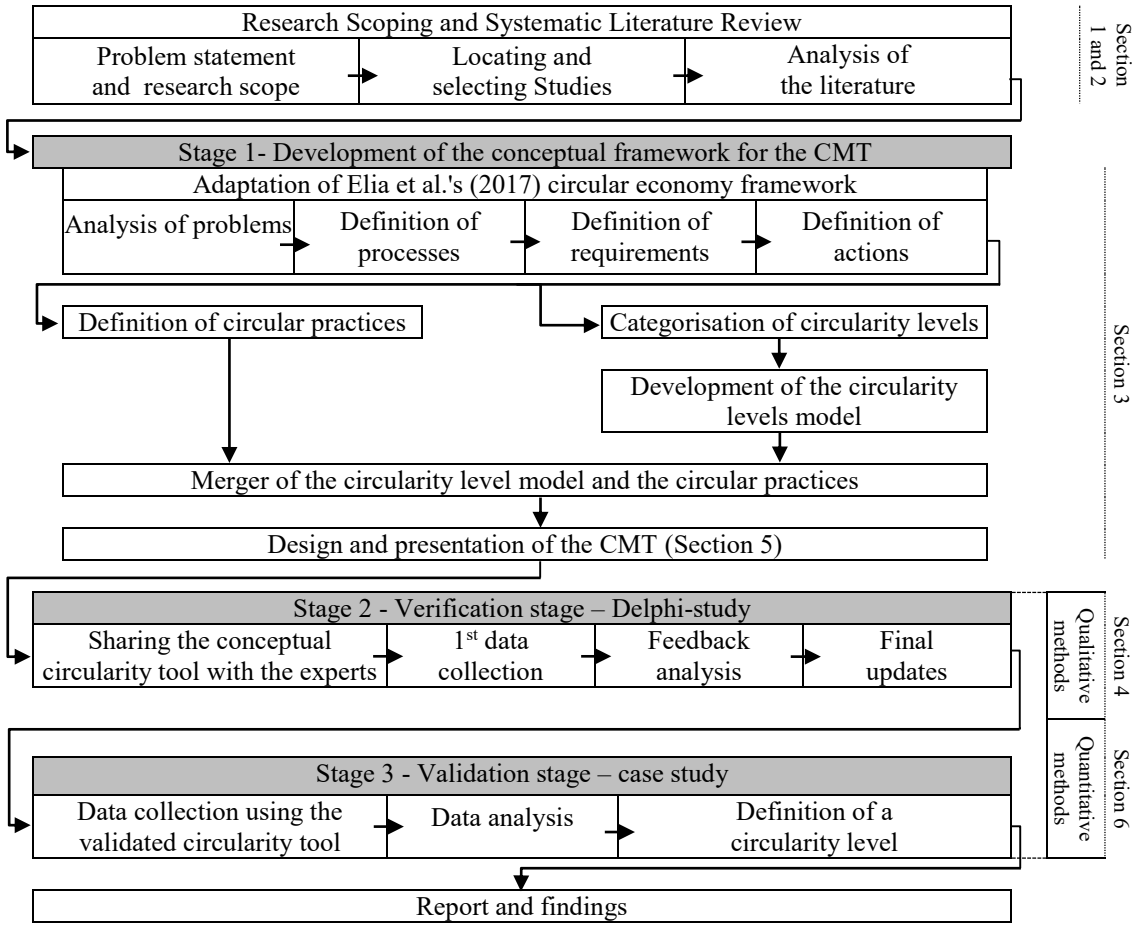


Figure 1. Research methodology and process overview for CMT development

### *2.2 Analysis of the literature*

As a result of the problem definition, the measurement framework proposed by Elia et al. (2017) was adopted for modification, as the proposed framework in its current form was not fully comprehensive (see Sections 1 and 3). A further exploration of the literature was conducted to identify the CE requirements to be measured and actions involved. This led to the identification of seven additional requirements to be measured (see Section 3.3), eight actions involved (see Section 3.4) and four additional processes to monitor (see Section 3.2) that have not been incorporated earlier in any of the eight tools discussed in Section 1 (See table 1).

### *2.3 Conceptual framework development*

Refer to Section 3

### *2.4 Verification of the conceptual framework*

To verify the conceptual CMT framework, a Delphi-study was conducted. A Delphi-study enables experts' assessment/opinions to be gathered to judge a phenomenon in the absence of existing knowledge (Bogner, Littig, and Menz 2009). Fifteen participants were invited using snowball sampling to ensure an enriched verification with the support of experienced professionals related to the field of study (Collis and Hussey 2014). Eight of the invited participants consented to participate in the study. The qualitative data collected

during the Delphi-study were analysed and the results used to improve the conceptually developed CMT framework, see Section 4.

### *2.5 Validation of verified toolkit*

The CMT was further validated through a case study where different CE practices of an SME were captured to measure the circularity level of the company. The study demonstrated the effectiveness of the CMT in measuring the degree of circularity of SMEs to understand which circular practices can be implemented in order to move from linear to more circular business practices. Even though the limitation exists that the CMT has only been validated in one company, its widespread applicability remains true due to the fact that the toolkit incorporates a broad range of measures, actions and processes to measure.

By following the methodology described above, the research progressed in a logical manner, leading to reliable findings, while avoiding participants/ researchers' errors and bias (Saunders, Lewis, and Thornhill 2012).

## 3. Conceptual development of the framework for the proposed CMT

As illustrated in Figure 1, the development of the conceptual CMT framework involved the adaptation of an existing circular economy framework. After an exhaustive review of the literature, the framework by Elia et al. (2017) was determined to be the closest towards achieving the objectives of this research of proposing an effective tool to measure the circularity of practices embedded in the operations of manufacturing SMEs. However, the framework was considered limited as it lacked various circularity requirements, actions and processes. The adapted framework is shown in Figure 2, where the shaded elements represent the modifications and additions made through this research. These were determined to be critical elements of the measurement and practices of CE initiatives as suggest by Masi et al. (2017).

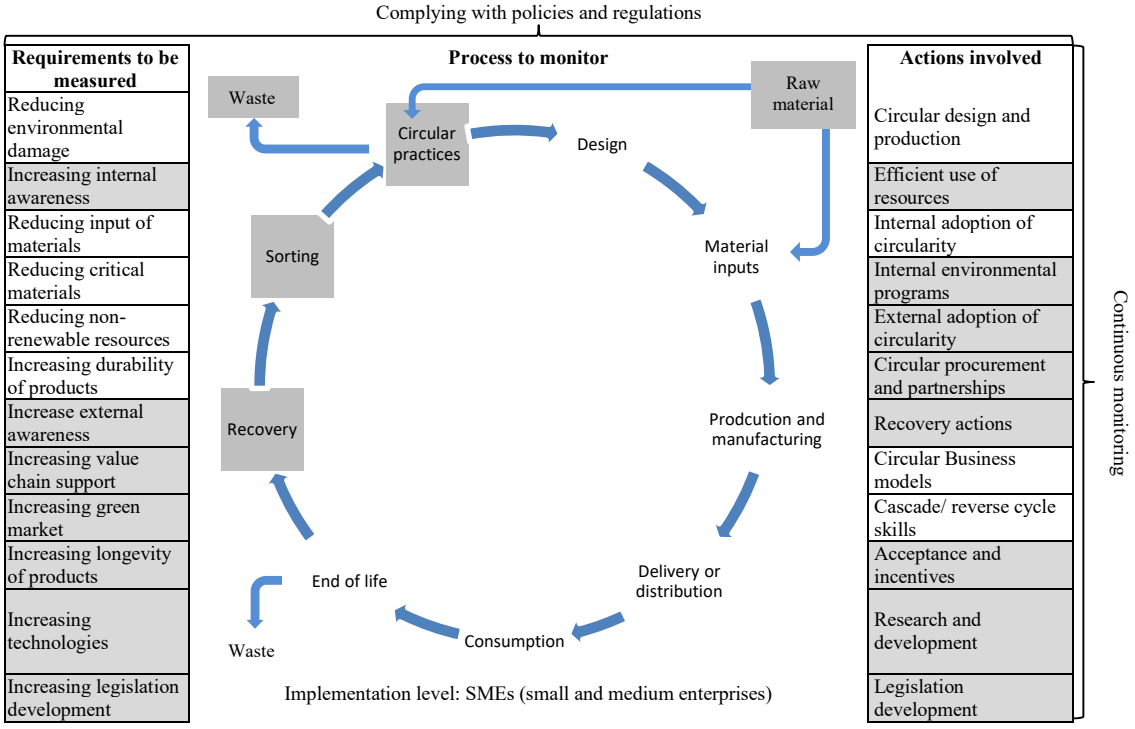


Figure 2. Circularity measurement framework (adapted from Elia et. al., 2017)

In order to adapt Elia et al.'s (2017), the activities outlined in Figure 1 under "Adaptation of Elia et al.'s (2017) circular economy framework" were carried out as described in the following sub-sections.

### *3.1 Analysis of problems*

To provide clarity on the requirements of the framework, a review of the problems/challenges faced by SMEs was necessary. These included:

- exhaustion of resources due to escalated linear consumption;
- resource scarcity due to the complexity of the extraction processes and the lack of technologies;
- price volatility, mainly because of the increasing costs related to the extraction of raw materials;
- waste generation, also related to the linear consumption pattern among a growing population;
- environmental damage due to industrialisation and utilisation of non-renewable resources;
- weak supply chains due to the lack of awareness, partnerships, and collaborative support across the value chain where the responsibilities are not shared (Ellen MacArthur Foundation 2013).

### *3.2 Definition of processes*

The problems outlined above enabled a further critique of the framework by Elia et al. (2017) exposing the lack of several circularity processes stages leading to the following modifications:

- The addition of a stage related to the extraction of raw materials, which can not only be used for the manufacturing of products but also during circular activities such as recycling or remanufacturing where there is always a need of extra raw material as currently recycling process is not 100% efficient (Grubbström and Tang 2006).
- The exchange of design and materials input stage, as in CE it is necessary to apply a circular design from the beginning of the process in order to select the adequate materials and processes (Bonciu 2014).
- Separation of the production and delivery stages, as although the technology has made production processes very efficient, transportation has not obtained the same results. It has been confirmed that 15% of the global $CO_2$ emissions come from the transport sector. Thus, the stage related to transportation and especially when the CE is applied at a macro level can be one of the most pollutant phases (Rodrigue, Comtois, and Slack 2017).
- The addition of a recovery stage, as authors consider that it is the most challenging part of CE as it is difficult to make customers share the responsibility and help organisations by losing the ownership of a product (Ellen MacArthur Foundation 2015a).
- Addition of circular practices or business models stages due to the post work that can be done at the end of life and end of used materials, components and products (Sempels and Hoffmann 2013).

### *3.3 Definition of requirements*

With the enhancement of processes, it was also necessary to adopt the CE requirements to be measured based on peer-reviewed published literature. These additional requirements were added to complement the existing ones, see shaded elements in the "Requirements to be measured" in Figure 2. The new additional requirements included: increasing internal and external awareness (Lewandowski 2016; Van Weelden, Mugge, and Bakker 2016); increasing value chain support and green market (Masi et al. 2017); increasing products longevity (Franklin-Johnson, Figge, and Canning 2016); increasing technologies (Ghisellini, Cialani, and Ulgiati 2016); and increasing environmental legislation (Ellen MacArthur Foundation 2013). Moreover, the requirement of reducing the emissions levels was substituted by reducing environmental damage, which is broader as it includes damages generated by emissions, water pollution, wastes and land degradation (Kang and Zhang 2017).

### *3.4 Definition of actions*

Lastly, the general actions involved, see shaded elements in Figure 2 "Actions involved" column, were also complemented, additionally to the four actions already included in Elia et al.'s (2017) framework. The adapted framework included: efficient use of resources (Kang and Zhang 2017); internal adoption of circularity (Lewandowski 2016); internal environmental programmes (Masi et al. 2017); external adoption of circularity (Van Weelden, Mugge, and Bakker 2016); circular procurement and partnerships (Masi et al. 2017); recovery actions (Ellen MacArthur Foundation 2015a); acceptance and incentives (Esposito, Terence Tse, and Soufani 2016); research and development (Ghisellini, Cialani, and Ulgiati 2016); and legislation development (Ellen MacArthur Foundation 2013). These additional actions were included due to their direct relevance with CE implementation which is discussed by scholars. All these activities must be carried out subject to the compliance of policies and regulations established by the countries, geography or other regulatory institutions (Ellen MacArthur Foundation 2013) and the continuous monitoring and inspection of all the components of the framework (Lewandowski 2016).

### *3.5 Definition of circular practices*

In light of the adapted framework, it was necessary to define the detail practices that could contribute in performing those actions; for this, the study by Masi et al. (2017) was used as a base. Masi et al. (2017) highlighted 25 practices for the implementation of CE after conducting an in-depth analysis of different conceptual antecedents, see Table 2. However, to consider all the components of the framework, see Figure 2, 11 additional practices widely referred to in the literature were included, see Table 2.

Table 2. Circular practice incorporated in CMT

| **25 circular practices proposed by Masi et al. (2017)** | |
|---|---|
| 1. Designing of products for reduced consumption of resources. | 2. Design of products for reuse and or recovery of materials and or component parts. |
| 3. Design of processes for minimisation of waste. | 4. Reducing material consumption. |
| 5. Using renewable materials and energy in the production process. | 6. Reducing energy consumption. |
| 7. Reducing pollutants emissions. | 8. Reducing wastes. |

| | |
|---|---|
| 9. Green packaging | 10. Special training for workers on environmental issues and circular economies. |
| 11. Including environmental factors in the internal performance evaluation systems. | 12. Environmental auditing programs. |
| 13. Eco-labelling of products. | 14. Selecting suppliers using environmental criteria. |
| 15. Cooperating with other firms to establish eco-industrial chains. | 16. Reusing energy and/or water across the value chain. |
| 17. Taking back products from consumers after the end of their functional life. | 18. Taking back products from customers at the end of their usage. |
| 19. Refurbishing products. | 20. Remanufacturing products. |
| 21. Use of recycled materials. | 22. Adopting a leasing or service based marketing strategy. |
| 23. Cascading use of components and materials. | 24. Targeting Green segments of the market. |
| 25. Cross functional cooperation for environmental improvements. | |
| **Additional 11 circular practices** | |
| 1. Design for durability (Lieder and Rashid 2016; Ghisellini, Cialani, and Ulgiati 2016; Witjes and Lozano 2016). | 2. Circular management, culture and continuous monitoring (Lewandowski 2016). |
| 3. Awareness within customers (Lieder and Rashid 2016; Van Weelden, Mugge, and Bakker 2016; Lewandowski 2016; Weetman 2016). | 4. Awareness within the supply chain (Van Weelden, Mugge, and Bakker 2016). |
| 5. Reusing products (Van Weelden, Mugge, and Bakker 2016). | 6. Recycling of scrap or waste (Ghisellini, Cialani, and Ulgiati 2016). |
| 7. Recycling of end of life products (Ghisellini, Cialani, and Ulgiati 2016). | 8. Recycling of products after usage (Ghisellini, Cialani, and Ulgiati 2016). |
| 9. Adopting an updating market strategy (Pialot, Millet, and Bisiaux 2017). | 10. Incentives (Esposito, Terence Tse, and Soufani 2016). |
| 11. Legislation and policies (Ellen MacArthur Foundation 2013). | |

### *3.6 The categorisation of circularity levels*

In a simultaneous manner, a categorisation of nine circularity levels that are akin to maturity levels were designed, with level nine being the lowest and level one the highest as described below. The top three levels represent where circularity is fully implemented and even improved outside the company. These levels are named in accordance with their characteristics described below.

**Level 1:** **Circular Developer** are leading organisations for CE implementation, with the commitment/ability to go an step further to participate in the development of new technologies and environmental regulations that can benefit and improve circularity.

**Level 2:** **Circular Promoter** are organisations that have successfully integrated CE into their business strategy and are actually satisfying customers and growing the environmentally aware and circular market.

**Level 3:** **Circular** are the organisations that have fully integrated CE practices in their business and value chain, including activities related to circular procurement and increase of longevity with customers, suppliers and other companies.

**Level 4:** **Waved** are those organisations that are initiating external awareness and introducing the CE principles to customers and their supply chain, to promote CE to the complete value chain.

**Level 5:** **Curved** are organisations that have fully integrated CE practices and hasve adopted circularity as a culture. However, the efforts are only made internally and no practices are done with the support of customers, suppliers, other companies or competitors.

**Level 6:** **Saw-Tooth** are organisations that have introduced some important CE practices internally, they recognise the improvements and are in the process of adopting them as part of their culture.

**Level 7:** **V-shape up** are the organisations that have not applied any CE practices, nevertheless, they are curious about them and are starting to learn the benefits that CE can generate. Usually, because a member of the top management is an environmentally aware person.

**Level 8:** **∧-shape down** are organisations that without noticing it, are already applying some internal CE practices generally related to resource consumption, utilisation and efficiency. They are not aware of CE, however, they realised that economic benefits can be obtained with the adoption of certain practices.

**Level 9:** **Linear** are organisations applying only a linear approach without any knowledge about CE. Characterised for being business focused only in the economic benefits that comply with the minimum governmental or legislative requirements to be able to operate.

### *3.7 Development of the circularity levels factors*

After the categorisation of circularity levels, its characteristics were "converted" into formulas. First, it was necessary to establish circularity factors, see below, and then introduce them in the formulas that can be observed in Table 6, Section 5.4.

A = Internal practices of resource utility and efficiency percentage
B = Internal awareness percentage
C = A+B
D = External awareness percentage
E = Value chain support percentage
F = External practices for longevity percentage
G = Green market development percentage
H = Technological development percentage
I = Legislation development percentage

### *3.8 Merge of the circularity level factors and the CE practices*

In this step, the 36 practices previously defined and included in Table 2 were grouped into the factors A,B,D,E,F,G,H,I, see Section 3.7, as presented in Table 3. This categorisation of 36 practices under 7 factors is based upon the nature/characteristics of the practice in relation to the corresponding factor. Factor C, which is not shown in Table 3, is the sum of factors A and B, due to the fact that organisations can be already performing some internal activities (Factor A) without being aware (Factor B) or vice-versa, therefore factor C was designed to measure any of these conditions.

Table 3. Circularity practices grouped into circularity factors

| | |
|---|---|
| A. Internal practices - Resources | A.a) Designing of products for reduced consumption of resources |
| | A.b) Designing of products for reuse and or recovery of materials and or component parts |
| | A.c) Designing of processes for minimization of waste |
| | A.d) Designing products for durability |
| | A.e) Reducing material consumption |
| | A.f) Using renewable materials and energy in the production process |
| | A.g) Reducing energy consumption |
| | A.h) Reducing pollutants emissions |
| | A.i) Reducing wastes |
| | A.j) Green packaging |
| B. Internal awareness | B.a) Circular management, culture and continuous monitoring |
| | B.b) Special training for workers on environmental issues and circular economies |
| | B.c) Including environmental factors in the internal performance evaluation systems |
| | B.d) Environmental auditing programs |
| D. External awareness | D.a) Eco-labelling of products |
| | D.b) Awareness within customers |
| | D.c) Awareness within the supply chain |
| E. Value chain support | E.a) Selecting suppliers using environmental criteria |
| | E.b) Cooperating with other firms to establish eco-industrial chains |
| | E.c) Reusing energy and/or water across the value chain |
| F. External practices - Longevity | F.a) Taking back products from consumers after the end of their functional life |
| | F.b) Taking back products from customers at the end of their usage |
| | F.c) Refurbishing products |
| | F.d) Remanufacturing products |
| | F.e) Use of recycled materials |
| | F.f) Adopting a leasing or service based marketing strategy |
| | F.g) Reusing products |
| | F.h) Recycling of scrap or waste |
| | F.i) Recycling of end of life products |
| | F.j) Recycling of products after usage |
| | F.k) Adopting an updating market strategy |
| | F.l) Cascading use of components and materials |
| G. Green market development | G.a) Targeting Green segments of the market |
| | G.b) Incentives |
| H. Technological research and development | H.a) Cross-functional cooperation for environmental improvements |
| I. Legislation development | I.a) Legislation and policies |

### *3.9 Design of the conceptual CMT questionnaires*

A key element of the proposed CMT is a series of questionnaires for collecting information regarding the circularity practices of manufacturing SMEs. The development of the questionnaires is discussed in this section. The top-level view of the proposed CMT and how to use it to carry out circularity measurement is presented in Section 5.

Eight questionnaires were designed as part of the proposed CMT. In this context, each questionnaire corresponds to each of the factors/practices/formulas (i.e. A, B, D, E, F, G, H, I) presented in Table 4. For each practice within a factor, questions were developed to capture the extent to which such practice is in use within a manufacturing SME. Table 4 presents a partial example the questionnaires, in this case for factor A. The full eight questionnaires are included in Appendices 1 to 8.

Table 4. Questionnaires partial example – Factor A

**A. Internal Practices – Resource utility and efficiency**

| Design | | | |
|---|---|---|---|
| **A.a) Designing of product for reduced consumption of resources** | **Yes** | **Partially** | **No** |
| The design of products in the company consider the utilisation of the minimum amount of resources? | | | |
| Does the company avoid the use of non-renewable resources in the design unless it is impossible? | | | |
| | | | |
| **A.b) Designing products for reuse, recycle, and/or recovery of material and/or component parts** | **Yes** | **Partially** | **No** |
| Does the company consider and apply design for reuse? | | | |
| Does the company consider and apply design for disassembly? | | | |
| Does the company consider and apply design for refurbishing? | | | |
| Does the company consider and apply design for remanufacturing? | | | |
| Does the company consider and apply design for recycling? | | | |

### *Questionnaire A*

Questionnaire A measures the internal practices related to the efficient use of resources, see Appendix 1. The section mainly focuses on two aspects, namely: design (Singh and Ordoñez 2016; Ellen MacArthur Foundation 2013) and production. The design aspect includes questions about material selection, efficient use of resources, reduction or elimination of non-renewable resources (Witjes and Lozano 2016; Ghisellini, Cialani, and Ulgiati 2016; Lieder and Rashid 2016); disassembly, separation, manufacturing processes, standardization of components (Lieder and Rashid 2016; Ghisellini, Cialani, and Ulgiati 2016); waste and scrap generation, recyclability of materials (Masi et al. 2017); and quality/robustness of products (Ghisellini, Cialani, and Ulgiati 2016).

In the same manner, the production aspect includes questions about the reduction of materials and energy consumption (Masi et al. 2017); use and register of renewable and non-renewable materials and energy (Kang and Zhang 2017; Witjes and Lozano 2016); risk analysis of resources (Ghisellini, Cialani, and Ulgiati 2016); possibility of producing energy from the processes and waste of the factories, identification and measurement of greenhouse gas emissions (Kang and Zhang 2017); fertilizers and pesticides utilisation polluting the soil, prevention/elimination of resources going into the landfill (Ghisellini, Cialani, and Ulgiati 2016); understanding of waste as an input (Ilić and Nikolić 2016); and the efficient/adequate use of resources in packaging (Masi et al. 2017).

### *Questionnaire B*

Questionnaire B measures practices related to internal awareness, see Appendix 2, with questions focused on the formulation and sharing of a circular strategy; support of the stakeholders (Frost 2016); adoption of circularity culture and its understanding as a continuous improvement process (Lewandowski 2016); utilisation of information technologies (Lieder and Rashid 2016; Ellen MacArthur Foundation 2013); efforts to understand, adopt and implement circularity (Masi et al. 2017; Van Weelden, Mugge, and Bakker 2016; Lewandowski 2016); establishment of environmental targets per employee and assessment as part of employees performance (Masi et al. 2017; Ilić and Nikolić 2016); and measuring/monitoring of environmental risks, impacts, regulations and mitigation activities (Ilić and Nikolić 2016) through formal auditing programmes and standards (Ghisellini, Cialani, and Ulgiati 2016).

***Questionnaire D***
Questionnaire D assesses practices focus on external awareness, see Appendix 3. This includes questions regarding customers' awareness about CE business models and their benefits (Lieder and Rashid 2016; Van Weelden, Mugge, and Bakker 2016; Lewandowski 2016; Weetman 2016); environmental information sharing through products (Masi et al. 2017); and suppliers knowledge of CE (Van Weelden, Mugge, and Bakker 2016).

***Questionnaire E***
Questionnaire E, see Appendix 4, measures the support provided by companies, suppliers and customers to the organisation being assessed. Questions covered the aspects of circular procurement to improve materials, secure resources (Ghisellini, Cialani, and Ulgiati 2016; Lieder and Rashid 2016; Witjes and Lozano 2016); develop and assess suppliers (Weetman 2016; Witjes and Lozano 2016); partnership with companies or educational institutions to share the responsibility of the materials and products (Ilić and Nikolić 2016; Ellen MacArthur Foundation 2013; Weetman 2016; Esposito, Terence Tse, and Soufani 2016; Witjes and Lozano 2016); and reusing and sharing of energy/water within the organisation (Masi et al. 2017).

***Questionnaire F***
Questionnaire F, see Appendix 5, evaluates the CE practices that require external collaboration and that are related to the longevity of materials, components and products. This questionnaire includes questions regarding the recuperation of products; avoidance of post usage quality variability to enhance the possibility of refurbishment, remanufacturing or recycling (Esbensen and Velis 2016; Lewandowski 2016; Masi et al. 2017); reusing, refurbishing and remanufacture and the availability of spare parts (Van Weelden, Mugge, and Bakker 2016); use of recycled materials for production; recycling of scrap/waste, and recovered products (Steeneck and Sarin 2017; Ghisellini, Cialani, and Ulgiati 2016); transformation of products into services (Zijm et al. 2016); addition of functionalities or updating (Pialot, Millet, and Bisiaux 2017; Van Weelden, Mugge, and Bakker 2016); and the alternative use of components/materials not fit for original use, avoiding landfill (Ellen MacArthur Foundation 2013).

***Questionnaire G***
Questionnaire G, see Appendix 6, measures the green market development by including questions about the understanding and satisfying the needs of such market (Masi et al. 2017); and the incentives offered by companies, e.g. price incentives, warranties and trial periods to increase confidence, reduce the perceived risk of obsolescence; to boost the support of customers, suppliers and members of the organisation (Esposito, Terence Tse, and Soufani 2016; Ellen MacArthur Foundation 2013; Van Weelden, Mugge, and Bakker 2016); and support the transition and engage in cooperation (Esposito, Terence Tse, and Soufani 2016; Frost 2016).

***Questionnaire H***
Questionnaire H assesses the efforts within the organisation and in collaboration with other companies/institutions to develop new technologies capable of improving the efficiency of circular practices, see Appendix 7. It analyses the infrastructure; research and development within the company, financial institutions, companies from the same or different sectors and educational institutions to discover and enhance technologies that

can generate environmental improvements (Lieder and Rashid 2016; Ghisellini, Cialani, and Ulgiati 2016; Weetman 2016; Ellen MacArthur Foundation 2013).

***Questionnaire I***

Finally, Questionnaire I, see Appendix 8, measures the development of regulations related to circularity with questions about the compliance and the collaborative work done with organisations and governments to promote the development of legislation that can benefit and promote the adoption of CE (Ellen MacArthur Foundation 2013).

## 4. Verification of the proposed CMT

Once that the CMT framework and all of its elements, as well as the questionnaires, were designed, the next stage consisted in verifying the conceptually developed CMT (see Figure 1). Within the context of this study, the verification of the proposed CMT referred to the process of ensuring that its structure – i.e. requirements to be measured, monitoring process and actions involved, see Figure 1 – was sufficiently precise to represent an accurate picture of the level of circularity of manufacturing SMEs. For this purpose, a Delphi study is a widely utilised method to verify a novel development of some kind (McMillan, King, and Tully 2016; Fernández-Llamazares et al. 2013; Culley 2011; Okoli and Pawlowski 2004) that does not have any other adequate source of reference to compare against (Linstone and Turoff 1975). In such scenario, experts in the field of a given area are communicated to express their opinion, criticism and suggestions (Reguant-Álvarez and Torrado-Fonseca 2016; Skulmoski, Hartman, and Krahn 2007) to improve the novel development to be of practical relevance. The process of communication with experts is done through a series of questionnaires. The experts, however, are not aware of other experts involved in the study. These experts could be a mixture of academics and practitioners, as long as they have direct knowledge and/or hands-on expertise/experience in managing the area that is being discussed. Upon receiving the feedback from the Delphi study's participants, the researcher conducting the study then compiles the results, make the changes for which there is consensus and re-send the updated framework. This process of reiteration continues until a consensus has been reached (Delbecq, Ven, and Gustafson 1975; Meijering, Kampen, and Tobi 2013). The process of Delphi study for this research is discussed in the subsequent sections.

### *4.1 Selection of Delphi-study group*

Since subject experts judge according to their experience, it is crucial to ensure their diversity in terms of their orientations, backgrounds and sectors, to enrich the study and keep anonymity to avoid bias that can be provoked by their previous experience or current jobs. In particular, this study engaged 8 participant experts, which is determined to be an acceptable number of participants for a Delphi-study (Landeta 1999; Gordon 1994). Table 5 presents the profile of the experts that contributed to the verification of the proposed CMT.

As it can be observed in Table 5, 87% of the participants were from the private sector, whereas 13% came from governmental institutions. Furthermore, 43% of the participants were from the beverage sector, which is known as one of the most well developed and hence significant industrial sectors in CE (Ellen MacArthur Foundation 2013).

Table 5. Delphi-study – experts' profile

| Expert | Position | Industry Affiliation | Years of Experience |
|---|---|---|---|
| 1 | Representative | Ministry of Environment | 5 |
| 2 | Project controller | Beverage | 30 |
| 3 | Corporate procurement manager | Fast moving consumer goods | 14 |
| 4 | Deputy director operations/ Director supply chain | Chemicals – oil and gas | 22 |
| 5 | Production Manager | Plastic and metals | 6 |
| 6 | Sustainable procurement executive | Beverage | 12 |
| 7 | Sustainability manager | Beverage | 6 |
| 8 | CEO | Consultancy | 8 |

Experts were briefed about the purpose of the proposed CMT, whereas at the same time the conceptual CMT, see Figure 2, was shared with them for their critical review, comment and feedback about the content of the tool, its reliability, participant and observer error/bias, elimination of irrelevant/ambiguous questions, etc. This further strengthened and aligned the CMT to enable the effective measurement of circularity among manufacturing SMEs. Due to time constraints, several cycles of the review were not possible, therefore when an expert differed against the others, it was discussed directly with the expert to better understand and achieve consensus (Reguant-Álvarez and Torrado-Fonseca 2016).

### *4.2 Delphi-study results*

The reviewers suggested modifications/updates on 48 issues. The level of consensus was defined as follows: consensus up to two experts was defined as low; consensus up to four experts was defined as a medium; consensus among more than five was defined as high. Likewise, the impact on the CMT was defined as follows: if the modification was related to the order, instructions, descriptions or the vocabulary of the questions, the impact was considered low; if it involved the removal or inclusion of questions, it was considered medium; and if it involved a major change in the questionnaire, results, calculations and/or categorisation, it was considered high. The modifications/updates were classified based on three aspects; (1) basic modifications/updates, (2) inclusions and exclusions, and (3) technical modifications.

#### *4.2.1 Basic modifications/updates*

The basic modifications suggested by the experts were:

- Methodology to obtain the circularity level should not be shared with the person answering the questionnaire or the company being assessed as it can generate confusion and misinterpretations;
- Format the CMT questionnaires in a more dynamic way to reduce confusions and tiredness that can generate participants' errors;
- Detailed instructions should be included with a tool for the purpose of clarity, and understanding, as manufacturing SMEs might not be aware or have in-depth knowledge on the topic;
- Ensure that there is a clear explanation regarding the fact that circularity is not about the implementation of activities only but also about economic sustainability.

*4.2.2 Inclusions and exclusions*

Upon experts' recommendation, three of the questions previously included in the questionnaires were eliminated due to their repetitive nature and twenty-one questions were added to complement certain practices that experts considered relevant to measure/improve circularity. These additions were related to management, market expansion, partnerships with different sectors, indirect employment, awareness within the community and government, environmental innovation, budget, environmental reports, purchasing rules, environmental costs, marketing strategies, reputation, economic benefits and sustainability frameworks.

*4.2.3 Technical modification*

Experts further recommended changes in the calculations of the degree of circularity, as follows:

- Addition of a practice related to the delivery and distribution of products, as this is one of the most pollutant activities of the product lifecycle;
- Correction of formulas and ranges that did not match the description of the circularity levels;
- Modification of the options given to answer the questions;
- Simplification and shortening of the proposed CMT, especially for the calculation of factor F, where previously an additional calculation table detailing the longevity activities per product existed.

The updated and improved CMT, along with the guidelines for the user, is presented in subsequent two sections, with brief instructions for its utilisation and along with the results of its validation through an industrial case study.

## 5. Circularity measurement toolkit (CMT) for manufacturing SMEs

This section presents an overview of the proposed CMT. The first part of the CMT introduces CE and the tool, and the remainder discusses how to use it to carry out circularity assessments.

### *5.1 What is the circular economy (CE)?*

*"The circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles"* (Ellen MacArthur Foundation 2015b)

In other words, the objectives of CE are the reduction of resource consumption and waste generation through the maximum utilisation of resources, and at the end of the lifecycle to be disposed to bio and technosphere, appropriately.

### *5.2 Circularity level/degree of circularity in SMEs*

The circularity level is a standardised categorisation of companies which compares the efforts done towards the adaptation of CE principles, see Table 6. It comprises 9 different levels and can be applied to manufacturing SMEs.

### *5.3 What is a circularity measurement toolkit?*

The questionnaires that form part of the proposed CMT, see Appendices 1-8, are designed to assess the circularity level of manufacturing SMEs, with the purpose of identifying any corrective actions needed or strategies to be developed to reduce negative environmental impacts, while achieving economic benefits.

The first section of the proposed CMT captures a broad overview of the company, their type of business, processes and waste types, etc., see Table 7 in Section 6. The questionnaire consists of 8 sections as follows; internal circular practices; internal awareness; external awareness; value chain support; external practices for longevity; increasing green market; technological development; and legislation development, see Appendices 1-8.

### *5.4 How to use the proposed CMT*

To complete the circularity assessment, a representative of the participant organisation will be required to answer the questions, i.e. in the questionnaires located in Appendices 1-8, by marking them with a number '1', under any one of the options of 'Yes', 'Partially', or 'No'. The representative person should only mark one answer per row or question. If the question is considered irrelevant, it should then be marked as 'N/A'. This will not affect the scoring. The range for three choices of answers is as follows:

No= If the company has not considered the practice suggested by the question asked, or if 0% of its products count with its characteristics.
Partially= If the company is performing the practice mentioned in the question asked, between the range of 1–70% of its products or activities.
Yes= If the company is performing the practice mentioned in the question asked, in between 70–100% of its products or activities.

In this case, the answers must be justified with documented evidence.

Each section of the questionnaire is labelled with a letter, e.g. 'A', 'B', etc., which corresponds to the every one of the factors introduced in Section 3.8 and that are presented in Table 3. These factors are employed by the formulas introduced in Table 6 to calculate the circularity level and are directly correlated with the circularity level and their relevant factors (see Sections 3.6 and 3.7). For instance, if an organisation falls under the'curved' categorisation of circularity level, it would have an overall sum of factor C and D within the range of 2.5–3. Likewise, for a company to fall into Circular categorisation, it must have value chain support and external practices for longevity and thus the factors E and F would be included to see if the organisation has achieved that level.

The subsequent section shows the calculations method to measure and categorise the circularity level of manufacturing SMEs. As suggested by the experts during the Delphi-study, this section is suggested not to be shared with the responding SMEs, but only to be used by the observer, or the person, conducting the circularity final assessment.

The scoring method consists of the following three rules:

- If the 'No' general percentage of the tab equals 50% or higher, then the awarded mark for the section would be '0';

- If the 'Yes' general percentage of the tab equals 50% or higher, then the awarded mark for the section will be '1';
- If both 'No' and 'Yes' are equal to 50% or lower, then the awarded mark for the section would be '0.5'.

After replacing the letters of the formula with the awarded values, the circularity level will be obtained. Most of the levels, except for the lower ones, have a range, as not all the companies will be implementing everything at the same time. Nevertheless, the CMT will help the manufacture SMEs to understand and determine potential further actions.

Table 6. Level of circularity and their descriptions

| Circularity level | Characteristics | Formula | Range | |
|---|---|---|---|---|
| | | | Min | Max |
| 1. Circular developer | Leading organisations for CE implementation, with the commitment/ability to go on step further to participate in the development of new technologies and environmental regulations that can benefit and improve circularity. | C+D+E+F+G+ H+I | 6.5 | 8 |
| 2. Circular Promoter | Organisations that have successfully integrated CE into their business strategy and are actually satisfying customers and growing the environmentally aware and circular market. | C+D+E+F+G | 5.5 | 6 |
| 3. Circular | Organisations that have fully integrated CE practices in their business and value chain, including activities related to circular procurement and increase of longevity with customers, suppliers and other companies. | C+D+E+F | 3.5 | 5 |
| 4. Waved | Organisations that are initiating external awareness and introducing the CE principles to customers and the supply chain, to promote CE to the complete value chain. | C+D | 2.5 | 3 |
| 5. Curved | Organisations that have fully integrated the CE practices and has adopted circularity as a culture. However, the efforts are only made internally and no practices are done with the support of customers, suppliers, other companies or competitors. | C=A+B (where A=1 and B=1) | 2 | 2 |
| 6. Saw tooth | Organisations that have introduced some important CE practices inside their company, they recognise the improvements and are in the process of adopting it as part of their culture. | C=A+B (where A=0.5 to 1 and B=0.5 to 1) | 1 | 1.5 |
| 7. V-shape up | Organisations that have not applied any CE practices, nevertheless, they are curious about it and are starting to learn the benefits that CE can generate. Usually, because a member of the top management is an environmentally aware person. | C=A+B (where A=0 and B=0.5 to 1) | 0.5 | 1 |
| 8. ∧-shape down | Organisations that without noticing, are already applying some internal CE practices generally related to the resource consumption, utilisation and efficiency. They are not aware of CE, however, they realised that economic benefits can be obtained with the adoption of certain practices. | C=A+B (where A=0.5 to 1 and B=0) | 0.5 | 1 |
| 9. Linear | Organisations applying only a linear approach without any knowledge about CE. Characterised for being business focused only in the economic benefits that comply with the minimum governmental or legislative requirements to be able to operate. | Linear=0 | 0 | 0 |

## 6. Validation of the CMT – A case study approach

As indicated in Figure 1, after its verification through the Delphi-study, the proposed CMT was validated by applying the tool in a real industrial case scenario, see Figure 1. Unlike its verification stage, which focused on ensuring that the CMT's structure and composition were accurate, the validation stage consisted in ensuring the effective practicality/ implementation of the CMT when measuring the circularity level of manufacturing SMEs. Since a case study is a research method used to test ideas/hypothesis by comparing them against information considered as relevant to justify it (Shadish, Cook, and Campbell 2001), this approach was considered the most appropriate to assess the accuracy of the CMT for its purpose. It is important to highlight the fact that, unlike verification, validation did not intend to add accuracy but simply justifying the relevant theory (Reichardt 2011), i.e. testing the practicality of the CMT.

To conduct the validation of the proposed CMT, its application was studied in a small, poultry equipment manufacturing company located in Mexico City (see Table 7). The case organisation was found to be suitable as it was located in an emerging economy and had a clear commitment to move towards sustainability goals. These characteristics made the case organisation ideal for this study. The context of the case study was also encouraged by scholars (De Massis et al., 2016; Shakeel Sadiq Jajja et al., 2014) who advocate that developing and emerging nations present the best context to study innovative approaches (Maldonado-Guzmán et al., 2018). This organisation had been in operation for more than 60 years, and at the time of the study, it employed a total of 18 people. Its main processes were injection and blow moulding of polyethylene and the forming of metals, specifically steel.

After the initial briefings and explanations of the CMT to the top management, the assessment part was assigned to a senior staff responsible for the design of the company's products and its procurement. This person was selected by top management due to the person's considerable knowledge and expertise in environmental engineering. Through the process of assessment, the observer was in real-time communication with the senior staff to guide him and clarify any potential questions during the assessment process. The results were categorised by following the same sequence and classification of factors, as in the CMT. All the responses 'Yes' or 'Partially' responses were supported with evidence (e.g. resume, pictures, contracts, official company documents, etc.). The actual circularity assessment of the case company is shown in Appendices 1-8, and a discussion of the results per every factor is presented in the followings sections.

Table 7. Company's profile

| | |
|---|---|
| *Company's name:* | XYZ (the name is kept anonymous) |
| *Country:* | Mexico |
| *Main product types:* | Poultry equipment |
| *Type of industry sector:* | Plastics and metals |
| *Type of processes used:* | Injection moulding, blow moulding and metal forming |
| *Waste types:* | High-density polyethylene and steel |
| *Amount of employees:* | 18 |
| *Name of the person responsible for the assessment:* | ABC (the name is kept anonymous) |
| *Number of people employed for circular practices:* | 2 |
| *Has the company identified savings due to circular practices?* | Yes |

### *6.2 Factor 'A' results - Internal Practices – Resource utility and efficiency*

1) The company demonstrated the efficient utilisation of resources through better design and production, given the skills of the responsible personnel. Also, in the manufacturing site, the efficient use of resources was strongly promoted by sharing/encouraging workers through informational posters.
2) The company used the design for disassembly and recycling. More than 90% of their products were made of only two pieces and no more than three types of materials. These materials were never combined, which helped recycling activities.
3) Within the same catalogue, the company also proved a design strategy for the minimisation of waste as they only utilised three types of easily recyclable materials. The only waste was scrap steel sheets, no plastic waste was generated, as the company had a grinder that turned any plastic into pellets that could be transformed into new products with the existing processes.
4) Additionally, the company demonstrated durability as one of the core values shared among personnel, ensuring the application of design for durability and the maintenance of resources inside a system for longevity.
5) Likewise, the record register of discharged water utilised energy, and consumed materials (i.e. petrol and diesel) was kept up-to-date.
6) Also, the company demonstrated the implementation of programmes to reduce water consumption by utilising a pump that only worked during specific periods of time during the day.
7) Finally, the company proved landfill disposal prevention, through distinguishing the waste to ensure its circularity by selling it to a recycling company, and to adequately dispose of what could not be recycled. However, although the amount of waste generated was known, the records were not kept by the company but were with workers who performed this function. As it can be observed in Appendix 1, the value awarded for this factor was the only one that was not 0, as per guidelines defined for the CMT's usage.

See Appendix 1 for the answers provided by the company for this factor. All the remaining factors obtained a null value as the company's performance was lower than 50% of the activities. Nevertheless, the current circularity state of the company and the answers to every section/factor of the CMT assessment are presented in subsequent sections.

### *6.2 Factor 'B' results – Internal awareness*

The company had a person in charge of environmental and circular activities. However, a lack of a strong support from top management and resources had not allowed an adequate implementation of environmental practices. The offers recycled products at a lower price but with higher revenue; confirming that it is a better business to sell the recycled version of their products. See Appendix 2 for the answers provided by the company for this factor.

### *6.3 Factor 'D' results – External awareness*

Results for factor 'D' revealed that the company did share the environmental benefits of its products in its main communication channel, i.e. webpage, in order to motivate their purchasing. See Appendix 3 for the answers provided by the company for this factor.

### *6.4 Factor E results – Selecting suppliers using environmental criteria*

The results for Factor 'E' demonstrated the sustainable procurement of the case company, mainly by purchasing used products in order to grind/transform the material into new products. Moreover, the company had a partnership with a metal forming company that used some of the waste to manufacture a specific component and start with the generation of an industrial chain. See Appendix 4 for the answers provided by the company for this factor.

### *6.5 Factor 'F' results – External practices for longevity*

Results for Factor 'F' showed the partial recovery of some company's products at the end of their life cycle. Nevertheless, the company had not made any final decision for those products. See Appendix 5 for the answers provided by the company for this factor.

### *6.6 Factor 'G' results – Increasing green market*

Results for Factor 'G' established that the company offered price incentives, to their clients, to promote the purchasing of products related to a circular activity such as recycling. The company also offered economic incentives to motivate staff for circular activities. For example, it lets employees keep all the cash recovered from the selling of scrap materials to companies that ensured their adequate re-use or disposal. See Appendix 6 for the answers provided by the company for this factor.

### *6.7 Factors 'H' – Technological development and 'I' – Legislation development*

Finally, for factors 'H' and 'I', no analysis could be carried out as the company had not implemented any of the related activities. See Appendices 7 and 8 for the answers provided by the company for these factors.

### *6.8 Calculation of circularity level*

With the obtained values for all the factors, see Appendices 1-8, the circularity level of the case company was calculated as follows:

$$Circularity\ level = C+D+E+F+G+H+I \quad (1)$$

$$Since:\ C = A+B \quad (2)$$

$$Circularity\ Level = (A+B)+D+E+F+G+H+I \quad (3)$$

$$Circularity\ Level = (0.5+0)+0+0+0+0+0+0=0.5 \quad (4)$$

After comparing the calculation results with the ranges of the different circularity levels, see Table 6, and since A=0.5 and B=0, it could be determined that the case company fell within the 'ʌ-shape down' level. As previously indicated, this suggested that the company was already applying some internal practices aligned with CE principles, but without knowing it. The results further suggested that the organisation was aware of the potential economic benefits that it may achieve due to the adoption of environmentally friendly practices.

## 7. Discussion, conclusions, limitations and future research directions

With the rise of fast pace production and short life cycle products, the demand for natural resources has increased, consequently resulting in the planet not being able to replenish itself at the pace of consumption. This difference has generated three main problems; first the exhaustion of resources; second the complexity in the access to them; and third the relevant amount of wastes produced (Elia, Gnoni, and Tornese 2017). These problems are subsequently generating price volatility, environmental damage and weak supply chains that are affecting companies' performance due to uncertainty (Franklin-Johnson, Figge, and Canning 2016).

Considering the aforementioned challenges, the role of CE has become vital and necessary to divert the flow of production and consumption from linear to circular business models (Loon, Delagarde, and Van Wassenhove 2017). However, its measurement mechanism has not been well defined yet, especially for SMEs, which account for a large majority of over 90% of the established enterprises in Europe (Eurostat 2017) and worldwide. Few attempts have been made to propose models or frameworks that enable the measurement of CE practices. Nevertheless, these are either too complex to be adopted by SMEs or partial in their approach to measuring the full spectrum of CE. The current study has therefore proposed a CMT in response to this current limitation in the scholarly literature. The proposed CMT was developed to measure the current state of transition from a linear to a circular business approach, as well as to provide manufacturing SMEs with an understanding and identification of the corrective actions or future efforts for the adoption of CE practices. For this, it was necessary to define: (1) the different types of circular practices; (2) the classification or levels of circularity; (3) ways to avoid errors, bias and not applicable practices that could have reduced the accuracy of the proposed CMT's; and finally, (4) the verification and validation procedures that could enhance the development and testing of the proposed CMT.

The case study demonstrated that the studied organisation was applying some CE related practices, but the reason for such choice was not based upon its concern for the environment, on the contrary, it related these activities to economic and even political aspects. For instance, the rise in prices was not associated with the exhaustion of resources but to political and economic conjunctures. This attitude is in line with the findings of Masi et al. (2017), whose study suggested that companies mainly adopt CE practices due to marketing and economic rather than environmental reasons. Moreover, there was a lack of communication and a strong relationship with customers. Companies are not aware of the customers' needs and vice versa (Wang and Hazen 2016). Finally, people do not trust circular products due to the possibility of losing ownership. The case study further revealed the existence and application of internal CE practices, but not the rest of the circular factors. This may provide a broad and realistic overview of the general state of most SMEs, categorising them on a lower CE level. Another important deficiency in the processes exposed through the CMT was the lack of data analysis. For example, even though the company does register some useful information, it did not analyse or use it for the decision-making process, economic benefits or environmental benefits. This further confirms the effectiveness of the proposed CMT to streamline the processes to support CE adaptation.

### *7.1 Limitations and future research directions*

The research conducted to develop the CMT faced two limitations. Firstly, in relation to the Delphi-study group being relatively small and having no re-iterations of the study after improving the CMT based on the experts' feedback. Secondly, in relation to the CMT's validation as the case company utilised a relatively low number of raw materials, which may make it easier for the organisation to adopt and/or have CE practices. Researchers are highly recommended to further validate the developed CMT through the application and modify as necessary. Although the strict validation and verification stages suggest that the proposed CMT is capable of effectively measuring the degree of circularity of individual manufacturing SMEs, it is crucial to understand that circularity is not about one company, it is about the interconnection of organisations (Di Maio and Rem 2015). This confirms that the adaptation of this tool should consider circularity calculation by adding the scores of all the members involved in the value chain, not as an individual enterprise only.

The research presents a novel circularity measurement toolkit (CMT) to analyse and determine the circularity degree of manufacturing SMEs. The authors strongly believe that the research has advanced the knowledge in the CE field; by defining the factors that comprise a wider spectrum of CE, challenges for SMEs with regards to CE, and by proposing a CMT. Although the proposed CMT is quite simple in its formation, its potential is not only limited to measure SMEs circularity as it can also serve as a starting point to trigger initiatives for CE implementation through the identification of economic leakages in industries. Similarly, although the tool was specifically developed taken into consideration the needs of manufacturing SMEs, it may also be adapted to be applicable in organisations of other sizes and industries. This can be considered one of the research streams proposed as part of the future research directions derived from this work. Finally, since the proposed CMT was validated through a single case study approach, the future research agenda can also involve the validation of the CMT in other manufacturing industries and countries different to those of the case organisation. This will provide further robustness to the proposed CMT.

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# Appendix 1

Questionnaire for factor A

**A. Internal Practices – Resource utility and efficiency**

| **Design** | | | |
|---|---|---|---|
| **A.a) Designing of product for reduced consumption of resources** | **Yes** | **Partially** | **No** |
| The design of products in the company consider the utilisation of the minimum amount or resources? | 1 | | |
| Does the company avoid the use of non-renewable resources in the design unless it is impossible? | | | 1 |
| | | | |
| **A.b) Designing products for reuse, recycle, and/or recovery of material and/or component parts** | **Yes** | **Partially** | **No** |
| Does the company consider and apply design for reuse? | N/A | N/A | N/A |
| Does the company consider and apply design for disassembly? | 1 | | |
| Does the company consider and apply design for refurbish? | | | 1 |
| Does the company consider and apply design for remanufacture? | N/A | N/A | N/A |
| Does the company consider and apply design for recycling? | 1 | | |
| | | | |
| **A.c) Designing processes for minimisation of waste** | **Yes** | **Partially** | **No** |
| Does the company consider and apply design for minimisation of waste? | 1 | | |
| | | | |
| **A.d) Designing products for durability** | **Yes** | **Partially** | **No** |
| Does the company consider and apply design for durable products? | 1 | | |
| | | | |
| **Production** | | | |
| **A.e) Reducing Material (i.e. raw material and/or water)** | **Yes** | **Partially** | **No** |
| **Raw Material** | | | |
| Does the company keep register of material consumption? | | | 1 |
| Is the company already analysing and identifying possible ways to reduce the amount of materials? | 1 | | |
| Is the company already implementing actions to reduce the amount of material use? | | 1 | |
| **Water** | | | |
| Does the company keep register of the rate of discharged water and water consumption? | 1 | | |
| Does the company apply water conservation measures? | 1 | | |
| Does the company treat waste water? | | | 1 |
| | | | |
| **A.f) Reducing energy (i.e. electricity, coal, gas) consumption** | **Yes** | **Partially** | **No** |
| Does the company keep register of energy consumption? | 1 | | |
| Is the company already analysing and identifying possible ways to reduce the amount of energy consumed? | | | 1 |
| Is the company already implementing actions to reduce the amount of energy consumed? | | | 1 |
| Is the company already analysing or identifying if any of their processes can produce energy? | | | 1 |
| Is the company using energy produced by themselves? | N/A | N/A | N/A |
| Is the company using renewable energy? | | | 1 |
| | | | |
| **A.g) Using renewable materials and energy in the production process** | **Yes** | **Partially** | **No** |
| **Renewable materials** | | | |
| Does the company keep register of non-renewable materials consumption? | | 1 | |

| | | | |
|---|---|---|---|
| Is the company already analysing and identifying possible ways to reduce or eliminate the amount of non-renewable materials by substituting them with renewable materials? | | | 1 |
| Is the company already implementing actions to reduce the use of non-renewable materials? | | | 1 |
| **Renewable energy** | | | |
| Does the company keep register of non-renewable energy resource consumption? | 1 | | |
| Is the company already analysing and identifying the possibility of manufacturing their products with the use of renewable energy? | | | 1 |
| Is the company already implementing actions to substitute non-renewable energy with source of renewable energy? | | | 1 |
| | | | |
| **A.h) Reducing pollutants emissions** | **Yes** | **Partially** | **No** |
| Does the company keep records of pollution? | | | 1 |
| Does the company keep register of their Greenhouse Gas (GHG) emissions? | | | 1 |
| Is the company already analysing and identifying possible ways to reduce the amount of GHG emissions? | | | 1 |
| Is the company already implementing GHG reduction actions? | | | 1 |
| Does the company keep register of the use of fertilizers? | N/A | N/A | N/A |
| Is the company already analysing and identifying possible ways to reduce the amount of fertilizers? | N/A | N/A | N/A |
| Is the company already implementing fertilizers reduction actions? | N/A | N/A | N/A |
| Does the company keep register of the use of pesticides? | N/A | N/A | N/A |
| Is the company already analysing and identifying possible ways to reduce the amount of pesticides? | N/A | N/A | N/A |
| Is the company already implementing pesticides reduction actions? | N/A | N/A | N/A |
| Does the company keep register of the use of petrol? | 1 | | |
| Is the company already analysing and identifying possible ways to reduce the amount of petrol? | | 1 | |
| Is the company already implementing petrol reduction actions? | | 1 | |
| Does the company keep records of the use of diesel? | 1 | | |
| Is the company already analysing and identifying possible ways to reduce the amount of diesel? | | 1 | |
| Is the company already implementing diesel reduction actions? | | 1 | |
| Does the company keep records of the use of natural gas? | N/A | N/A | N/A |
| Is the company already analysing and identifying possible ways to reduce the amount of natural gas? | N/A | N/A | N/A |
| Is the company already implementing natural gas reduction actions? | N/A | N/A | N/A |
| | | | |
| **A.i) Reducing wastes** | **Yes** | **Partially** | **No** |
| Does the company support landfill prevention? | 1 | | |
| Does the company keep records of waste generation? | | 1 | |
| Does the company separate waste in an efficient way? | 1 | | |
| Does the company support the circulation of waste, understanding waste as an input? | 1 | | |
| In case of disposing, is the company doing it in an adequate form regarding the environment? | 1 | | |
| **Packaging and distribution** | | | |
| **A.j) Green Packaging** | **Yes** | **Partially** | **No** |
| Does the company use green and efficient packaging? | | 1 | |
| | | | |
| **A.k) Green distribution** | **Yes** | **Partially** | **No** |
| Does the company choses transport options with comparatively less environmental impact like rail or water for the distribution of their products? | | | 1 |

| | | | |
|---|---|---|---|
| Is the company using nay management tools, techniques, and technologies to optimise the distribution and shipping efficiency? | | | 1 |
| **Total** | **38.1%** | **19.0%** | **42.9%** |
| | **<50%** | | **<50%** |
| | | **A=0.5** | |

# Appendix 2

Questionnaire for factor B

**B. Internal awareness**

| **B.a) Circular management, culture and continuous monitoring** | **Yes** | **Partially** | **No** |
|---|---|---|---|
| Does the organisation have formulated a circular economy strategy? | | | 1 |
| Has the company assigned a person to be responsible for environmental and circular matters? | | 1 | |
| Does the company have a functional structure in charge of the circularity practices? | | | 1 |
| Is management committed and involved in circularity? | | | 1 |
| Are shareholders and investors involved and supporting circularity? | N/A | N/A | N/A |
| Is the organisation developing the circular economy as a culture? | | | 1 |
| Is circularity part of the values of the organisational culture of the company? | | | 1 |
| Has the company assigned a yearly budget for environmental expenditures? | | | 1 |
| Is the company creating and sharing annual environmental reports with their stakeholders? | | | 1 |
| Is the company applying continuous monitoring regarding circularity? | | | 1 |
| Is the company using systems and information technologies to generate and communicate accurate data? | | | 1 |
| Has the company recognised any competitive and reputational advantage due to circular practices? | | | 1 |
| Has the company recognised any economic benefits or cost avoidance due to circular practices? | 1 | | |
| | | | |
| **B.b) Special training for workers on environmental issues and circular economies** | **Yes** | **Partially** | **No** |
| Is the company contributing to increase environmental awareness among all the members of the organisation? | | | 1 |
| Is the company offering formal and periodic training, sharing of information and achievements regarding circular economy to new and existing members of the organisation? | | | 1 |
| | | | |
| **B.c) Including environmental factors in the internal performance evaluation system** | **Yes** | **Partially** | **No** |
| Has the company established targets of reduction of water, energy, waste, raw materials, etc.? | | | 1 |
| Is the company taking into account environmental factors when assessing internal performance? | | | 1 |
| Does the organisation uses an indicators dashboard to understand and visualise their targets? | | | 1 |
| | | | |
| **B.d) Environmental auditing program** | **Yes** | **Partially** | **No** |
| Is the company identifying the environmental risks? | | | 1 |
| Does the company measure and monitor their environmental impacts through tools like ISO14000, lifecycle analysis or material flow analysis? | | | 1 |

| | | | |
|---|---|---|---|
| Is the company following a sustainability framework such as Carbon Disclosure Project (CDP), Global Reporting Initiative (GRI) or Dow Jones Sustainability Index (DJSI)? | | | 1 |
| Does the company have an environmental policy? | | | 1 |
| Is the company doing something to reduce the environmental impact of their activities in the energy sector? | | | 1 |
| Is the company doing something to reduce the environmental impact of their activities in the water sector? | | | 1 |
| Is the company doing something to reduce the environmental impact of their activities in the conservation of the environment? | | | 1 |
| **Total** | **4.2%** | **4.2%** | **91.7%** |

**>50%**

**B=0**

## Appendix 3

Questionnaire for factor D

**D. External awareness**

| **D.a) Awareness within customers** | **Yes** | **Partially** | **No** |
|---|---|---|---|
| Is the company measuring or doing something to understand the level of awareness of their customers? | | | 1 |
| Is the company contributing to increase circular awareness among their customers? | | | 1 |
| Is the company contributing to increase circular awareness among the community? | | | 1 |
| | | | |
| **D.b) Eco-labelling of products** | **Yes** | **Partially** | **No** |
| Is the company sharing with the customers the environmental benefits in order to motivate the purchase of their products? | | 1 | |
| | | | |
| **D.c) Awareness within suppliers** | **Yes** | **Partially** | **No** |
| Is the company measuring or doing something to understand the level of awareness of their suppliers? | | | 1 |
| Is the company contributing to increase social awareness among their suppliers? | | | 1 |
| **Total** | **0.0%** | **16.7%** | **83.3%** |

**>50%**

**D=0**

## Appendix 4

Questionnaire for factor E

**E. Value chain support**

| **E.a) Selecting suppliers using environmental criteria** | **Yes** | **Partially** | **No** |
|---|---|---|---|
| Is the company using sustainable/circular procurement to improve materials? | | | 1 |
| Is the company using sustainable/circular procurement to secure future sustainable resources? | | | 1 |
| Is the company using sustainable/circular procurement to find recycled or second hand materials if possible? | 1 | | |
| Is the supply chain involved in circularity? | | | 1 |
| Are suppliers required to provide environmental information on their activities and products? | | | 1 |
| Is the company using sustainable/ circular procurement to develop suppliers? | | | 1 |

| | | | |
|---|---|---|---|
| Is the company using sustainable/circular procurement to assess suppliers' circularity? | | | 1 |
| Is the company basing their purchasing decision in a total cost assessment which considers transportation, use and waste management costs? | | | 1 |
| Is the company communicating the environmental purchasing criteria with all the stakeholders? | | | 1 |
| | | | |
| **E.b) Cooperating with other firms to establish eco-industrial chains** | **Yes** | **Partially** | **No** |
| Is the company working in partnerships with companies from the same sector? | | | 1 |
| Is the company working in partnerships with companies from different sector? | | 1 | |
| Is the company working in partnerships with suppliers? | | | 1 |
| Is the company working in partnerships with educational institutions? | | | 1 |
| Has the company identified the amount of direct and indirect employments generated by the creation of partnership? | | | 1 |
| | | | |
| **E.c) Reusing energy and/or water across the value chain** | **Yes** | **Partially** | **No** |
| Is the company sharing energy produced by their processes with another company for future utilisation? | N/A | N/A | N/A |
| Is the company sharing used water with another company for further utilisation? | | | 1 |
| Is the company utilising energy generated by another company? | | | 1 |
| Is the company utilising water generated by another company? | | | 1 |
| **Total** | **5.9%** | **5.9%** | **88.2%** |
| | | | **>50%** |
| | | **E=0** | |

# Appendix 5

## Questionnaire for factor F

**F. External practices for longevity**

| **F.a) Taking back products from consumers after the end of their functional life** | **Yes** | **Partially** | **No** |
|---|---|---|---|
| Is the company already taking back products from consumers at the end of their functional life? | | 1 | |
| Does the company work to avoid the misconception or misunderstanding of recovering at the end of their products functional life? | | | 1 |
| Is the company already implementing methods to avoid or reduce variability of conditions in waste recovery even if they were manufactured together? | | | 1 |
| | | | |
| **F.b) Taking back products from consumers after the end of their usage** | **Yes** | **Partially** | **No** |
| Is the company already taking back products from consumers at the end of usage? | N/A | N/A | N/A |
| Does the company work to avoid the misconception or misunderstanding of recovering at the end of their product usage? | N/A | N/A | N/A |
| Is the company already implementing methods to avoid or reduce variability of conditions in waste recovery even if they were manufactured together? | N/A | N/A | N/A |
| | | | |
| **F.c) Reusing products** | **Yes** | **Partially** | **No** |
| Is the company already implementing reusing as a business model? | N/A | N/A | N/A |

| | | | |
|---|---|---|---|
| Does the company work to avoid the misconceptions or misunderstanding of reused products against second hand products? | N/A | N/A | N/A |
| | | | |
| **F.d) Refurbishing products (i.e. returning them to good working condition by replacing or repairing major faulty components)** | **Yes** | **Partially** | **No** |
| Is the company already implementing refurbishing as a business model? | | | 1 |
| Does the company work to avoid the misconception or misunderstanding of refurbishing against second hand products and obsolescence risk? | | | 1 |
| Does the company work to avoid the lack of spare parts for refurbishing? | | | 1 |
| | | | |
| **F.e) Remanufacturing products** | **Yes** | **Partially** | **No** |
| Is the company already implementing remanufacturing as a business model? | N/A | N/A | N/A |
| Does the company work to avoid the misconception or misunderstanding of remanufacturing against second hand products? | N/A | N/A | N/A |
| Does the company work to avoid the lack of spare parts for remanufacturing? | N/A | N/A | N/A |
| | | | |
| **F.f) Use of recycled materials** | **Yes** | **Partially** | **No** |
| Is the company already using recycled materials for production? | 1 | | |
| Does the company work to avoid the misconception or misunderstanding of recycling materials? | 1 | | |
| | | | |
| **F.g) Recycling of scrap** | **Yes** | **Partially** | **No** |
| Is the company already recycling the scrap generated by production processes? | 1 | | |
| | | | |
| **F.h) Recycling of products recovered after the end of functional life** | **Yes** | **Partially** | **No** |
| Is the company already recycling products recovered from the customers at the end of their functional life? | | | 1 |
| | | | |
| **F.i) Recycling of products recovered after usage** | **Yes** | **Partially** | **No** |
| Is the company already recycling products recovered from the customers at the end of their usage? | N/A | N/A | N/A |
| | | | |
| **F.j) Adopting a leasing or service-based marketing strategy** | **Yes** | **Partially** | **No** |
| Is the company already implementing leasing as a business model? | N/A | N/A | N/A |
| Does the company work to avoid the misconception or misunderstanding of leasing? | N/A | N/A | N/A |
| | | | |
| **F.k) Adopting an updating market strategy?** | **Yes** | **Partially** | **No** |
| Is the company already implementing updating as a business model? | | | 1 |
| Does the company work to avoid the misconception or misunderstanding of updating? | | | 1 |
| | | | |
| **F.l) Cascading use (i.e. multiple usages/applications) of components and materials once its properties are lost and cannot be recycled anymore** | **Yes** | **Partially** | **No** |
| Is the company already implementing cascading actions for the materials that are not adequate anymore or have lost their properties? | | | 1 |
| **Total** | **23.1%** | **7.7%** | **69.2%** |

**>50%**

**F=0**

## Appendix 6

Questionnaire for factor G

**G. Increasing green market**

| G.a) Targeting 'green' segments of the market | Yes | Partially | No |
|---|---|---|---|
| Does the company fully understand the needs of the green or environmentally aware market? | | | 1 |
| Is the company implementing actions to fully satisfy the needs of the green or environmentally aware market? | | | 1 |
| Does the company have an expansion plan or strategy for the green market? | | | 1 |
| Does the company marketing strategy includes the environmental aspects of their products? | | | 1 |
| | | | |
| **G.b) Incentives** | **Yes** | **Partially** | **No** |
| Is the company offering price incentives in recovered, reused, refurbished, remanufactured, recycled, leased, and updated products to persuade the growth and development of circular economy? | 1 | | |
| Is the company offering incentives such as warranty services for reused, refurbished, remanufactured, recycled, leased and updated products to relieve obsolescence risk? | 1 | | |
| Is the company offering incentive such as trial periods for reused, refurbished, remanufactured, recycled, leased and updated products to generate confidence? | | | 1 |
| Is the company offering incentives within the organisation in order to persuade the growth and development of circular economy? | 1 | | |
| Is the company offering incentives within their suppliers to persuade the growth and development of circular economy? | | | 1 |
| **Total** | **33.3%** | **0.0%** | **66.7%** |

**>50%**

**G=0**

## Appendix 7

Questionnaire for factor H

**H. Technological development**

| H.a) Cross-functional cooperation for environmental improvements | Yes | Partially | No |
|---|---|---|---|
| Is the company investing in infrastructure to support the circular economy? | | | 1 |
| Is the company following the environmental innovations and productivity improvements within their sector? | | | 1 |
| Is the company evaluating the environmental costs of capital purchases and new technologies to be acquired? | | | 1 |
| Is the company making any research and development in circularity? For example, recycling processes. | | | 1 |
| Is the company continuously looking for financing programs in order to create development programs? | | | 1 |
| Is the company working in collaboration with other companies to develop useful technologies for circular economies? | | | 1 |
| Is the company working in collaboration with educational institutions to develop useful technologies for circular economies? | | | 1 |
| **Total** | **0.0%** | **0.0%** | **100%** |

**>50%**

**H=0**

# Appendix 8

Questionnaire for factor I

**I. Legislation development**

| **I.a) Legislation and policies** | **Yes** | **Partially** | **No** |
|---|---|---|---|
| Is the company complying with the environmental legislation and policies according to the geographies of their operations? | | | 1 |
| Is the company working with ONG's to improve the circular economies outside their value chain? | | | 1 |
| Is the company working with governmental agencies in the development of environmental legislation and policies such as taxation against non-renewable resources? | | | 1 |
| Is the company contributing to increase awareness in the government? | | | 1 |
| **Total** | **0.0%** | **0.0%** | **100%** |

**>50%**

**I=0**