A literature review on circular economy adoption in the manufacturing sector

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Abstract

This paper aims to investigate how the sustainable development is pursued by manufacturing companies according to the extant literature, especially by focusing on circular economy (CE) paradigm that is considered one of the major drivers for sustainability. Indeed, this research aims to study how CE principles have been adopted in the manufacturing sector leading towards the creation of Circular Manufacturing (CM) strategies. To achieve this goal, a systematic literature review has been conducted. Scopus and Web of Science are the scientific databases used for the review process. The 215 papers selected for the review were analysed through a theoretical framework developed by the authors. This framework enabled to individualize the research streams and the perspectives through which CE strategies adopted by manufacturers have been studied in the extant scientific literature. These research streams are technologies, and evaluation methods and models. Besides, both of these two are studied under two different lenses since they both are mutually considered supportive tools to shift or to maintain a circular system. To conclude, one of the major contributions of this literature review is to provide a clearer definition of CM and to figure out how CM strategies have been addressed by academics in the scientific literature, with the final aim to reduce the confusion emerged in the extant literature around this concept. Last, this review elucidates some scientific literature gaps and suggests future research directions.

Keywords: Circular Economy; Circular Manufacturing; Literature Review; Sustainability; Manufacturing

Nomenclature

AM	Additive Manufacturing	ICT	Information and Communication Technologies
BM	Business Model	PSS	Product-Service System
CBM	Circular Business Model	RQ	Research Questions
CE	Circular Economy	SLR	Systematic Literature Review
CM	Circular Manufacturing	WoS	Web of Science
I4.0	Industry 4.0	3Rs	Remanufacturing, Recycle, Reuse

1. Introduction

The limited availability of resources present on our planet is drastically increasing and primary materials consumption is expected to double, reaching 167 gigatonnes in 2060 (OECD, 2019). Indeed, to pursue more sustainable development (WCED, 1987), different countermeasures have been proposed. Among all, United Nations designed the "*sustainable development goals*", that are 17 urgent actions to be undertaken by countries worldwide (United Nations, 2019). In particular, the 12th, "*responsible production and consumption*", refers to the need to identify new and sustainable strategies to run systems. This impacts not only on consumers' behaviours but also on industrial actors among which manufacturers, considering that the manufacturing sector is one of the most polluting and resource greedy sectors (Halstenberg et al., 2017). For these reasons, manufacturers are required to move towards economic, environmental, social sustainability, characterising the triple bottom line (Elkington, 2013).

To pursue this direction, one of the most promising sustainable paradigms recently identified is the Circular Economy (CE) (Geissdoerfer et al., 2017). CE is defined as "*an industrial economy that is restorative and regenerative by intention and design*" (The Ellen MacArthur Foundation, 2012), and it relies on three principles: *(i) preserve and enhance natural capital, (ii) optimize resource yields and (iii) foster systems effectiveness* (The Ellen MacArthur Foundation, 2015). CE aims to reduce resources consumption by slowing, closing and narrowing resource loops (Geissdoerfer et al., 2017; Wang et al., 2018a). According to Ghisellini et *al*. 2016, CE principles have been adopted at different scales: the micro one that corresponds to products and firms view, the meso one corresponding to a network of companies, and macro one that corresponds to actions undertaken by cities, regions and nations (Ghisellini et al., 2016). CE principles adoption are promising especially for manufacturers to reduce material consumption and resource toxicity while carrying on their business activities (Garza-Reyes et al., 2019; Wang et al., 2018a). In line with that, CE adoption has been promoted by policymakers through the recent action plan (European Commission, 2020).

Although the CE potentialities on manufacturing processes are recognized, there is not a clear definition of circular manufacturing (CM) and how it takes place, being this concept often mislead with the more general sustainable one. Indeed, the research objective is to investigate the state-of-the art of the scientific literature about CM in order to cover these gaps by reducing the confusion around CM concept. This objective has been tackled through a systematic literature review (SLR) by answering the following research questions (RQ): (1) what are the CE strategies adopted in the manufacturing sector? (2) What are the current research streams dealing with CE in manufacturing to envisage gaps and possible future directions?

This finally enabled to provide a definition of CM, to elucidate the related CM strategies addressed by researchers through different scientific research streams, and to suggest future research directions on the basis of the gaps identified.

The paper is structured as follows: (2) *methodology* in which the review process is described; (3) *literature review results and discussions* which provides both descriptive statistics and analysis of the eligible documents; (4) *conclusions and future research directions* in which literature gaps are elucidated and future research directions are suggested.

2. Methodology

This contribution operates a SLR which enabled to identify the eligible papers for the review, and to analyse them through a structured process (Tranfield et al., 2003). Moreover, a theoretical framework was developed to classify the contributions selected for this review. The framework aims to identify the CE strategies adopted by manufacturers and to first analyse them looking at the sustainable pillars addressed and the scale of adoption view (see step 1 reported in Section 3.2.1.); second, it aims to identify the research streams under which these CE strategies are studied in the extant literature (see step 2 in Section 3.2.2).

In the following sub-sections the entire review process is explained in detail.

2.1 SLR methodology

Considering that CE is an inflated term often used as a synonym of sustainability, and being the aim of this review to focus only on CE adoption in manufacturing, the structured methodology given by SLR helps in spanning the scientific literature appropriately. This SLR relies on papers accessible on Scopus and Web of Science (WoS), being them the most diffused scientific databases for industrial engineering. The collection process was stopped on 31st July 2019 without limiting the time-span. To select the eligible papers through a screening process, keywords and eligibility criteria were defined.

2.1.1. Keywords definition

To define the keywords, adopted to query the scientific databases to search them in keywords, abstract and title, the SLR was anticipated by a random research on articles dealing with the scope of the research. Through this random research emerged a misleading understanding of the CE concept, easily mixed-up with the more general sustainable one, especially as regards the manufacturing sector. Therefore, the keywords used are: ("circular economy" AND "manufacturing") OR "circular manufacturing". This choice enables to limit the research scope to those papers focused on CE studied through manufacturing lenses.

2.1.2. Eligibility criteria choice

To select the papers for the review, a screening process, summarized in **Figure 1**, was undertaken leveraging on pre-defined eligibility criteria.

First, the authors limited the study to articles and reviews published in journals, whose writing language is English. Conference papers were not included since during the random screening for the keywords definition, it was perceived a misleading understanding of CE concept, and journals papers were found to be mostly in line with the CE definition given by Ellen Macarthur (The Ellen MacArthur Foundation, 2012). Subsequently, duplicates coming from the usage of the two databases were eliminated from WoS.

The last screening was performed by first reading the title and the abstract, and second by reading the entire document. The criteria used to discard papers were: (i) papers focused on chemical transformation processes and new materials development (20%), (ii) papers focused on organic cycles (28%) and (iii) papers not focused on CE practices, but focused on sustainability (52%). These criteria limited the sample to CE strategies adopted by manufacturers, and not general sustainable approaches, focused on technical resources cycles (The Ellen MacArthur Foundation, 2015).

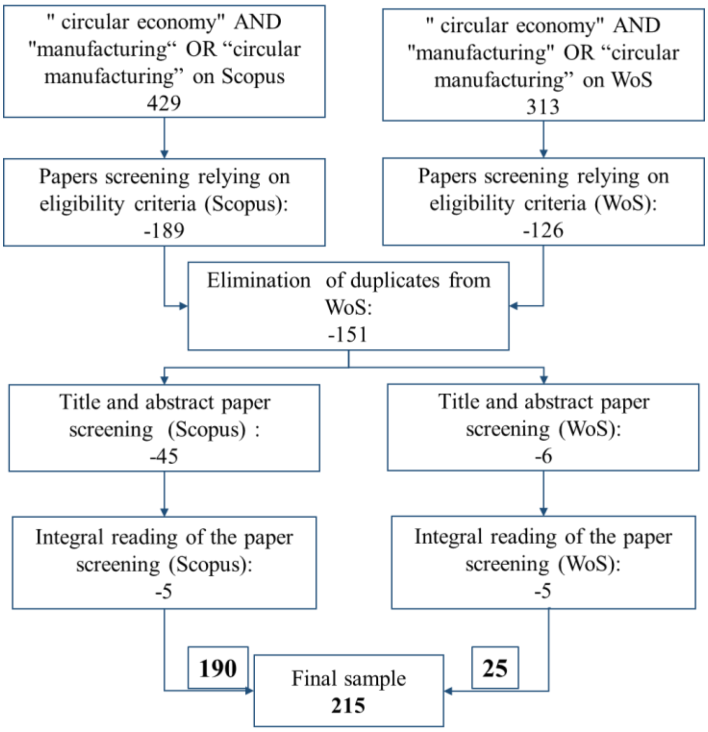

Figure 1 Paper screening process

2.2. Theoretical Framework

In this section, the theoretical framework, together with the related analysis dimensions defined to perform the review, are reported and summarized in **Figure 2**. In Section 3, leveraging on Table 1 (that summarizes Table 2 in the Appendix), the results and their discussions will be provided.

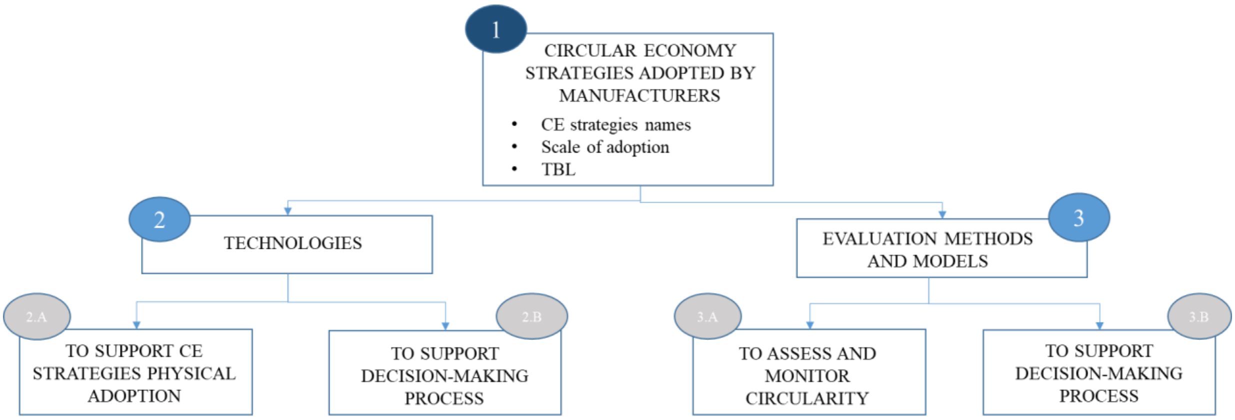

Figure 2 Theoretical framework throughwhich each CE strategy is analsysed.

This theotetical framework aims to elucidate how the review process has been conducted. Indeed, the first line (block 1 in **Figure 2**) corresponds to the first step of this review process (see Section 3.2.1), which answers to RQ1. At this level, the extant scientific literature has been analysed to identify how manufacturers have implemented the CE principles in their plants and thus, to identify the CE strategies adopted in manufacturing companies (i.e. CM strategies). In particular, each CM strategy has been analysed looking at the scale of adoption and the sustainable pillars addressed. The second line (blocks 2 and 3 in **Figure 2**) aims to highlight how the CM strategies has been tackled by researchers and thus, it aims to envisage the research streams currently present in the scientific literature (see Section 3.2.2) by answering to RQ2.

2.2. 1. Step 1 analysis dimensions

The first step of the analysis is conducted relying on both standard analysis dimensions, usually adopted in reviews, and analysis dimensions gathered from the extant literature concerning CE (i.e.the scale of adoption and sustainable pillars). All these dimensions are following reported:

- Source (i.e. the journal name);
- Publication year (i.e. year in which the contribution was published);
- Industries (i.e. according to the NACE codes (European Commission, 2008));
- Paper contribution;
- Scale of adoption (Ghisellini et al., 2016):
    - micro: product and single firm level;
    - meso: network of firms level;
    - macro: city, region, nation level .
- Sustainable pillars (i.e. environmental, economic and social (Elkington, 2013)).

These dimensions allowed to screen and review the papers in a structured way, enabling to individualize the CM strategies adopted by manufacturers according to the scientific literature, and to build up the theoretical framework which envisages the current research streams. More in detail, “Source”, “Publication Year” and “Sector” were used to perform the statistics (see Section 3.1), the other dimensions were used to perform a narrative analysis (see Section 3.2) and create the ground for the next step of the analysis.

2.2.2. Step 2 analysis dimensions

The contributions were furtherly analysed and clustered according to the research streams identified in the extant literature, by relying on the theorectical framework developed by the authors. Indeed, two main research streams have been pinpointed and both of them are explored by researchers following two different directions respectively (see block 2 and block 3 in **Figure 2**). The two main research streams are: (i) technologies (Bhandari et al., 2019; Okorie et al., 2018a) and (ii) evaluation methods and models (Sassanelli et al., 2019). On the one hand, technologies are studied in extant literature either to support the physical adoption of a CM strategy (e.g. Sauerwein et al., (2019) studied how additive manufacturing (AM) supports circular product design strategy), or to support the decision-making process by simulating future scenarios to envisage the implications of certain actions to embrace CE (e.g. (Charnley, F., Tiwari, D., Hutabarat, W., Moreno, M., Okorie, O., Tiwari, 2019)). On the other hand, evaluation methods and models are studied either to assess the circularity level of a manufacturing company, once CM strategies have been adopted (e.g. (Pagotto and Halog, 2016)), or to support decision-making process to evaluate the best actions to be implemented to embrace CE (e.g. (Accorsi et al., 2015)) relying on assessment methodologies such as the Lyfe Cycle Assessment (LCA).

3. Results and discussions

3.1 Descriptive statistics

In order to briefly present the sample of papers selected for the review, some statistics are reported below: (i) number of publications per year to investigate the interest in the scientific literature about these topics (see **Figure 3**), (ii) the top 5 journals to evaluate where the scientific contributions were published (see **Figure 4**), and (iii) manufacturing industries tackled by researchers to evaluate the major interests of the contributions (see **Figure 5**).

First, although no-time frame was used, the sample of eligible papers resulted to be published quite recently: from 2010 to 2019, as reported in **Figure 3**. In 2010, a timid initial interest around these concepts is perceived. In the last three years, the number of publications has increased, accounting 84% on the total amount of publications from 2010.

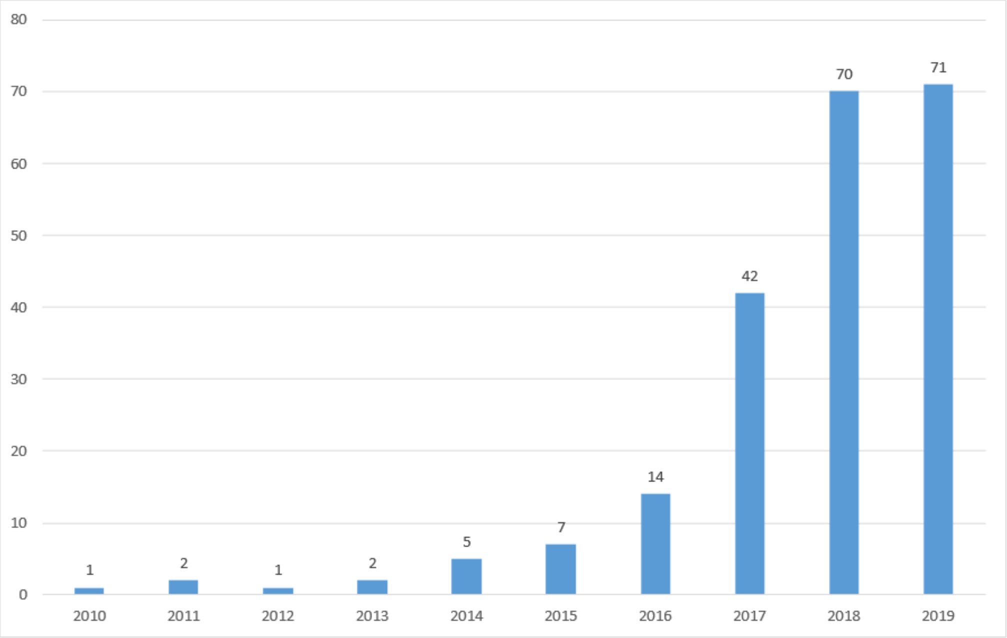

Figure 3 Descriptive statistics: publications trend by years;

Second, the majority of the papers were published in three main journals: *Journal of Cleaner Production*, *Sustainability (Switzerland)* and *Resources, Conservation and Recycling*; and the top 5 journals used for the dissemination of these topics are reported in **Figure 4**.

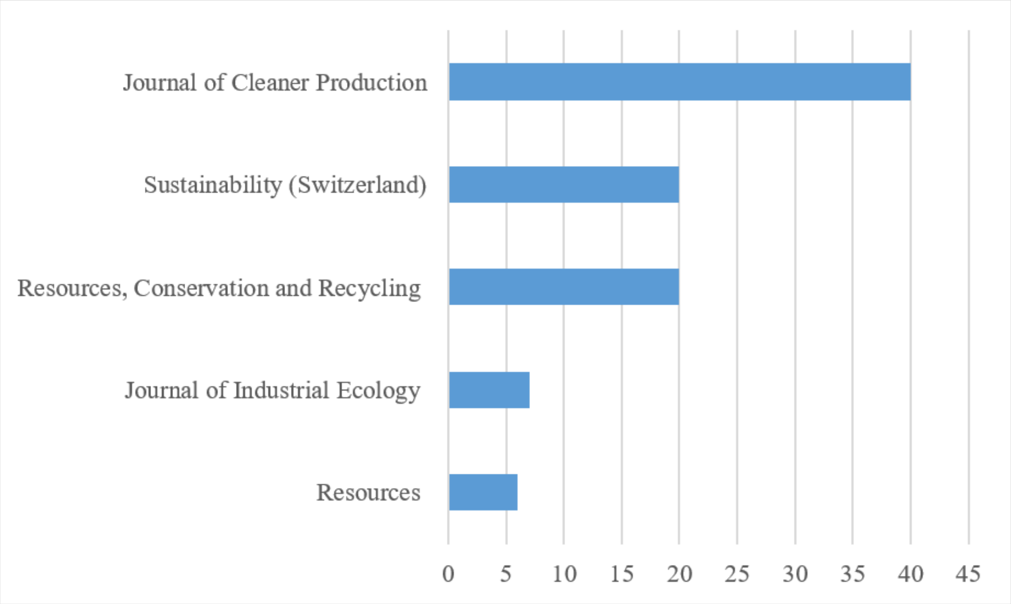

Figure 4 Descriptive statistics: top 5 journals

Leveraging on the definition given by (European Commission, 2008) regarding the different manufacturing industries characterizing the manufacturing sector (i.e. the NACE codes), a cluster analysis have been conducted on them. **Figure 5** provides information about 53% of the total amount of papers, that corresponds to those in which the industry is reported. Metals and transport equipment are the most diffused. The 47% of the papers selected for the review tackles the manufacturing sector in general and are not focused on a specific industry.

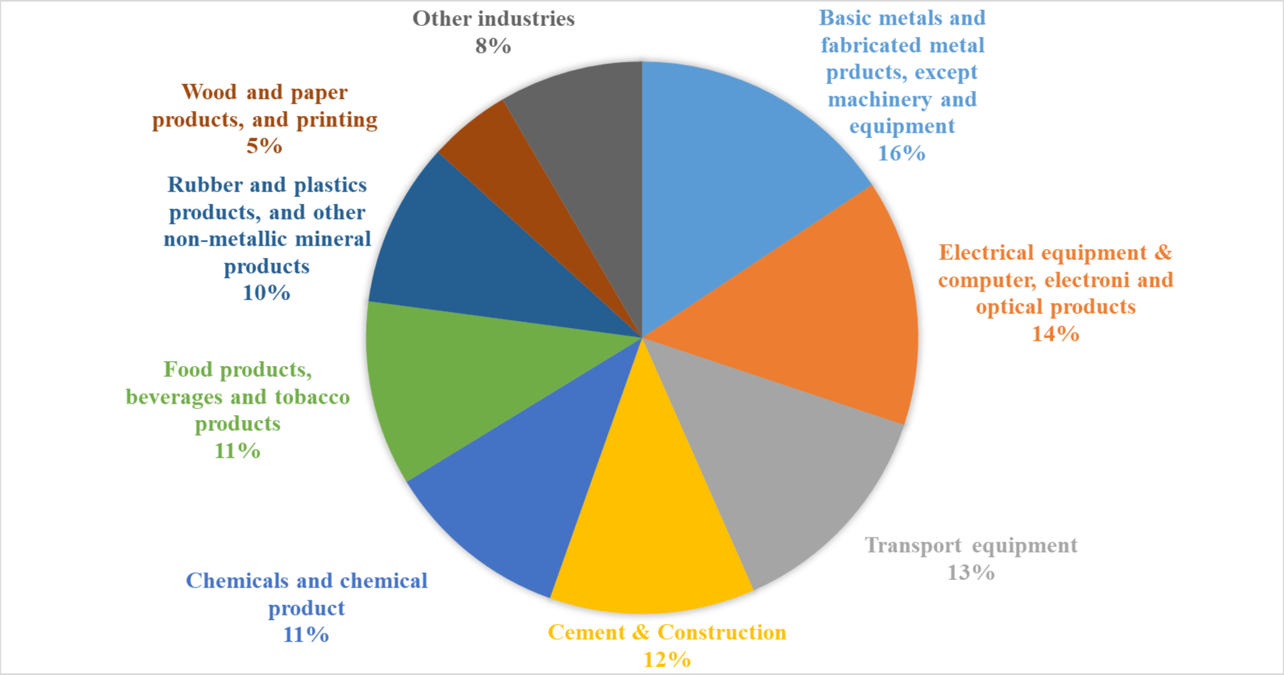

Figure 5 Manufacturing industries papers' focus

3.2. CM strategies

CM strategies studied in the extant scientific literature are clustered in **Table 1**. More in detail, **Table 1,** leveraging on the analysis dimensions explained in the “methodology” section (see *2.2.1* and *2.2.2*), clarifies the number of contributions related to each CM strategy by investigating the scale of adoption, sustainable pillars and research streams. Moreover, their analysis, looking at the scale of adoption and the sustainable pillars, is provided in Section 3.2.1, while the analysis of the contributions through the research streams is conducted in Section 3.2.2. The extensive version of **Table 1** is reported in the Appendix in **Table 2**.

Table 1 Analysis of CM strategies

CE strategy	**References**	**SCALE OF ADOPTION**			**SUSTAINABLE PILLARS**			**TECHNO-LOGIES**		**EVALUA-TION METHODS & MODELS**	
		Micro	**Meso**	**Macro**	**Environmental**	**Economic**	**Social**	**Decision support**	**Physical adoption**	**Circularity assessment**	**Decision support**
Cleaner production	(Bhandari et al., 2019); (Jia et al., 2019); (Vimal et al., 2019); (Mendoza et al., 2019); (Kalmykova et al., 2018); (Niero et al., 2018); (Fisher et al., 2018); (Ridaura et al., 2018); (Zhong and Pearce, 2018a); (Minunno et al., 2018); (Franciosi et al., 2017); (Despeisse et al., 2017); (Ingarao, 2017); (Trentesaux and Giret, 2015); (Paredes-Sánchez et al., 2018).	14	2	1	15	8	7	2	4	4	5
Circular Business Model	(Virtanen et al., 2019); (Gusmerotti et al., 2019); (Parida et al., 2019); (Liakos et al., 2019); (Jabbour et al., 2019); (Gitelman et al., 2019); (Kumar et al., 2019); (Agyemang et al., 2019); (S. Mishra et al., 2019); (Ünal et al., 2019); (Nascimento et al., 2019); (Doni et al., 2019); (Moreno et al., 2019); (Ünal and Shao, 2019); (Frishammar and Parida, 2019); (J. L. Mishra et al., 2019); (Schino, 2019); (Erro-Garcés, 2019); (Garcia-Muiña et al., 2018); (Lopes de Sousa Jabbour et al., 2018); (Okorie et al., 2018a); (Camacho-Otero et al., 2018); (Singh et al., 2018); (Sousa-Zomer et al., 2018b); (Sinclair et al., 2018a); (Schmidt and Lueder, 2018); (Wastling et al., 2018); (Rajala et al., 2018); (Azevedo et al., 2017); (Lieder et al., 2017); (Nußholz, 2017); (Smieja and Babcock, 2017); (Linder and Williander, 2017); (Ge and Jackson, 2014); (Aranda-Usón et al., 2019)	29	2	4	33	17	18	5	9	10	11
Waste Management	(Rodgers et al., 2019); (Byard et al., 2019); (Nascimento et al., 2019); (Swain and Lee, 2019); (Araújo et al., 2019); (Schilkowski et al., 2019); (Rapsikevičienė et al., 2019); (Aubrey L. Woern et al., 2018); (Bobba et al., 2018); (Quina et al., 2018); (Aubrey L Woern et al., 2018); (Coughlan et al., 2018); (Fujii and Kondo, 2018); (Cristóbal et al., 2018); (Djuric Ilic et al., 2018); (Fisher et al., 2018); (Faussone, 2018); (Minunno et al., 2018); (Lahtela and Kärki, 2018); (Ren et al., 2017); (Atlason et al., 2017); (Testa et al., 2017); (Pei et al., 2017); (Jaria et al., 2017); (Puyol et al., 2017); (Dong et al., 2017); (Alvarez-de-los-Mozos and Renteria, 2017); (Umer and Abid, 2017); (Parajuly and Wenzel, 2017); (Singh and Ordoñez, 2016); (Shahbazi et al., 2016); (Jiménez Rivero et al., 2016); (Kulczycka et al., 2016);	28	3	6	34	13	12	1	14	14	7

	(Jiménez Rivero et al., 2015); (Mirabella et al., 2014); (Jones et al., 2013)										
Disassembly	(Hasegawa et al., 2019); (Marconi et al., 2019); (Mandolini et al., 2018); (Talens Peiró et al., 2017)	4	0	0	3	3	1	1	0	1	2
Remanufacturing	(Ponte et al., 2019); (Sitcharangsie et al., 2019); (Hasegawa et al., 2019); (Charnley, F., Tiwari, D., Hutabarat, W., Moreno, M., Okorie, O., Tiwari, 2019); (Nakajima et al., 2019); (Liu et al., 2018); (Bradley et al., 2018); (Krystofik et al., 2018); (S. Yang et al., 2018); (Low and Ng, 2018); (Xiao et al., 2018); (Atlason et al., 2017); (Zhou et al., 2017); (Jensen and Remmen, 2017); (Tolio et al., 2017a); (Shahbazi et al., 2016); (Tsiliyannis, 2016); (Zhang et al., 2011); (Nakajima et al., 2019); (Liao, 2018); (Xu, 2016)	16	3	2	19	11	7	2	5	6	8
Recycling	(Ali et al., 2019); (Kuo et al., 2019); (Bendikiene et al., 2019); (Hasegawa et al., 2019); (Rodgers et al., 2019); (Byard et al., 2019); (Reich et al., 2019); (Tan and Guo, 2019); (Jensen, 2019); (Charnley, F., Tiwari, D., Hutabarat, W., Moreno, M., Okorie, O., Tiwari, 2019); (Romeo, 2019); (Stropnik et al., 2018); (Banguera et al., 2018a); (Aubrey L. Woern et al., 2018); (Bobba et al., 2018); (Aubrey L Woern et al., 2018); (Coughlan et al., 2018);(Bradley et al., 2018); (Wanassi et al., 2018); (Fujii and Kondo, 2018); (Sauerwein and Doubrovski, 2018); (Clemon and Zohdi, 2018); (Zhong and Pearce, 2018a); (Minunno et al., 2018); (Atlason et al., 2017); (Helmer Pedersen and Conti, 2017); (Testa et al., 2017); (Rizzo et al., 2017); (Zhou et al., 2017); (Ingarao, 2017); (Jensen and Remmen, 2017); (Alvarez-de-los-Mozos and Renteria, 2017); (M et al., 2017); (Câmpean et al., 2017); (O'Connor et al., 2016); (Broadbent, 2016); (Karayannis, 2016); (Shahbazi et al., 2016); (Tsiliyannis, 2016); (Cucchiella et al., 2015); (Smol et al., 2015); (Giurco et al., 2014); (Pauliuk et al., 2012); (Takata et al., 2019); (Lin, 2018); (Wu et al., 2017); (Broadbent, 2016)	39	5	4	39	17	17	3	16	14	14
Reuse	(Hasegawa et al., 2019); (Rodgers et al., 2019); (Tua et al., 2019); (Bag et al., 2019); (Nascimento et al., 2019); (Biganzoli et al., 2019); (Charnley, F., Tiwari, D., Hutabarat, W., Moreno, M., Okorie, O., Tiwari, 2019); (Stropnik et al., 2018); (Migliore et al., 2018); (Liu et al., 2018); (Coughlan et al., 2018); (Bradley et al., 2018); (Minunno et al., 2018); (Atlason et al., 2017); (Zhou et al., 2017); (Jensen and Remmen, 2017); (Gilbert et al., 2017); (Saritas and Proskuryakova, 2017); (Shahbazi et al., 2016); (Tsiliyannis, 2016); (Zhu and Chertow, 2016); (Takata et al., 2019); (Mohammed et al., 2018); (Wu et al., 2017)	18	3	3	24	7	9	2	2	13	7
Servitization	(P. P. Pieroni et al., 2019); (Camacho-Otero et al., 2018); (M. Yang et al., 2018); (Sinclair et al., 2018b); (Azcárate-Aguerre et al., 2018); (Tukker, 2015)	3	2	1	6	3	5	1	0	5	0
Close-loop supply chain and Reverse logistics	(Ponte et al., 2019); (Ali et al., 2019); (Kuo et al., 2019); (Bag et al., 2019); (Alkhayyal, 2019); (Lapko et al., 2019); (Abuabara et al., 2019); (Secondi et al., 2019); (Niu et al., 2019); (Banguera et al., 2018a); (Gaustad et al., 2018); (Rieckhof and Guenther, 2018a); (Mangla et al., 2018); (M. Yang et al., 2018); (Braun et al., 2018a); (Moktadir et al., 2018); (Minunno et al., 2018); (Low et al., 2016); (Accorsi et al., 2015); (Wei et al., 2013); (Jiliang and Chen, 2013); (Zhu et al., 2011); (Zhu et al., 2010); (Martín-Gómez et al., 2019)	7	17	0	23	14	8	0	4	12	8

Industrial symbiosis and Eco-industrial parks	(Ali et al., 2019); (Barreira et al., 2019); (Nuss et al., 2019); (Domenech et al., 2019); (Migliore et al., 2018); (Minunno et al., 2018); (Editors et al., 2018); (Prosman et al., 2017); (Halstenberg et al., 2017); (Husgafvel et al., 2016); (Karayannis, 2016); (Mirabella et al., 2014); (Martín Gómez et al., 2018a)	3	10	0	12	3	1	2	4	4	3
Material Efficiency	(Choi et al., 2019); (Cooper, 2019); (Jakhar et al., 2019); (Medeiros et al., 2019); (Dominish et al., 2018); (Braun et al., 2018b); (Neligan, 2018); (Walker et al., 2018); (Wang et al., 2018b); (Wang and Zhang, 2018); (Wang et al., 2018a); (Zairul et al., 2018); (Smieja and Babcock, 2017); (Ingarao, 2017); (Di Maio et al., 2017); (Câmpean et al., 2017); (Shahbazi et al., 2016); (Pagotto and Halog, 2016); (Li et al., 2019); (Graedel et al., 2019); (Wiedenhofer et al., 2019); (Yu et al., 2018); (Garmulewicz et al., 2018);(Cooper et al., 2017)	17	1	6	22	11	12	1	3	13	6
Circular Design Practices	(Ali et al., 2019); (Sauerwein et al., 2019); (Mesa et al., 2019); (Mendoza et al., 2019); (Favi et al., 2019); (Niu et al., 2019); (Bovea et al., 2018); (Low and Ng, 2018); (Mandolini et al., 2018); (Comanita et al., 2018); (Atlason et al., 2017); (Lieder et al., 2017); (De los Rios and Charnley, 2017); (den Hollander et al., 2017); (Lin, 2018); (Mesa et al., 2018); (Almeida et al., 2017); (Iraldo et al., 2017); (Moreno et al., 2016); (Andrews, 2015)	19	2	1	16	8	6	2	2	10	6

Among all, *cleaner production* strategy is considered a precursor of CE since it enables systems to reduce at minimum toxic substances used in the production process and to limit and reduce resources consumption. It is based on principles such as product optimization, input substitution, sharing of renewable and recyclable resources (Sousa-Zomer et al., 2018a). More recently, the so-called 3Rs strategies (i.e. reuse, remanufacture and recycle) have been considered a gear to adopt CM. *Reuse* aims to reuse the product directly at the end of its life cycle (Liu et al., 2018), *remanufacturing* aims to restore a used product in compliance with its original quality, specifications, performances, and warranty (Sitcharangsie et al., 2019) and last, *recycling*, through transformation processes, aims to reuse the components or materials by reducing resources consumption and pollution generation (Zhong and Pearce, 2018b). A hybrid strategy between reuse and recycling is *repurposing*, used whenever the product cannot directly be reused due to economic or technical feasibility (Coughlan et al., 2018). All these practices are eased by *disassembly* that allows the disassembling in sub-components and materials the product (Favi et al., 2019; Marconi et al., 2019) to ease the circular end-of-life.

Furthermore, *circular design practices* are adopted to prevent excessive resources consumption. These design practices facilitate the adoption of end-of-life CM strategies , such as the 3Rs, bearing in mind end-users' requirements and the entire product life cycle at the beginning of life of the product (den Hollander et al., 2017). For instance, design for remanufacturing aims to push the producer to think in advance to design the product to ease its remanufacturing at the end of its useful life (S. Yang et al., 2018).

Considering the goal of CE of reducing waste and toxic substances, *waste management* is also tackled. This enables to dismantle waste generated by manufacturers by also handling hazardous waste (Rapsikevičienė et al., 2019). Moreover, to reduce at minimum the consumption of energy and materials during production activities and to ensure environmental, economic and social benefits, manufacturers put in place *material and energy efficiency* practices (Choi et al., 2019). Additionally, s*ervitization*, that is reflected into *Product-Service System* (PSS), is one of the most promising business models (BM) since it combines tangibles (products) and intangibles (services) to satisfy final customers' needs, through products reuse, refurbishment and repair, by limiting resources consumption (Bocken et al., 2014).

The CM strategies presented until now are mostly focused on micro level and usually aim to cover all the three sustainable pillars with a greater attention on the environmental one. Nevertheless, there are other CM strategies which are majorly focused on the meso level. Indeed, CE can also be implemented through *Industrial symbiosis* that refers to the physical exchange of resources such as materials, energy and by-products among industrial actors that do not belong to the same supply chain (Domenech et al., 2019). The physical implementation of this strategy is the Eco-Industrial Park (Martín Gómez et al., 2018a). In case companies would belong to the same supply chain, cl*osed-loop supply chains* are established, and these rely on the activities put in place to enable the return flows of materials and components (Lapko et al., 2019). Under this concept, green logistic, reverse logistics and sustainable supply chain management are included.

To conclude, according to the characteristic of each CM strategy, some CM strategy are majorly applicable at either micro or meso level, but all of them can be analysed from a macro level perspective whenever incetivised by policymakers. Therefore, the integration and complementation of the adoption of different CM strategies by manufacturers inevitably modify their BM by creating *circular business models* (CBM) where resources are made recirculate (Linder and Williander, 2017) under the respect of the three sustainable pillars.

3.2.1. Analysis: step 1

In this section, CM strategies emerged from the extant scientific literature (see **Table 1**) are analyzed looking at the scale of adoption (Ghisellini et al., 2016) and the sustainable pillars (WCED, 1987) that correspond to the first 6 columns of the **Table 1**.

Most of the strategies identified concern the micro (70%) and the meso levels views (21%); while the macro level has been tackled in a few studies (12%). In particular, the micro level view is especially adopted by scholars while dealing with strategies such as the 3Rs, disassembly, circular design, servitization, cleaner production, material efficiency, waste management and circular business model in general. The meso level view is tackled by scholars to investigate industrial symbiosis and closed-loop supply chains. This is aligned with the origin of these two strategies since, to be adopted, they both require the interaction among different actors. The macro level perspective is often used to investigate the adoption of specific CM strategies to provide a wider overview looking at nations and regions CM adoption (Umer and Abid, 2017). Wrapping up, the same CM strategy might be analysed though a micro, meso or macro level view according to the objective of the researcher.

In addition, from the scientific literature emerged that, even though the contributions are usually focused on a specific CM strategy, to ease the shift from a linear economy towards a CE successfully usually, the integration among different CM strategies is required.

On one side, regarding the integration among different CM strategies at the same scale of adoption, for instance, at micro level, material efficiency supports the transition towards CE by improving recyclability, reusability, reduction and prevention of industrial waste (Shahbazi et al., 2016). Reuse and remanufacturing practices, being them mutually exclusive choices, are often addressed together by researchers (Liu et al., 2018) as well as the 3Rs (Nakajima et al., 2019). Moreover, disassembly decisions at the beginning of product life cycle (Talens Peiró et al., 2017) ease circular end-of-life management (Mandolini et al., 2018; Marconi et al., 2019), especially the 3Rs adoption (Hasegawa et al., 2019). Indeed, circular design practices rely on the life cycle thinking approach to ensure to design products by considering in advance future end-of-life management practices and thus, ease the reintroduction of materials, components and products in next life cycles (den Hollander et al., 2017). To support the decision process in pursuing this direction, adequate data and information are required to appropriately link design decisions with business strategy (Lieder et al., 2017). Nevertheless, few and only theoretical works have been developed until now around these topics.

On the other side, the integration between meso and micro level strategies are widely diffused in the extant literature. Indeed, return flows are fundamental to ensure the applicability of the CM strategies adopted at firm level, thus majorly analysed from a micro view (Takata et al., 2019). Therefore, the 3Rs strategies can be implemented only in case return flows of materials, components or products are put in place through closed-loop supply chains or industrial symbiosis. These resources can be returned back either to the original producer (Ponte et al., 2019) or to a company that uses waste as a resource trhough the adopting of the 3Rs strategies. Nevertheless, in both of the cases return flows management must be designed appropriately to ensure the closing of the resource loops (Banguera et al., 2018b). Moreover, as stated before, the macro level view is also used to evaluate the adoption of a certain CM strategy at city, region, nation level and thus by considering either CM strategies adopted at firm level such as material efficiency (Virtanen et al., 2019) or by considering CM strategies adopted through the interaction among different firms such as the industrial symbiosis (Domenech et al., 2019).

Concerning the sustainable pillars, more than one per time is usually addressed, and those pillars highly investigated are environmental (90%) and economic (41%), while few address social aspects (35%). The lack in social impact investigation is evident especially for some of the CM strategies, while others rely on them. For instance, servitization relies on PSS in which user perspective, acceptance and needs require to be investigated and satisfied to maximise both the utility of the product delivered through the service (Camacho-Otero et al., 2018), and to improve its future developments (Sinclair et al., 2018b). This impacts inevitably on product design decisions since customers' preferences are analysed and studied to enable circular product acceptance (Atlason et al., 2017; Bovea et al., 2018; Low and Ng, 2018). In line with that, another social implication is visible on designers, that are required to adapt their competences to concurrently address customers' needs and climate change problematics through product design decisions to enable the closure of material loops (De los Rios and Charnley, 2017). Together with designers, managers are asked to adapt themselves to manage firms' resources and boost innovative capabilities taking into account stakeholders pressure to shift towards CE successfully (Jakhar et al., 2019).

3.2.2. Analysis: step 2

As reported in the methodology section, through the papers reading, the authors individualized some commonalities characterising the research streams (i.e. Technologies and Evaluation Methods and Models), that are summarized in **Figure 2** and are analysed below**.** In **Table 1** are reported the numbers of the publications related to the different research streams.

3.2.2.1. Technologies

Technologies are considered by researchers one of the gears boosting sustainable development, especially for CE adoption.

Concerning technologies supporting the physical implementation of CE (see block 2.4 of **Figure 2**), in the extant literature are reported technologies enabling green and cleaner production (Bhandari et al., 2019; Rizzo et al., 2017)**,** but also digital technologies for material efficiency (Neligan, 2018), and waste management. Within this latter type, Lahtela and Kärki, (2018) studied how sorting technologies support the adoption of waste manegement strategy, and Swain and Lee, (2019) investigated technologies used to separate and analyze waste to enable waste reintroduction as a new resource in the cycle. 3Rs adoption is supported by technologies too. For instance, Romeo, (2019) investigated the recycling technologies to recycle plastic, while Bendikiene et al., (2019) studied recycling tehcnologies to recycle metals, and other researches proposed technologies to recover resources (Jones et al., 2013; Kulczycka et al., 2016; Quina et al., 2018). Among them, O'Connor et al., (2016) studied technologies to digeste and separate waste, while O'Connor et al., 2016; Puyol et al., (2017) technologies to recover resources through wastewater treatments. Specifically, for the discrete manufacturing sector, a prominent role is given to technologies to remanufacture products (Nakajima et al., 2019) and to design products for remanufacturing (Tolio et al., 2017a).

Moreover, digital technologies empowered by Industry 4.0 (I4.0) technologies are studied by different researchers (e.g. (Erro-Garcés, 2019; Garcia-Muiña et al., 2018; Lopes de Sousa Jabbour et al., 2018; Nascimento et al., 2019)) since they could hardly have impacted on the sustainable development (Okorie et al., 2018b). Remanufacturing is an example where I4.0 technologies enhance its adoption (S. Yang et al., 2018) and, other promising examples are collaborative robots used to recycle electronic equipment (Alvarez-de-los-Mozos and Renteria, 2017). Additive Manufacturing (AM) is one of the most diffused I4.0 technologies (Despeisse et al., 2017). On one side, AM adoption has been studied to recycle materials like plastic (Reich et al., 2019; Aubrey L Woern et al., 2018; Aubrey L. Woern et al., 2018), metal (Giurco et al., 2014) and organic materials (Sauerwein and Doubrovski, 2018). On the other side, AM adoption has been studied to design circular products (Sauerwein et al., 2019) to facilitate resource circularity at products end-of-life. This technology is proved to be energy and cost-efficient with respect to traditional production, but it can be adopted only for small scale production (Byard et al., 2019). Greater flexibility to systems is given by cloud manufacturing that is adopted to promote resource recovery, recycling and waste minimization (Fisher et al., 2018). Actually, all the above mentioned technologies referred to the micro level, while at meso level, innovative technologies to enable industrial symbiosis development were studied too (Rizzo et al., 2017; Swain and Lee, 2019).

To conclude, these technologies were highly focused on a micro level view, rather than meso or macro and very few attention is provided on sustainable pillars. In **Table 2** are summarized the most diffused technologies supporting the physical implementation of CE strategies according to the extant scientific literature.

Table 2 Technologies emerged to be used to support the pysical implementation of CM strategies

Technology Type	References
Recycling Technologies	(Alvarez-de-los-Mozos and Renteria, 2017; Bendikiene et al., 2019; Kulczycka et al., 2016; Romeo, 2019; Swain and Lee, 2019; Aubrey L. Woern et al., 2018)
Additive Manufactuirng	(Byard et al., 2019; Clemon and Zohdi, 2018; Despeisse et al., 2017; Garmulewicz et al., 2018; Giurco et al., 2014; Nascimento et al., 2019; Reich et al., 2019; Sauerwein et al., 2019; Aubrey L Woern et al., 2018; Zhong and Pearce, 2018b)
Cleaner and Green Technologies	(Bhandari et al., 2019; Nascimento et al., 2019; Neligan, 2018; Rizzo et al., 2017; Sarc et al., 2019)
Waste Recovery Technologies	(Alvarez-de-los-Mozos and Renteria, 2017; Helmer Pedersen and Conti, 2017; Jones et al., 2013; Lahtela and Kärki, 2018; Migliore et al., 2018; O'Connor et al., 2016; Puyol et al., 2017; Quina et al., 2018; Swain and Lee, 2019)
Remanufacturing Technologies	(Nakajima et al., 2019; Tolio et al., 2017b)
Digital Technologies empowered by I4.0 (IoT)	(Erro-Garcés, 2019; Garcia-Muiña et al., 2018; Lopes de Sousa Jabbour et al., 2018; Martín-Gómez et al., 2019; Okorie et al., 2018a; S. Yang et al., 2018; Zairul et al., 2018)
Cloud Manufacturing	(Fisher et al., 2018)
Tracking Technologies	(Minunno et al., 2018)

Moreover, in the extant literature, technologies emerged also to be supporting means for decision-making process in adopting CM strategies (see block 2.B **Figure 2**). Manufacturers struggle to identify the best choice to maximise the economic benefits while limiting and reducing environmental damage, and without any support, these decisions become tricky (Bai et al., 2017). Considering the potentialities that data and advanced information technologies have, these aspects are investigated to support manufacturers while approaching CE (Schmidt and Lueder, 2018). To cite some examples, Big Data management is studied as supporting tool for the ReSOLVE framework adoption (Jabbour et al., 2019) developed by Ellen MacArthur (The Ellen MacArthur Foundation, 2012), and also in automotive for cost reduction by relying on PSS (Ge and Jackson, 2014).

I4.0 technologies, embedded into products, give rise to smart products. These are functional to monitor product usage and customers' behaviours to map future product design strategies, especially while PSS are adopted (Sinclair et al., 2018b). They also enable to identify required products characteristics in line with customers' preferences, since recycled products are often not easily accepted by the final users (Lin, 2018), but also to ease circular end-of-life management practices by designing products that can be easily disassembled through adequate disassembly tasks (Talens Peiró et al., 2017). Indeed, smart products boost the sustainability of industrial ecosystems by shaping closed-loop systems (Rajala et al., 2018) and enabling to decide the best end-of-life strategy choice (Jensen and Remmen, 2017).

To pursue sustainable development through CE, I4.0 technologies are complemented with techniques, such as simulation. Indeed, qualitative analysis of circular scenarios developed thanks to digital intelligence tools, integrated into products, can be complemented with quantitative analysis developed relying on discrete event simulation techniques, providing a promising method to take beneficial economic decisions (Moreno et al., 2019). This integration enables to provide reliable decisions support to pursue circular production and consumption. Simulation techniques are also used to reduce production costs on the shop-floor, for instance, by choosing whether to do or not remanufacturing activities (Charnley, F., Tiwari, D., Hutabarat, W., Moreno, M., Okorie, O., Tiwari, 2019) or in other cases, to define for each product component the best among the 3Rs strategies, by assessing the environmental impacts of the different scenarios and by taking into account the BM of the company under analysis (Lieder et al., 2017).

At meso level, being information sharing and communication one of the major barriers in embracing CE principles (Jabbour et al., 2019), Information and Communication Technologies (ICT) have been investigated as supporting tools (Garcia-Muiña et al., 2018). For the construction industry, Building Information Modelling was used to collect data regarding both design and usage gathered through tracking technologies, in order to boost reuse and recycling of building materials at end-of-life (Minunno et al., 2018). Data management and information sharing are required to support industrial symbiosis to identify what resources, by-products and waste can be shared among partners and thus, a standard model should be developed (Halstenberg et al., 2017), and some attempts to develop an ontological framework have been done (Martín Gómez et al., 2018a).

At macro level, considering both the lenses, none studies have been developed regarding technologies.

Wrapping up, these technologies were studied not only from a micro level perspective but also from a meso one, so there is more homogeneity in respect to the technologies studied to physical adopt CM strategies. Moreover, all the sustainable pillars are taken into account while dealing with the adoption of these technologies. In **Table 3** are reported the most diffused technologies, according to the extant scientific literature, adopted to support the manufacturers' decision making processes in implementing CM strategies.

Table 3 Technologies emerged to support to be used the decision process to adopt CM strategies

Technology Type	References
Big Data Analytics	(Ge and Jackson, 2014; Jabbour et al., 2019; Lin, 2018; Schmidt and Lueder, 2018)
Simulation and Digital Intelligence	(Charnley, F., Tiwari, D., Hutabarat, W., Moreno, M., Okorie, O., Tiwari, 2019; Lieder et al., 2017; Moreno et al., 2019)
Ontology-based systems	(Halstenberg et al., 2017; Martín Gómez et al., 2018b)

IoT	(Jensen and Remmen, 2017; Rajala et al., 2018; Sinclair et al., 2018b; Trentesaux and Giret, 2015)
ICT and Green Information Technologies	(Bai et al., 2017; Halstenberg et al., 2017; Talens Peiró et al., 2017)

3.2.2.2. Evaluation methods and models

As underlined before, the technological support research stream is flanked by evaluation methods and models that ease the CE adoption by manufacturers too (see 3 block **Figure 2**).

On one side, evaluation methods and models are used to evaluate the circularity of an entity (see block 3.A **Figure 2**). Usually, the CM strategies tackled in this research stream refer to the micro level view, as for example the evaluation of environmental impacts of recycling processes related to different materials, such as iron and steel, proposed by different researches (e.g. (Broadbent, 2016; Wu et al., 2017)), of remanufacturing (e.g. (Liu et al., 2018; Xiao et al., 2018; Xu, 2016)), and reuse (e.g. (Biganzoli et al., 2019; Tua et al., 2019)). Circularity is also assessed for waste management adoption as the case of Ren et al., (2017) that evaluated the environmental impact once the waste is used to prepare sulfoaluminate clinker or to monitor PSS adoption as proposed by Doni et al., (2019) or the adoption of circular design initiatives. Other studies evaluate the economic benefits, for instance, Mendoza et al., (2019) assessed cost reduction coming from the introduction of new circular design initiatives in creating glueless baby-diapers.

The view of the above mentioned contributions is the micro one, but the circularity is assessed at meso level too. For instance, Husgafvel et al., (2016) evaluated the environmental implications once forest product industrial residues are recycled to create fertilizer putting in place industrial symbiosis, while Low et al., (2016) assessed the economic implications to reuse or recover product components along a closed-loop supply chain.

At macro level the evaluation is performed to monitor national circularity whenever manufacturers adopt CM strategies (Nuss et al., 2019). For instance, Virtanen et al., (2019) evaluated the material efficiency of firms operating in the region under analysis. Schilkowski et al., (2019)**,** focusing on waste management, analysed and quantified the waste input-output for regional industrial waste, and Wang et al., (2018a), by using dynamic material flow analysis and stock dynamics, quantified the manufacturing role in enabling to achieve CE goals, among which reducing materials consumption.

At all three levels, social implications are marginally evaluated. Among the researches developed, Jakhar et al., (2019) analysed how stakeholders pressure impacts on CE initiatives undertaken by manufacturers, in line with the work developed by Jing, (2018) according to which the competitive advantage is given also by a deep understanding of customers' behaviour and product quality.

To sum-up, evaluation methods and models to evaluate the circularity of an entity, once adopted a CM strategy, are studied through all the three scale of adoption and the evaluations are highly based on the three sustainable pillars with a limited attention only on the social aspects. In **Table 4** are reported the most diffused assessment methods to estimate the circularity of an entity.

Table 4 Evaluation methods and models emerged to be used to assess the circularity of an entity

Evaluation Methods and Models	References
Network Circularity Indicators	(Virtanen et al., 2019)(Nuss et al., 2019)(S. Mishra et al., 2019)(Schilkowski et al., 2019)(Azevedo et al., 2017)(M et al., 2017) (Mesa et al., 2018)(Cooper et al., 2017)
Carbon Footprint Indicators	(Husgafvel et al., 2016)(Low et al., 2016)
Life Cycle Assessment	(Jia et al., 2019)(Tua et al., 2019)(Jensen, 2019)(Biganzoli et al., 2019)(Medeiros et al., 2019)(Niero et al., 2018)(Rieckhof and Guenther, 2018b)(Xiao et al., 2018)(Walker et al., 2018)(Ren et al., 2017)(Gilbert et al., 2017)(Broadbent, 2016)(Zhu and Chertow,

	2016)(Jiménez Rivero et al., 2016)(Kulczycka et al., 2016)(Mohammed et al., 2018) (Iraldo et al., 2017)
Qualitative Assessment	(Jakhar et al., 2019)(Doni et al., 2019)
Life Cycle Costing and Economic Indicators	(Mendoza et al., 2019)(Wang and Zhang, 2018)(Jing, 2018)(Zhou et al., 2017)(Iraldo et al., 2017)(Xu, 2016)
Dynamic and Fixed Material Flow Analysis	(Liu et al., 2018)(Coughlan et al., 2018)(Rieckhof and Guenther, 2018b)(Wang et al., 2018b)(Wang et al., 2018a)(Zhou et al., 2017)(Ingarao, 2017)(Di Maio et al., 2017)(Pagotto and Halog, 2016)(Wiedenhofer et al., 2019)(Yu et al., 2018)(Wu et al., 2017)
Total Quality Environmental Assessment	(Garza-Reyes et al., 2018)

Changing the perspective, some methods are used also to evaluate and compare different future scenarios in case a certain CM strategy would be adopted by supporting the decision-making process to select the right strategy (see block 3.B **Figure 2**).

Life cycle assessment is used at micro level to evaluate future environmental impacts, in adopting CE strategies as reuse (Bobba et al., 2018; Stropnik et al., 2018). Hasegawa et al., (2019) proposed a model aiming to evaluate both the economic and the environmental implications, respectively the recovery costs, compared to the second-hand market revenues, and the CO2 emissions, in contexts in which disassembly parts can be reused, recycled or disposed. Bradley et al., (2018) used the traditional total life cycle cost model to support the decision process along the entire product life cycle. Rapsikevičienė et al., (2019) proposed a model supporting producers acting to prevent waste creation and to guarantee high-efficiency level, by assessing environmental, social and economic implications of different scenarios generated according to the producer decisions, while Comanita et al., (2018) developed the economic and environmental performance efficiency evaluation of eco-designed products.

At meso level, economic and environmental implications are assessed to support the decision process in designing circular operations in a closed-loop supply chain network (Accorsi et al., 2015; Vimal et al., 2019), while Takata et al., (2019) developed a life cycle simulation system enabling to compare different life cycle options to choose the best closed-loop strategy.

Social implications are rarely included in the evaluation; here some examples are reported. Considering the quality implications affecting products due to CE strategies adoption, Wanassi et al., (2018) analysed and optimized the right trade-off between quality and costs. Indeed, customers' perception, customers' personal income, economic cycles and advent of technology impacts on the instability and uncertainty of product demand. Actually, this instability must be managed since it is reflected in augment of product stock that, in the future, becomes end-of-life flow. To cope with this issue, Tsiliyannis, (2016) proposed a linear algebraic law to link the two dimensions and put in place best actions boosting CE adoption.

To conclude, the most diffused views adopted by scholars for this research stream are micro and meso levels. The sustainable pillars gain momentum also in this research stream. In **Table 5** are reported the most diffused evaluation methods and models to support the decision process.

Table 5 Evaluation Methods and Models emerged to be used to support the decision process by assessing circularity

Evaluation Methods and Models	**Reference**
Toxicity Assessment Indicators	(Zapelloni et al., 2019)(Rapsikevičienė et al., 2019)
Material Flow Analysis	(Zapelloni et al., 2019)(Rapsikevičienė et al., 2019)(Moktadir et al., 2018)(Pauliuk et al., 2012)(Li et al., 2019)
Energy Flow Analysis	(Zapelloni et al., 2019)(Rapsikevičienė et al., 2019)(Moktadir et al., 2018)(Li et al., 2019)
Circular Economy Index	(Jiliang and Chen, 2013)

End-Of-Life cycle option	(Hasegawa et al., 2019)(Coughlan et al., 2018)(Takata et al., 2019)
(Multi-objective mixed / single objective) integer linear programming model and mathematical models	(Vimal et al., 2019)(Banguera et al., 2018b)(Tsiliyannis, 2016)
Life Cycle Assessment	(Alkhayyal, 2019)(Stropnik et al., 2018)(Bobba et al., 2018)(Broadbent, 2016)
Life Cycle Costing and Economic Indicators (cost-based and time-based)	(Alkhayyal, 2019)(Rapsikevičienė et al., 2019)(Bradley et al., 2018)(Wanassi et al., 2018)(Cristóbal et al., 2018)(Mandolini et al., 2018)(Cucchiella et al., 2015)
Synergies Evaluation	(Editors et al., 2018)
Multi-Criteria Decision Analysis and Conceptual Decisions Models	(Comanita et al., 2018)(Parajuly and Wenzel, 2017)(Accorsi et al., 2015)(Liao, 2018)(Almeida et al., 2017)

4. Conclusion and future research directions

This paper operates a systematic review of the state-of-the-art of CE adoption in manufacturing, with the goal to provide a definition of CM, to elucidate the research streams about this topic currently present in the extant literature, and to envisage possible future research directions.

To provide a definition of CM by answering to the RQ1, the authors identified and clustered the CE strategies adopted by manufacturers, called in this contribution CM strategies, which have been studied in the extant scientific literature. These strategies (i.e. circular design, remanufacture, disassembly, reuse, recycle, resource efficiency, cleaner production, servitization-based businessl models, industrial symbiosis and closed-loop supply chain) were first analyzed according to the scale of adoption and the sustainable pillars tackled. Second, to answer to RQ2, CM strategies were analyzed through a theoretical framework, developed by the paper's authors, that underlines the research streams under which scholars investigate CE adoption by manufacturers. Two main research streams emerged: technologies and assessment methods and models. In particular, technologies are studied to support either the physical implementation of CM strategies or the decision process to define the most suitable strategy, and assessment methods and models are studied either to evaluate the circularity of an entity once CM strategies have been adopted or to support the decision process in adopting a certain CM strategy.

CM is defined as the concurrent adoption of different CM strategies, which enable to reduce resources consumption, to extend resources lifecycles and to close the resources loops, by relying on manufacturers' internal and external activities that are shaped in order to meet stakeholders' needs. Indeed, some of the CM strategies like circular design, material efficiency, cleaner production, disassembly and the 3Rs, impact on internal manufacturing activities and processes that are currently undertaken by firms. Furthermore, the adoption of other CM strategies, such as servitization, industrial symbiosis or closed-loop supply chain, is supported and enabled by external activities, which are all those activities implemented thanks to the interaction with external actors, among which customers or companies internal or external to the supply chain, that ensure the return flows of resources.

Actually, in the extant literature, in most of the contributions, each strategy has been tackled as a separate entity with limited attention on how they can be concurrently adopted to make manufacturers embrace CE. Considering this comprehensive scenario, where both internal and external activities need to be shaped appropriately to embrace CM, manufacturers must be aware of the context in which they operate by taking into account all the stakeholders involved along product life cycle and the relative implications. In line with that, some attempts to support the decision-making process in pursuing the right CM strategy have been done in both of the research streams of the theoretical framework although, in most of the cases, they were focused on a single strategy and thus, neither all the variables characterizing these decisions have been tackled nor the stakeholders involved are considered in detail and in an holistic manner. In line with that, decision support tools and technologies, to ensure the creation of return flows of resources, emerged to gain momentum in the extant literature, and as a consequence the promising position of data and infromation has been confirmed by different contributions that unveiled the need to establish standard data models and standard communication protocols to be used in data management information systems (Dinggui Luo et al., 2011; Jensen and Remmen, 2017). Indeed, it is commonly recognized the need to share information to embrace CM, but it has not been studied how this can be addressed in a standard way, especially in discrete manufacturing (Halstenberg et al., 2017), considering also that manufacturers are collecting data without being able to value them, especially for a sustainable aim (Schmidt and Lueder, 2018).

In addition, as visible in **Table 2**, **Table 3**, **Table 4** and **Table 5** different solutions have been proposed according to the research stream considered, but it is still missing a comprehensive and holistic solution embracing CM as a whole. Even though CM aims to cover all the sustainable pillars, being it a driver of sustainability, regardless of the two research streams the most diffused sustainable pillars are the environmental and economic ones. The social aspects are often ignored, although people are fundamental parts of the ecosystem. Considering the scale of adoption of CM strategies, most of the studies are focused on micro and meso levels while the big picture given by the macro level is often neglected. However, comprehensive countermeasures by nations and cities should be studied as well while dealing with manufacturers, and this can be eased through the definition of a standard ontology and thus, by giving to data the right value under CM.

To conclude, in line with the key points emerged from this review, in future researches it is suggested:

- to include social aspects in future studies dealing with CM, to create an holistic model,
- to develop a model for risk management while adopting CM strategies, since different authors underlined it as a barrier but none have developed a model to manage it as visible in **Table 4** and **Table 5**. Indeed, this model could better support the decision makers;
- to monitor all the resources used along the entire product life cycle without limiting the focus on materials and energy consumption but also on data and information circulation;
- to further investigate the decision-making process to support manufacturers, especially discrete manufacturers, in embracing CM, by taking into account all the stakeholders, and the relative implications that might arise, to ease the cooperation with other industrial actors and final users,
- to identify necessary data and information to support the decision-making process of manufacturers while adopting CM strategies;
- to standardize data collection and information management and sharing among industrial actors and within compaies boundaries, by defining a new ontology or a standard data model.

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