Circular Business Models versus Circular Benefits: An Assessment in the Waste from Electrical and Electronic Equipments Sector

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Abstract

Huge depletion of raw materials, inefficient waste management practices, increasing population and consumerist lifestyles, are even more coping companies with the adoption of Circular Economy (CE) principles in their Business Models (BMs). However, benefits coming from the implementation of CE within companies are not always clear to managers. To this aim, the paper has a multiple purpose. Firstly, the work provides to academics the list of the benefits deriving from CE adoption through a systematic literature review, declined under the Triple Bottom Line (TBL) perspective of sustainability, also by validating and grounding them through four practical use cases. Secondly, the work links CE benefits with a set of CBMs – based on Product-Service Systems (PSSs) – through a set of interviews with experts belonging to the Waste from Electrical and Electronic Equipment (WEEE) sector, trying to support industrials in both i) detecting benefits related with the adoption of CBMs, ii) increasing their awareness on benefits and iii) reaching them into practice. Given that PSS-based CBMs are renown both by the scientific and industrial community as the most suitable ones to achieve circularity, they were considered as the most appropriate to adopt also in this work. Finally, four use cases coming from the WEEE sector demonstrate how to link CBMs with CE benefits.

Keywords: Circular Business Models; Circular Benefits; Waste Electrical and Electronic Equipments; Product-Service Systems; Circular Economy.

Acronyms

AM	Additive Manufacturing	KET	Key Enabling Technology
BM	Business Model	PCB	Printed Circuit Board
CBM	Circular Business Model	PSS	Product-Service System
CE	Circular Economy	SME	Small and Medium Enterprise
EoL	End-of-Life	TBL	Triple Bottom Line
FDM	Fused Deposition Modelling	WEEE	Waste from Electrical and Electronic Equipment
ICT	Information and Communication Technology		

1. Introduction

Nowadays, the manufacturing industry – like all the other sectors – is coping with several challenges (Taisch et al., 2018). Huge depletion of raw materials, inefficient waste management practices, increasing population and consumerist lifestyles (e.g. (Steffen et al., 2015; WCED, 1987)) are asking manufacturing companies for a rethinking of their Business Models (BMs), by shifting from linear to circular ones (Kirchherr et al., 2017). Together, Information and Communication Technology (ICT) and recent Additive Manufacturing (AM) practices are simplifying this transition (e.g. (de Lange and Rodić, 2013; Porter and Heppelmann, 2014; Sannö et al., 2014)). Even if several examples of best practices adopting CE principles exist (e.g. (The Ellen MacArthur Foundation, 2015)), there is still an urgent need for innovative solutions for making CE a reality (Bocken et al., 2016; Govindan and Hasanagic, 2018; Lewandowski, 2016). These solutions should be defined under the form of innovative Circular Business Models (CBMs). The scientific literature already proposed and classified CBMs (see Table 1). At macro level, CBMs can be divided following the ReSOLVE framework (The Ellen MacArthur Foundation, 2015) into six classes (also named "archetypes"). At micro level, CBMs can be allocated to each class following the OECD's report (OECD, 2017). This way, a set of fourteen sub-classes covering the whole portfolio of available CBMs can be identified.

Table 1. Circular business models classification - adapted from (OECD, 2017; The Ellen MacArthur Foundation, 2015)

Circular Business Models	
CBMs archetypes	**CBMs sub-classes**
Regenerate	Renewable energies
	Bio-/Secondary materials
Share	Co-ownership
	Co-access
	Use-oriented PSSs
	Reuse
	Repair
Optimize	Industrial Symbiosis
	Product-oriented PSSs
Loop	Refurbish/Remanufacture
	Recycling
Virtualize	Result-oriented PSSs
	De-materialize
Exchange	New technologies

Notwithstanding existing archetypes and sub-classes are declining the concept of CBM, they are still not adopted into practice. In literature, this trend is mirrored by a huge amount of research unable in providing instructions on how to implement CBMs in practice (Bocken et al., 2014). Hence, starting from the concept of CBMs – and related ReSOLVE classification – presented by several experts (e.g. (Bocken et al., 2014; The Ellen MacArthur Foundation, 2015)), the paper has a multiple purpose. Firstly, the work wants to detect the most important benefits expected by companies when approaching CE and declining them under the Triple Bottom Line (TBL) perspective of sustainability. Secondly, this research wants to link CE benefits with CBMs through a set of interviews with experts belonging to the Waste from Electrical and Electronic Equipment (WEEE) sector. CBMs considered and analysed are based on the Product-Service System (PSS) concept, given their strong relation with circular benefits (Lieder and Rashid, 2016; Michelini et al., 2017; Pacheco et al., 2019). Experts have been selected from the FENIX project consortium, given the strict coherence of this EU project with the main objectives of this paper. Finally, four use cases from the WEEE sector demonstrate into practice how to link CBMs with CE benefits.

The paper is structured as follows. Section 2 describes the research methodology adopted in this study, by detailing the literature review process and explaining the involvement of the experts in implementing the use cases. Section 3 is dedicated to results coming from both the literature review and experts' interviews. Section 4 presents some discussions on results. Finally, Section 5 provides some concluding remarks and future research streams.

2. Research methodology

Considering the multiple purpose of the paper, also the adopted research methodology presents several perspectives. As shown in Figure 1, the research uses multiple research methods complementing each other and arriving at an answer to the research questions. Firstly, section 2.1 describes the literature review on CBMs and CBM benefits into detail. Secondly, section 2.2 presents how the experts involved in this work have been selected and interviewed. Finally, section 2.3 describes the four use cases exploited to contextualize the results coming from both literature and interviews.

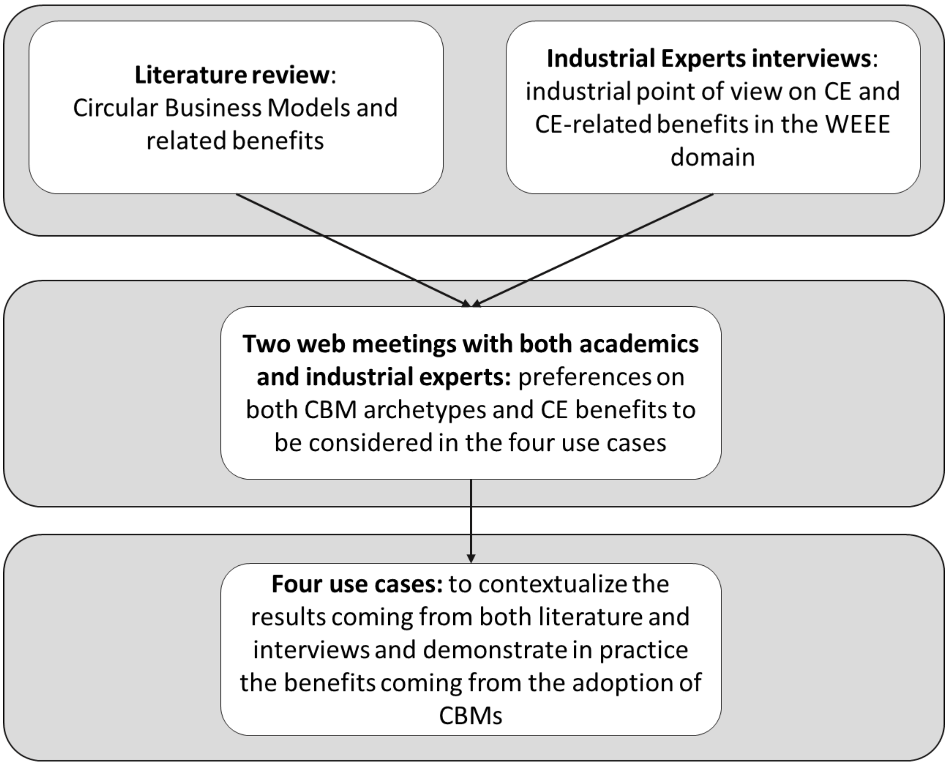

Figure 1. Research Methodology

2.1 Literature review

A systematic literature review (Brereton et al., 2007; Smart et al., 2017; Software Engineering Group, 2007) on scientific articles published (from 2000 up to the first quarter of 2018) in the most popular academic search engines (i.e. Scopus and Science Direct), has been carried out. Trying to remain inclusive and harness the variety in the knowledge base, the relevance criteria were initially guided by the question formulation, i.e. the research scope. Without considering any document type and field content limitations, a total of three searches have been performed, by combining the specific keywords "Circular Economy", "Business Model", "Circular Economy Business Model".

Table 2. Searches by keywords

Queries	**Search engine**

	Scopus	Science Direct
“Circular Economy” AND “Business Model”	728	661
“Circular Business Model”	125	95
“Circular Economy Business Model”	59	35
Total	**912**	**791**

In particular, Figure 2 fully explains the research strategy adopted in the systematic literature review (Smart et al., 2017). After detecting and removing redundancies among the results from the two databases, a first selection by title, abstract and keywords analysis, and a second screening by entire manuscript analysis were performed. The total amount of papers coming from the merge of the different searches has been 283 articles. The research strategy adopted in the systematic literature review is the one described by Smart et al. (2017). Searches on Science Direct and Scopus databases (using the three strings reported in Table 2) led to 1703 results. Moreover, 58 documents were detected through cross-referencing processes and 8 through hand search. Finally, 23 more documents recommended by experts were added to the list. Through the criteria application, the total amount of documents found was reduced to a final set of 283 selected articles. Two authors performed independently the entire process of selection and analysis of the documents for avoiding bias of interpretation during the review. Results obtained by each of them were compared and made consistent to each other.

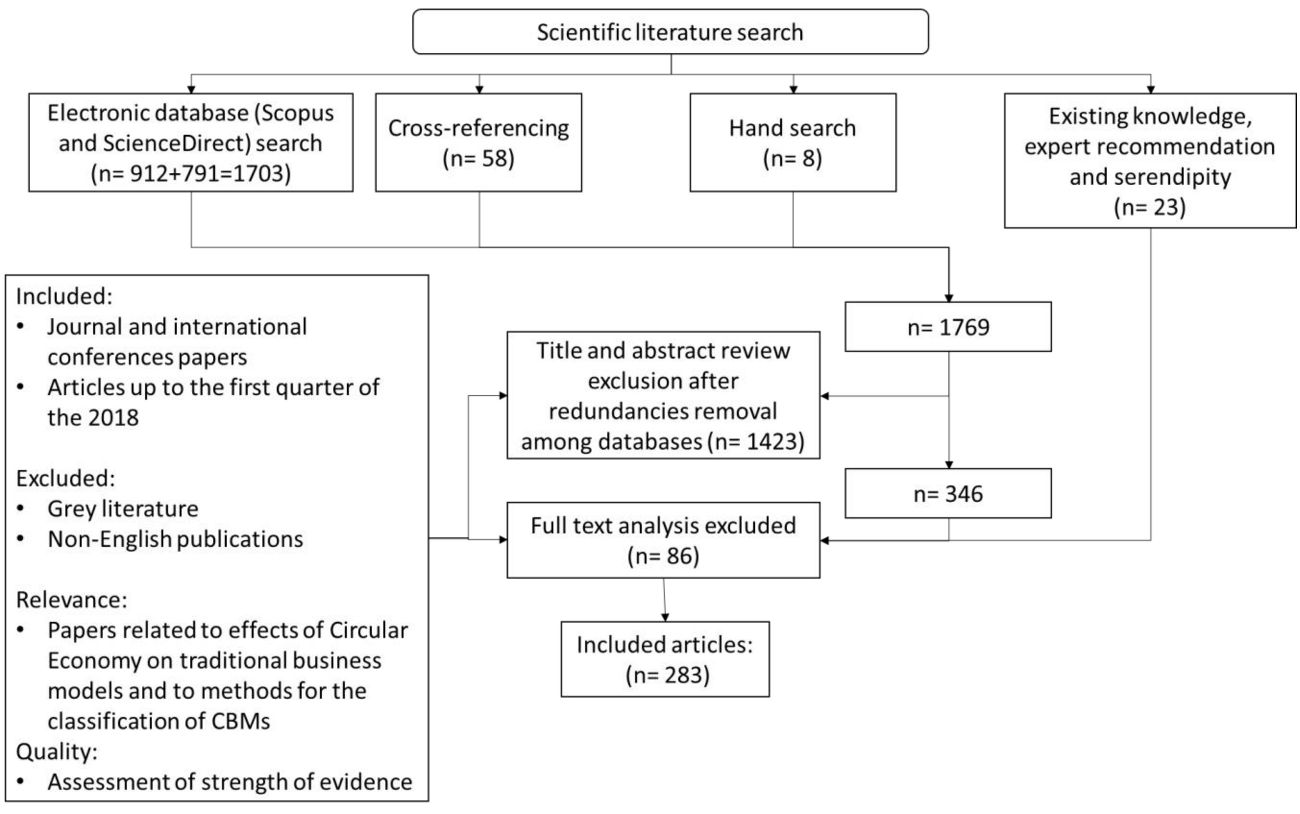

Figure 2. Research strategy (adapted by (Smart et al., 2017))

The 283 articles have been clustered into 8 macro topics (CBM design, Industrial strategies, Governmental policies, Environmental impact, Circular design, Theoretical analysis, Societal impact, New technologies) directly detected and gathered through a keyword analysis, and furtherly declined into 35 micro topics. The detection of benefits coming from a CE adoption focused on the micro topic named "CBM challenges", consisting in 17 documents and belonging to the "CBM design" macro topic. Compared to the entire research stream on CBMs, this area represents a quite under-investigated field, even though challenges and benefits linked to CE represent a pretty strategic topic for triggering the widespread adoption of CE in the industrial common practice.

2.2 Experts' selection and interview

Once identified the CE benefits through the literature analysis, the WEEE sector was selected as the reference context in which focusing this study because of: a) it represents an example of how unsustainable human behaviours can impact on the environment and b) WEEEs embed Printed Circuit Boards (PCBs), one of the most important wastes (Awasthi et al., 2018) in terms of critical raw materials needing for sustainable recovery actions. Both academic and industrial WEEE experts were involved in the assessment of findings coming from the literature. Given the strong affinity of this study with the main objectives of the European H2020 FENIX project (and considering that the use cases described in the following sub-section belong to FENIX), all the experts involved in this research come from to the FENIX consortium. The involved experts (4 academics and 6 industrials) are characterized by a strong and complementary experience in the WEEE industry.
Among academics, the first conducted two decades of environmental research in the field and founded several spin-off companies successfully positioned on the international market. The second founded three spin-off companies and invented ten patents in the field, by working on the valorisation of raw materials and industrial wastes, chemical and biotechnological processes, environmental technologies and bio-hydrometallurgy. The third is expert in sustainable mobility solutions, clean vehicles and technologies, pilot trials design, dangerous goods transport safety and development of training schemes. The last one has a strong experience in materials and processes providing additive manufacturing technological tools.
Among industrials, two of them belong to a WEEE treatment facility, other two deal with 3D printing and 3D scanning, another one works for a producer of nanostructured powder materials.
Industrial experts took part to a set of interviews conducted in the first quarter of 2018, either face-to-face sessions (also with the use cases' owners) or off-line calls. During these interviews, lasted 1 hour each, results from literature review have been presented and validated. Results were gathered to grasp from the experts some preliminary information about the industrial point of view on CE and CE-related benefits, specifically in the WEEE domain. Interviews were not based on a pre-defined questionnaire but on a set of open questions. Finally, two web meetings were organized with all the experts, trying to gather their preferences on both CBM archetypes and CE benefits to be considered in the four use cases.

2.3 Industrial use cases – the FENIX project

The intent of the four use cases is demonstrating into practice the benefits coming from the adoption of CBMs. The use cases considered, singularly characterized by linear supply chains, constitute all together a circular system. In particular, use case 1 represents a hypothetical startup building and selling modular pilot plants. Use cases 2, 3 and 4 focus on three existing companies (to which the selected industrial experts belong to) targeting innovative markets, both potentially linkable with WEEEs and presenting interesting growth rates, as Additive Manufacturing (AM) technologies, 3D printing filaments and customised jewellery.

Use Case 1: The modular pilot plants startup

This use case is represented by a startup building and selling mobile pilot plants dedicated to both recycling of wasted PCBs from WEEEs and recovering of secondary materials, namely precious and non-precious metals and non-metallic fractions. The added value of these plants stays in their ability of transforming recovered materials into valuable secondary raw materials directly adoptable in AM and 3D printing processes, with a full perspective on CE. These modular plants are the followings:

1. An assembly/disassembly module represents the initial stage. It automatically disassembles wasted PCBs, by selecting either valuable components to be reused or hazardous components to be dismantled before recycling,
2. A green chemical material recovery module constitutes the central stage. It shreds disassembled PCBs, separate and recover materials embedded into them, by making them ready for AM applications,
3. An AM module represent the last stage. It receives the recovered materials from the previous one and transform them both in valuable raw materials for AM applications, semi-finished and finished products. In case of semi-finished products, the assembly/disassembly module could represent the final step of the process.

Use Case 2: The 3D printing metal powders producer

This use case is focused on the recovery of basic metals from wasted PCBs. These materials could represent an alternative source of valuable raw materials for the AM industry. AM processes are affected by stringent powders requirements, asking for precise characteristics (e.g. shape, dimension, purity, etc.) of selected raw materials. However, the market is not always able to standardize these features and AM companies need dedicated departments for testing and modifying these materials basing on customer requirements. Secondary raw materials from wasted PCBs could allow AM companies in reducing this variability.

Use Case 3: The customized jewels manufacturer

This use case is focused on the recovery of precious metals from wasted PCBs. These materials could be reused in the production of customized jewels. The customization process will follow a sequence of steps. Firstly, the object to be reproduced in a jewel will be 3D scanned through a dedicated equipment, by gathering a highly accurate 3D mesh of it. Secondly, the 3D mesh will be exploited for the creation of a wax-based die. Finally, the obtained die will be filled in with precious metals to obtain the customized jewel. Secondary raw materials from wasted PCBs could get back their original market value.

Use Case 4: The 3D printing advanced filaments producer

This use case is focused on the recovery of basic metals and non-metal fractions from wasted PCBs for the manufacturing of 3D printing reinforced filaments. Considering issues as mechanical strength, chemical analysis, mixture technologies, toxicity and processing, several types of materials will be tested in laboratory as fillers for reinforcing thermoplastics used in 3D printing filaments for Fused Deposition Modelling (FDM) technologies.

3. Main findings

A systematic literature review was conducted aiming to identify the most important benefits expected by companies when approaching a CE strategy, by creating a reference list. In a second stage, the experts supported, through a set of direct interviews, the refining of this list. As discussed in Section 4, the aggregation of these two views allowed the selection of the main benefits expected to be more consistent with the WEEE sector.

3.1 Current state of the art on CE-related benefits

The current work gathered the benefits deriving by CE adoption and grouped them in macro categories, by easing industrials during the selection of the most important ones expected from the adoption of CBMs. A relevant contribution was given by Schaltegger et al. (2011) who defined the concept of business case for sustainability, or the creation of economic success with a voluntary intention of contributing in environmental and social issues. Based on this concept, they proposed the core drivers of a business case for sustainability:

- Sales and profit margin (Porter and Linde, 1995),
- Costs and costs reduction (Christmann, 2000; Epstein, 1996),
- Reputation and brand value (Jones and Rubin, 2001),
- Risks and risks reduction (Schaltegger and Wagner, 2006),
- Attractiveness for employees (Ehnert, 2009; Revell et al., 2010),
- Innovative capabilities (Cohen and Winn, 2007; Pujari, 2006; Schaltegger and Wagner, 2011).

Collins et al. (2010) identified in costs reduction (e.g. through resource efficiency) the most important driver, followed by regulatory risks management, staff and customers attraction and retaining, market share increase and good publicity.

Schaltegger et al. (2011) dealt with the existing links between companies' success and environmental, social and economic views, trying to explain how these links can be managed, enhanced or renewed. To this aim, four BM pillars (value proposition, customer view, infrastructure and network of partners, financial aspects) were identified.

Park et al. (2010) investigated challenges and opportunities for companies in striking a better balance between economic growth and environmental stewardship in China. Basing on three case studies from the electronics industry, they identified in cost reduction, new revenue streams, organizations and supply chains resiliency and regulatory compliance four ways for creating environmental and economic value.

Roos (2014) proposed a framework for green value creation and realization in BMs. Creating a multidimensional value for stakeholders by adopting a service-oriented approach and get the largest share of this value from paying customers or stakeholders represent the two elements for being successful.

McKinsey Global Institute (2011) identified resource-related value creation levers for businesses, grouping them in three macro areas: a) growth, b) return on capital and c) risk management. Growth means a better understanding of resource-related opportunities in new market segments and geographies, innovation and new products to meet customers and company needs. Return on capital proposed green sales and marketing, sustainable value chains and sustainable operations. Risk management is divided in regulatory management, reputation management and operational risk management.

Franco (2017) conducted an inductive qualitative study to investigate CE in different industries, by highlighting as the number of component parts in a product and the availability of ecological alternatives in the market represent a challenge for firms towards CE. Subsequently, (Novak and Eppinger, 2001) identified in complexity of products another challenge towards CE.

Sannö et al. (2014) detected the main challenges and perspectives composing an environmental sustainability framework. Four sub-categories at the base of this framework has been detected: a) resource efficiency, b) enablers for change and innovation, c) CBM research and d) emerging sustainable technologies.

de Lange and Rodić (2013) found three reference aspects needed to shift towards CE. Firstly, there is the need to manage product design and manufacturing to make the exploitation of resources more efficient through technical and biological cycles. Secondly, PSSs must be embedded in BMs. Thirdly, there is the need to focus on natural relationships among stakeholders, by enabling circular value chains through collaboration and long-term relations. Based on these three aspects, they also defined which actions should be practically performed in product manufacturing.

Rizos et al. (2016) investigated enablers and barriers for Small and Medium Enterprises (SMEs) in adopting CE. Results identified in: a) saving material costs, b) creating competitive advantages and c) creating new markets the main enablers to go towards CE. On the other side, company culture of staff and managers, networking with other SMEs, be supported by the demand network, proposing attractive BMs, external recognition of green BMs, personal knowledge and government support like the most important barriers.

Romero and Rossi (2017) attempted to demonstrate the compatibility of CE and lean principles in the context of PSSs, by proposing Circular Lean PSS supporting and fostering three main principles:

- Preserve and enhance natural capital, by controlling finite stocks and balancing renewable resources flows;
- Optimize resource yields, by circulating products, components, and materials at the highest utility both in technical and biological cycles;
- Foster system effectiveness, by revealing and designing out for negative externalities.

Basing on the literature review previously described, detected benefits were categorized based on the Triple Bottom Line (economic, environmental and social). Subsequently, they were grouped in macro categories to ease industrials in detecting the most important ones when adopting a CBM. A brief explanation of each benefit detected is reported below:

Economic benefits:

- Reducing overall costs (or improving sales and profit margin). From one hand, reducing costs concerns both with products and processes, starting from raw materials purchasing up to transportation of finished products. In this sense, reduced costs are not only focused on providers, but also customers during the use, service delivery and disposal phases of the product. Lower energy or maintenance costs through a better management of equipment, cost-efficient relationships and partnerships with suppliers are some good examples. From another hand, improving sales and profit margins means balancing cost reduction for customers with new cost structures able to increase profitability. This way, new strategic partnerships (e.g. cooperation) could be required to overcome market barriers. Again, new customer relationships could contribute in diversifying revenue streams.
- Reducing business risks. It can be achieved through reputation management (getting credits and reducing reputation risks through proper stakeholder management) and through operational risk management (managing risk of operation disruptions from resource scarcity, climate change impacts or community risks). Risks can be reduced through product-services, service-relationships with customers (increasing customers' loyalty). Resources, activities and partnerships can be set up to minimize internal and external risks.
- Opening new revenue streams. It can be achieved through effective lifecycle management of ICT products and internal resources. In addition, the business portfolio can be configured basing on resource trends.
- Reducing product/process complexity. Complexity could be reduced by decreasing the number of components to be specified, produced or procured. This way, modularity of products could also

be enhanced. The development of basic materials and components and the demand inducement from well-located players in the supply chain appeared to be good practices going in this direction.
- Improving competitive advantage. Innovations (in terms of both new products, functions, services and BMs) could be introduced to gain competitive advantage.

Environmental benefits:

- Complying with environmental regulations. A good regulatory management is required to mitigate risks from changes in current regulations.
- Reducing environmental impacts. It can be achieved by adopting closed loop energy mapping (e.g. through renewable energy source), CO_2 neutral lifecycle of products, using pure materials with known and healthy properties.
- Improving resource efficiency. It can be achieved in products (e.g. using renewable resource flows and by eliminating wastes), in production (e.g. through sustainable production techniques, regenerating energy during production or more efficient use of machines) or in logistics.
- Improving supply chain sustainability. It can be achieved by improving organizational and supply chain resiliency (e.g. through environmental practices like recycling), resource management or an accurate selection of suppliers.

Social benefits:

- Enhancing reputation and brand value. Sustainability becomes a distinctive element of good corporate reputation and a (green) marketing feature of the brand increasing customer loyalty. Reputation and brand value can be increased through strategic partnerships with sustainability leaders and the enhancement of sustainability performance to achieve good rating in sustainability indexes and funds. Brand value can also lead to attract employees through sustainable value proposition, increase employee motivation, improve customer service, enhance the quality of activities, resources and partnerships.
- Reaching new markets & countries. Understanding different market needs for efficiency and how to change behaviours and drivers of mind-set change becomes fundamental in global markets.
- Improving health & safety in workplaces. It is related with the concept of attracting new employees and improving their motivation. Healthier and safer workplaces could also have a positive impact on the environment.
- Developing innovative skills and knowledge. Innovative solutions to sustainability problems can improve customer retention. However, it may require new activities, resources and partnerships, higher innovation potential and expectations for profitable innovations leading to an increased shareholder value.

Considering what reported in Table 3, 4 and 5, some information can be gathered about the current focus of the literature on CE-related benefits and existing gaps. Just by numbering articles focused on CE-related benefits, it is possible to see that some of them are more frequent than others. The most important economic benefit (see Table 3) is the reduction of overall costs, followed by opening new revenue streams, improving competitive advantage and reducing product/process complexity. Reducing business risks (either operation or reputation), even if considered among important benefits, it doesn't seem to be as important as the others.

Table 3. CE-related economic industrial benefits from literature

Author	**Economic benefits**				
	Reducing overall costs	**Reducing business risks**	**Opening new revenue streams**	**Reducing product/process complexity**	**Improving competitive advantage**
(Christmann, 2000)	x				

(Epstein, 1996)	x				
(Porter and Linde, 1995)	x				
(Schaltegger and Wagner, 2006)		x			
(Schaltegger et al., 2011)	x	x			
(Park et al., 2010)	x		x		
(Jing and Jiang, 2013)			x		
(Roos, 2014)			x		
(McKinsey Global Institute, 2011)	x	x	x	x	x
(Franco, 2017)				x	
(Sannö et al., 2014)				x	x
(de Lange and Rodić, 2013)			x	x	x
(Rizos et al., 2015)	x				x
(Romero and Rossi, 2017)					x
(Bertoni, 2017)	x	x			x
(Lindström, 2016)	x		x		
(Velte and Steinhilper, 2016)				x	
(Schischke et al., 2016)				x	
(Jawahir and Bradley, 2016)	x				
(Kane et al., 2017)	x				
(Masi et al., 2017)	x	x	x		
Total	**12**	**5**	**7**	**6**	**6**

The environmental perspective deserved a high attention in literature. The improvement of resource efficiency and the reduction of environmental impact resulted to be the first and the third most cited benefits coming from a CE adoption (see Table 4). Then, improving supply chain sustainability, in terms of both organizational and supply chain resiliency, was quite considered. Finally, complying with environmental regulation had a marginal interest.

Table 4. CE-related environmental industrial benefits from literature

Author	**Environmental benefits**			
	Complying with environmental regulations	**Reducing environmental impacts**	**Improving resource efficiency**	**Improving supply chain sustainability**
(Park et al., 2010)	x			x
(Jing and Jiang, 2013)		x	x	
(Roos, 2014)		x	x	
(McKinsey Global Institute, 2011)	x	x	x	x
(Franco, 2017)		x	x	x
(Sannö et al., 2014)		x	x	
(de Lange and Rodić, 2013)		x		
(Romero and Rossi, 2017)		x	x	
(Tecchio et al., 2017)		x	x	
(Bertoni, 2017)	x			x
(Lindström, 2016)		x	x	x
(De los Rios and Charnley, 2017)			x	
(Ripanti et al., 2016)				x
(Rashid et al., 2013)			x	
(Jawahir and Bradley, 2016)			x	

(Kane et al., 2017)			x	
(Lieder and Rashid, 2016)		x	x	
(Masi et al., 2017)		x	x	
Total	**3**	**11**	**14**	**6**

The social perspective deserves to be furtherly deepened (see Table 5), since it resulted the less discussed in literature. Among the benefits pertaining to this class, the most important one is the enhancement of reputation and brand value through strategic partnerships and improvements in sustainability performances. Furthermore, the development of innovative skills and knowledge, together with the achievement of new markets and countries, deserved a good importance among the experts. Finally, the less cited benefit is the improvement of health and safety in workplaces.

Table 5. CE-related social industrial benefits from literature

Author	**Social benefits**			
	Enhancing reputation and brand value	**Reaching new markets & countries**	**Improving health & safety in workplace**	**Developing innovative skills and knowledge**
(Cohen and Winn, 2007)				x
(Pujari, 2006)				x
(Schaltegger and Wagner, 2011)				x
(Schaltegger et al., 2011)	x			x
(Jing and Jiang, 2013)	x			
(Roos, 2014)	x			
(McKinsey Global Institute, 2011)	x	x		
(Sannö et al., 2014)		x		
(Rizos et al., 2015)		x		
(Jones and Rubin, 2001)	x			
(Ehnert, 2009)	x			
(Revell et al., 2010)	x			
(Bertoni, 2017)	x	x		
(Lindström, 2016)			x	x
(Masi et al., 2017)	x			
Total	**9**	**4**	**1**	**5**

In general, CE-related benefits can be grouped into three classes, common, less common and uncommon ones. Common CE-related benefits described in literature are represented by resource efficiency, costs reduction and environmental impacts. Less common ones are focused on brand reputation, revenue streams, product/process complexity, competitive advantage and supply chain. Finally, uncommon benefits are represented by business risks, skills and knowledge, new markets, regulations and health and safety. What is evident from the presented literature is that there is a big research gap in terms of new ideas on how to involve final users in CE. Just in very few cases the experts present innovative ideas and implement them in practice. Again, the social aspect related with CE adoption is rarely considered by the experts if compared with the economic and environmental one. Since the FENIX project tries to fill in this research gap through the involvement of final users within CBMs, experts and use cases have been selected from its consortium.

3.2 Expected benefits selection

In order to gather information from the experts about the expected benefits related with the adoption of CE practices in the WEEE domain, three face-to-face interviews have been conducted in the first quarter of 2018. The overall summary about expected benefits is reported in Table 6, 7 and 8, divided in three sustainability views. Just by numbering the preferences, it is possible to specify (from a different perspective than literature) what are the benefits expected by a generic company from the adoption of CE practices. What must be evidenced here is the high importance reached by social aspects (e.g. developing innovative skills and knowledge within the company and enhancing brand reputation and value). This last point seems to be as much important as costs reduction or resource efficiency improvement. A second set of benefits is a mix of both economic and environmental ones. High attention is given to reducing the environmental impacts. Then, reduction of business risks, improvement of competitive advantage, supply chain sustainability and provisioning and opening new revenue streams share a lower rate. Finally, complying with environmental regulations, reaching new markets and countries, reducing product/process/supply chain complexity and improving health and safety of workplaces are scarcely considered by the experts.

Table 6. CE-related economic benefits selected by experts

Experts	**Economic benefits**				
	Reducing overall costs	**Reducing business risks**	**Opening new revenue streams**	**Reducing product / process complexity**	**Improving competitive advantage**
E1	x	x	x		x
E2	x	x	x		x
E3	x		x		x
E4	x				
E5		x			
E6		x			
E7	x	x	x		x
E8	x				x
E9	x	x			x
E10	x		x		
Total	**8**	**6**	**5**	**0**	**6**

Table 7. CE-related environmental benefits selected by experts

Experts	**Environmental benefits**					
	Complying with environmental regulations	**Reducing environmental impacts**	**Improving resource efficiency**	**Improving supply chain sustainability & provisioning**	**Reducing supply chain complexity**	**Enhancing reputation and brand value**
E1	x	x	x		x	x
E2	x	x	x	x	x	x
E3		x	x		x	
E4			x	x		x
E5		x		x		x
E6		x	x	x		x
E7	x	x	x		x	x
E8			x	x		x
E9				x	x	x
E10		x	x			
Total	**3**	**7**	**8**	**6**	**5**	**8**

Table 8. CE-related social benefits selected by experts

Experts	**Social benefits**

	Reaching new markets & countries	Improving health & safety in workplace	Developing innovative skills and knowledge
E1	x		x
E2	x		x
E3			x
E4			x
E5			x
E6			x
E7	x		x
E8			x
E9			
E10			x
Total	**3**	**0**	**9**

3.3 CBM archetypes selection

Starting from the CBMs classified in Table 1, the second purpose of this paper was the selection of the most suitable CBMs to be adopted in the WEEE sector through the support of the experts. The overall perspective coming from the experts is reported in Table 9. What needs to be clarified here is that those CBMs not considered by the experts like suitable for the WEEE sector have not been reported. It is clear from Table 9 as the best option (based on majority) enabling circularity refers to recycling strategy supported by PSS-based CBMs, like 1) product-oriented, 2) use-oriented and 3) result-oriented ones (Tukker, 2004). PSS-based CBMs will be better described in the next section 4.

Table 9. Circular Business Models selected by experts - adapted from (The Ellen MacArthur Foundation, 2015) and (OECD, 2017)

Experts		**CBMs**					
	CBMs archetypes	**Share**	**Optimize**	**Loop**		**Virtualize**	**Exchange**
	CBMs sub-classes	**Use-oriented PSSs**	**Product-oriented PSSs**	**Refurbish / Remanufacture**	**Recycling**	**Result-oriented PSSs**	**New technologies**
E1					x		
E2		x			x	x	x
E3					x	x	
E4		x	x		x	x	x
E5		x			x	x	
E6		x			x	x	
E7					x		
E8		x	x		x	x	x
E9			x	x	x	x	x
E10		x			x	x	
Overall perspective		**6**	**3**	**1**	**10**	**8**	**4**

Once both suitable CBMs and expected benefits related with CE have been identified, the final stage was the integration of these two views in a common assessment matrix. The following section 4 reports the relations expected by the experts on different use cases.

4. Discussions

The previous section identified in PSS-based CBMs the most suitable ones to be adopted in all the use cases within the WEEE sector. A combination of the four use cases is completely based on a multiple perspective, considering in parallel both a production plant and a final product view.

In the first use case, a product-oriented CBM could be adopted. Here, the focus of a company would be double. From one side, the focus could be selling modular pilot plants able to recycle WEEEs, recover materials and transform these materials in AM-ready raw materials. From another side, the company could sell, depending on the adopted AM process, either 3D printed jewels, metal powders for AM processes or 3D printing filaments. In the second use case – trying to increasingly involve both industrial and private customers – a result-oriented CBM could be adopted. Here, a company could decide to sell a modular service, by exploiting the potential offered by each module constituting the pilot plant in terms of disassembly, recycling, recovery and refining. This way, the object of transaction should be the use of the pilot plant (or single modules), by shifting from the customer to the PSS provider both the ownership and the maintenance of the pilot plant along the whole lifecycle. In the third use case – where the involvement of people into the process should be very high – a use-oriented CBM could be adopted. Here, a company could decide to sell the access to the pilot plant to final users. This way, the full potential offered by the pilot plant could be exploited not only by industrials, but also by private customers willing to implement their ideas, following the logic of fablabs. After a brief description of the main logics driving the three different PSS-based CBMs, a detailed description of each use case will be presented. Figure 3 shows the existing relation between the four use cases selected in this work.

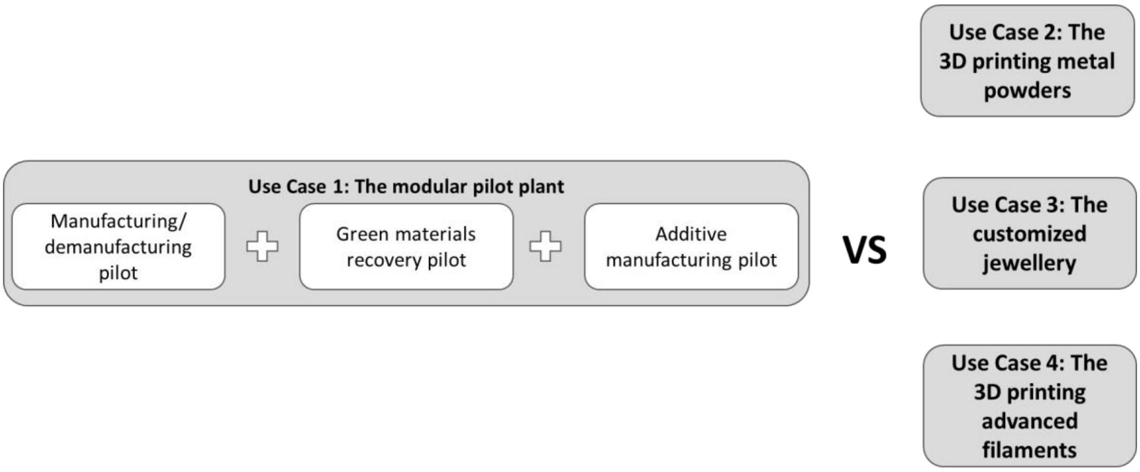

Figure 3. Multiple perspective of the four use cases – modular pilot plant (use case 1) vs final products views (use cases 2, 3, 4)

Starting with the use case 1 (left side of Figure 3), it is possible to adopt three kinds of PSS-based CBMs. They are product-oriented, use-oriented and result-oriented ones. Firstly, a product-oriented CBM could be adopted with the simple selling of modular pilot plants (or single modules). Secondly, a use-oriented CBM could be implemented if the final aim will be selling the access to the pilot plant (hypothesising that final users will have the right skills to exploit it). Finally, a result-oriented CBM could be adopted if the final aim will be selling several services (e.g. disassembly, materials recovery and additive manufacturing) related to each module constituting the pilot plant. A summary of these CBMs is presented in Figure 4.

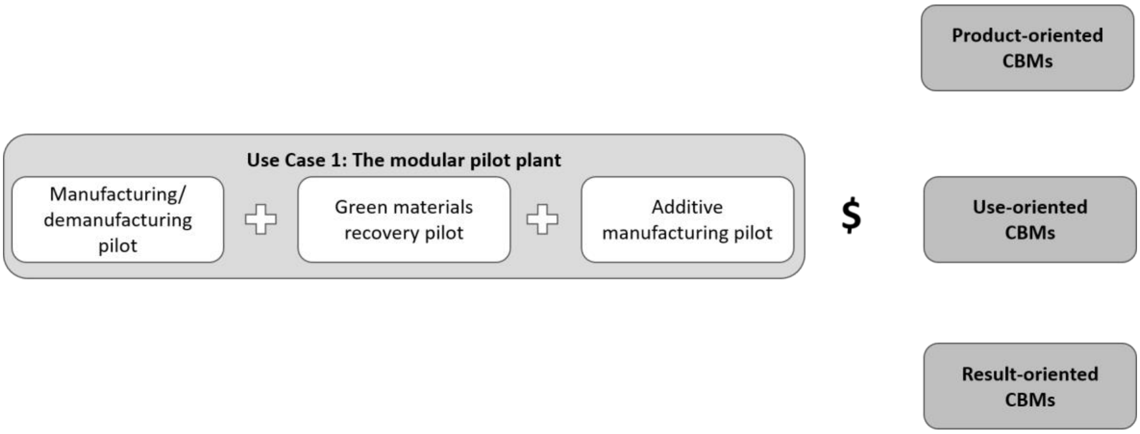

Figure 4. CBMs related with use case 1

Table 10 depicts the relation of selected CBMs with the benefits expected by the experts.

Table 10. The assessment matrix - use case 1

Use Case 1 – Selected benefits	**Selected CBMs**		
	Product-Oriented PSS	**Use-Oriented PSS**	**Result-Oriented PSS**
Reducing overall costs	U	U	U
Reducing business risks	P	P	U
Opening new revenue streams	-	P	P/U
Improving competitive advantage	P/U	P/U	P/U
Complying with environmental regulations	P/U	P/U	-
Reducing environmental impacts	P/U	P/U	P/U
Improving resource efficiency	P/U	P/U	P/U
Improving supply chain sustainability & provisioning	U	U	P
Reducing supply chain complexity	U	U	P
Enhancing reputation and brand value	P	U	U
Reaching new markets & countries	-	-	P
Developing innovative skills and knowledge	P/U	U	U

P= PROVIDER; U= USER

Considering what reported in Table 10**,** a first clarification must be given about nomenclature (it will be replicated also in the next tables). The symbol "U" means that the experts identified those benefits enabled by a specific CBM from the perspective of final users (or those who will use the pilot plant). Instead, the symbol "P" identifies those benefits enabled by a specific CBM from the perspective of providers (or those producing the pilot plant itself). The symbol "P/U" identifies those benefits in common between providers and users. Finally, the symbol "-" indicates that the specific benefit is not expected to be reached neither by providers nor users. Always considering what reported in Figure 3 (right side), the type of CBMs adoptable in use cases 2, 3 and 4 is different. In these cases, it is possible to adopt just two out of three PSS-based CBMs. They are product-oriented and result-oriented ones. Firstly, a product-oriented CBM could be adopted if the final aim will be selling products (e.g. metal powders, 3D printed jewels or 3D printing filaments). Secondly, a result-oriented CBM could be adopted if the final aim will be selling several services related to those products enabled by the combination of the modules constituting the pilot plant. More specifically, use case 2 is related with the production of green metal powders for AM processes. Starting from electronic scraps (that could be brought to the plant by either private or industrial customers), final products will be metal powders. Like described before, the business perspective could be either selling metal powders or metal powdering services (see Figure 5).

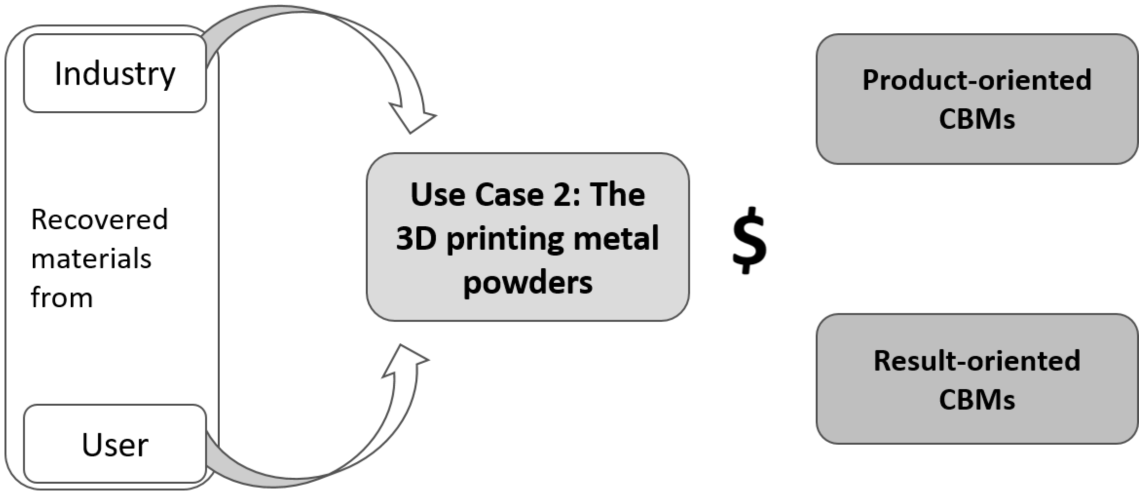

Figure 5. CBMs related with use case 2

Table 11 depicts the relation of selected CBMs with the expected benefits related with use case 2.

Table 11. The assessment matrix – use case 2

Use Case 2 – Selected benefits	**Selected CBMs**	
	Product-oriented PSS	**Result-oriented PSS**
Reducing overall costs	P/U	P/U
Reducing business risks	U	U
Improving competitive advantage	P/U	P/U
Improving supply chain sustainability & provisioning	P	P
Reducing supply chain complexity	P	P
Enhancing reputation and brand value	U	U

P= PROVIDER; U= USER

Use case 3 is related with the production of 3D printed jewels from green precious metals. Starting from electronic scraps (that could be brought to the plant by either private or industrial customers), final products will be 3D printed jewels. Like described before, the business perspective could be either selling jewels or 3D printing services for jewellery (see Figure 6).

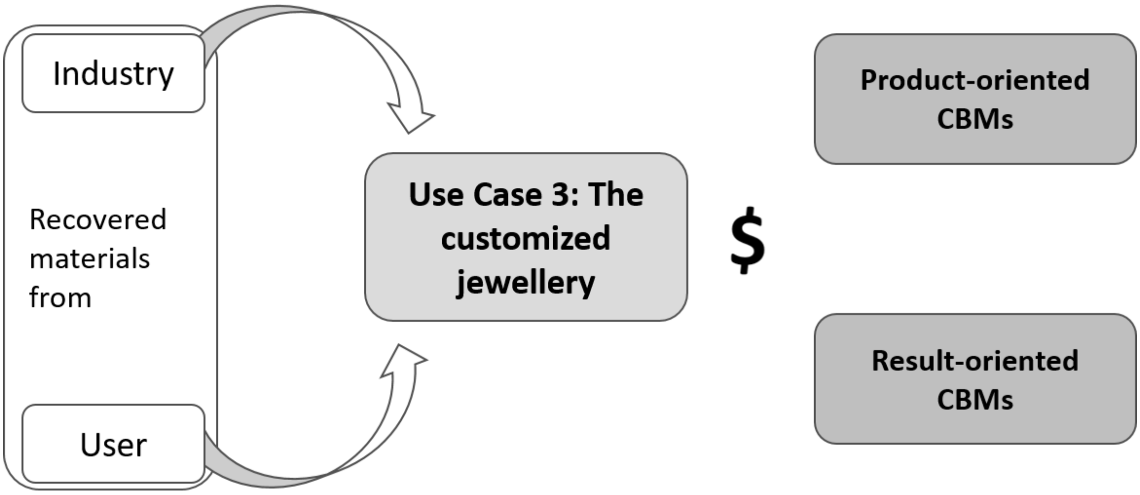

Figure 6. CBMs related with use case 3

Table 12 depicts the relation of selected CBMs with the expected benefits related with use case 3.

Table 12. The assessment matrix – use case 3

Use Case 3 – Selected benefits	**Selected CBMs**	
	Product-oriented PSS	**Result-oriented PSS**
Reducing overall costs	P	P
Reducing product/process complexity	P	P
Improving competitive advantage	P	P
Improving resource efficiency	P	P
Improving supply chain sustainability & provisioning	P	P
Enhancing reputation and brand value	P	P/U
Reaching new markets & countries	P	P
Reaching new markets & countries	P	P
Developing innovative skills and knowledge	P	P

P= PROVIDER; U= USER

Finally, use case 4 is related with the production of 3D printing filaments from WEEEs. Starting from electronic scraps (that could be brought to the plant by either private or industrial customers), final products will be advanced filaments. Like described before, the business perspective could be either selling these products or selling AM services (see Figure 7).

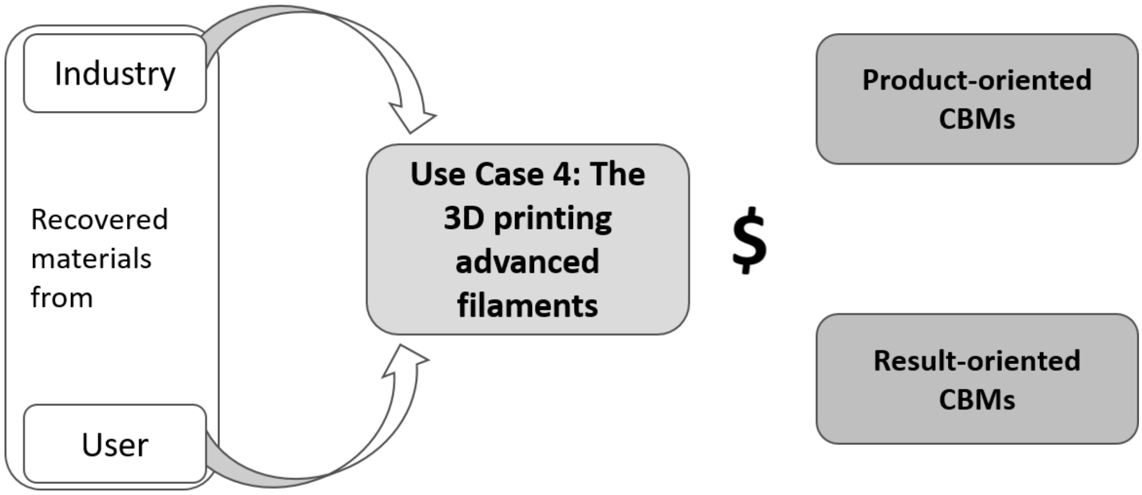

Figure 7. CBMs related with use case 4

Table 13 depicts the relation of selected CBMs with the expected benefits related with use case 4.

Table 13. The assessment matrix – use case 4

Use Case 4 – Selected benefits	**Selected CBMs**	
	Product-oriented PSS	**Result-oriented PSS**
Reducing overall costs	P/U	P/U
Improving competitive advantage	P/U	P/U
Improving resource efficiency	P/U	P/U
Improving supply chain sustainability & provisioning	P/U	P/U
Enhancing reputation and brand value	U	U
Developing innovative skills and knowledge	P/U	P/U

P= PROVIDER; U= USER

What is evident from all these tables is that there is not a prevalent CBM able to fill in great part of the expected benefits. Use-oriented and result-oriented CBMs will allow to better cope with social aspects related to CE, with a higher involvement of final users. Finally, when a certain benefit has occurred it doesn't necessarily mean its counterpart could not occur. Indeed, the achievement of CE benefits can be supported by the adoption of specific practices and, on the other hand, hindered by several barriers that could affect and compromise their full attainment. Both practices and barriers can occur in either internal or external environments and they can be related to one or more stakeholders. Govindan and Hasanagic (2018) selected 34 CE practices and gathered them into eight clusters based on functional aspects of CE (Governance initiatives, Economic initiatives, Cleaner production, Product development, Management support, Infrastructure, Knowledge, Social and culture). They also selected 39 barriers classified into eight clusters (Governmental issues, Economic issues, Technological issues, Knowledge and skill issues, Management issues, Circular economy framework issues, Culture and social issues, Market issues). The adoption of these CE practices could lead in achieving the benefits reported above but also, due to the existing barriers, their related disadvantages and/or adverse consequences. How CE practices and barriers could lead to or hamper the achievement of certain CE benefits must be better defined and clarified. The proposal in future researches of a thorough framework able to lead practitioners along the CE path could be useful.

5. Conclusions

This work identified both the benefits expected by companies approaching a CE strategy and the most suitable CBMs to be adopted within the WEEE domain. The detected benefits were declined according to the TBL dimensions of sustainability (economic, environmental and social). Regarding the two concepts sustainability and CE, it has been found that in the industrial context introducing sustainability could be often functional to a better understanding of CE and to the perception of its related benefits by practitioners. In literature the sustainability concept, especially under the social perspective, appeared several times in the place of CE. Sustainability can thus be considered as the first step on companies' path to be pursued to go down the river of CE. Moreover, three types of PSS-based CBMs (product-oriented, use-oriented and result-oriented) were identified. For their identification, a multiple perspective has been considered. Firstly, a state-of-the-art analysis allowed the definition of expected benefits deriving from the CE adoption. Secondly, a set of dedicated interviews, with both academic and industrial experts belonging to the WEEE sector, allowed, from one side, the identification of the most suitable CBMs among those detected in literature, and, from another side, the selection of the most important benefits expected from the adoption of CE practices. Together, the integration of both the scientific and industrial perspective, allowed to identify existing relations between CBMs and expected benefits to be considered within the four use cases belonging to the WEEE sector. In addition, a distinction among CBMs related to the pilot plant itself and those related with specific final products has been done. Trying to sum up all the findings coming from this work, it is possible to assert that PSS-based CBMs are renown both by the scientific and industrial community like the most suitable ones to achieve circularity. In addition, this kind of BMs is considered as the most appropriate for improving the involvement of common people in current industrial processes. This way, final customers become co-producers in the value-creation process. In this term, the modular pilot plant considered in this paper represents a great option to increase the involvement of final customers into the circular loop, also supported by the adoption of new technologies belonging to the Industry 4.0 context (Sassanelli et al., 2018). Another point suggested by experts is the need to focus on "Exchange CBMs", or CBMs focused on the adoption of new technologies. The whole selection of use cases presented in this paper follow this logic.

More in general, the results obtained through this research could be considered also in different application fields to furtherly explore the topic. The set of benefits connected to the adoption of CBMs can be indeed considered as a common basis to analyze different sectors and contexts as for WEEEs. Benefits can represent the starting point for researchers to furtherly explore this research stream, for governments to better plan and act also choosing the most suitable CBM to be adopted, and finally for industrials to be involved and guided in a more proficient way towards circularity, thanks to a major awareness of the advantages that they could achieve employing a specific CBM.

Finally, the results of this research provide to academics a set of benefits, categorized on the base of the TBL of sustainability that can disclose new research opportunities and represent the starting point for several further researches. Namely, a state-of-the-art analysis of the extant literature about CE and Industry 4.0 could be useful to understand the common areas of these macro research streams. A methodology could be needed to be able to quantify the circularity performance of CBMs (Sassanelli et al., 2019). A better understanding of what kind of PSS design and development practices could foster circularity would support manufacturers in switching towards a PSS-based CBMs. In addition, the interaction among the benefits detected in this research with CE practices and barriers provided in literature could be better investigated. Indeed, when a certain benefit has occurred it doesn't necessarily mean that its counterpart could not occur. The achievement of CE benefits can be supported by the adoption of specific practices and, on the other hand, hindered by several barriers that could affect and compromise their full attainment. Both practices and barriers can occur in environments either internal or external to the company and involve one or more stakeholders. A framework able to lead practitioners along the CE path could be useful to better understand which of the detected benefits can be reached through CBMs adoption depending on the practices adopted and the stakeholders involved.

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