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Building PSS-based circular business model canvases: an application in the waste from electrical and electronic equipment context

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***Abstract*— Circular Economy (CE) is becoming even more important for companies. Especially at product End-of-Life (EoL) level, companies must cope with the adoption of circular practices within their well-established business models to turn into Circular Business Models (CBMs), often Product-Service System (PSS) based. However, in very limited cases this transition is supported by a real exploration and detailing of the elements and assets needed to address the specific circular value propositions, even more by a quantification and continuous monitoring of their real implementation. The Business Model Canvas is a valuable method to make the first step. It helps to determine, also for these business model, the key partnerships, resources and activities related to the costs to be sustained, and the channels, customers relationships and segments that could be capable to generate revenues. The aim of this paper is, then, to explore which is the set of feasible and possible PSS-based CBMs, determining and characterizing each of them through the application of the Business Model Canvas method.**

Keywords—Circular Business Model, Business Model Canvas, Product-Service Systems, Circular Economy

I. INTRODUCTION

Circular Economy (CE), grounded on the concept of sustainable development [1], is one of the major paradigms of the last decades [2], pushed by multiple actions launched by policy makers worldwide. At the European level, the Commission has recently developed the Green Deal [3] to convert Europe in a resource efficient and competitive economy and lead the world as the first climate-neutral continent by 2050. These kinds of actions provide new guidelines to advance the use of resources in an efficient way through CE embracement and shrink pollution to restore biodiversity.

Manufacturing is considered a main strategic industry to bolster through CE embracement the achievement of sustainable development, detailed in 17 sustainable development goals by United Nations [4]. Indeed, recently, the concept of circular manufacturing was introduced [5], [6], also proposing plenty of researches on how guide manufacturers to implement CE. Based on some recent literature reviews in the CE context, the most common Circular Business Models (CBMs) are Product-Service System (PSS)-based (mainly use-oriented PSSs, not neglecting product- and result- oriented ones) [7]. Each of these CBMs can both trigger several benefits under the threefold Triple Bottom Line (TBL) perspective [8] and unveil strategic potentialities towards CE in terms of addressing recycling practices.

What is evident from the literature is the big research gap in terms of how to practically transform a linear BM into a circular one, with very few cases implementing CE into practice. In addition, benefits coming from the implementation of CE within companies are not always clear to managers. This can be due to the fact that while many researches have been conducted to explore the different facets related to the CE implementation (i.e., CBMs [7], [9], CE benefits [8], managerial [10] and design [11]–[13] practices, relevance for CE of the I4.0 [14], [15] and simulation [16] technologies), companies have still to face with a shortage of knowledge on how to actually combine all these CE-related principles in their Business Models (BMs) with the final aim of turning their linear BM into circular ones. These CBMs are often Product-Service System (PSS) based [7], [17], and thus can be categorized as product-, use-, or result-oriented [18], [19]. A research, actively involving industrials, should be conducted for verifying and better comprehending which kind of PSSs, or CBM archetypes, could better back the adoption and achievement of CE and which benefits could be obtained by companies [8]. A well-known consolidated tool to develop BMs, able to keep both the company and customer perspective, is the BM Canvas [20]. Assuming the value proposition as the core of the BM Canvas, the left part of the model (constituted by key partners, activities and resources and resulting in costs) deals with the efficiency in addressing such value, while the right part (composed by customer relationship, channels and customer segments, and resulting in revenue streams) is more related with the sharing of such value. Basing on the different perspectives (i.e., reference final product delivered, reference PSS) different BM Canvas will be developed and compared. One of the final aims of this research is trying to assess if the BM Canvas is suitable (or not) to underline differences among similar CBMs, by checking each of the nine constituting elements. To do this, this paper applies the BM Canvas to the CE context with the aim of defining the main characteristics of BM Canvases related to the different PSS-based CBMs detected. In the future steps of this research, a comparison among the

Business Model Canvases detailed will enable to lead to the selection of the most sustainable ones, based on the quantitative evaluation of actual costs and revenues.

The paper is structured as follows. Section 2 presents the research context, introducing the CBMs in the Waste from Electrical and Electronic Equipment (WEEE) sector. Section 3 explains the research method and introduces the use cases. Section 4 shows the results, with the BM Canvases related to the different cases analysed and based on the different CBM considered to deliver a given output (metal powders, filaments, jewels, pilot plants). Section 5 discusses the results and Section 6 concludes the paper, unveiling its limitations and opening room for future research.

II. RESEARCH CONTEXT: CBMS IN THE WEEE SECTOR

A. From Linear to Circular BMs to address sustainability

The whole article is based on the concept of CBM, described in literature by several works (e.g. [21]). This concept tries to go beyond the common perspective of BM widely discussed in literature. The main difference lies in the way the value embedded into products is maintained within the boundaries of the value chain in order to create new market opportunities. In literature there are several attempts to bridge such a transition. One of the first is the ReSOLVE framework [22] proposing a set of principles aimed at supporting companies and governments during the definition of CE policies and the transition from a linear to a circular BM. This framework identifies six different ways to be circular (i.e. Regenerate, Share, Optimize, Loop, Virtualize, Exchange). Even if the ReSOLVE framework is not actually a classification method, many researches used it for developing new classification methods [7].

B. CBMs Classification: a focus on PSS

So far, different types of CBMs have been proposed in literature. [9] classified CBM archetypes starting from circular product design principles. Then, [7] analysed all the extant classification frameworks and archetypes, detecting the ReSOLVE framework and the BM Canvas [20] (also used together in a hybrid way) as the referring frameworks to classify them. In particular, [26] detected five CBMs (Circular Supplies, Resource Recovery, Product Life Extension, Sharing Platforms and Product as a Service), supported by ten main technologies (mostly 'digital', e.g. social, cloud, big data analytics and 3D Printing). Instead, [7] analysed the adoption in literature of the main circular actions associated with the CBMs proposed by the ReSOLVE framework. They stated that the most common ones are recycling practices and use-oriented PSSs. However, also product- and result- oriented PSSs have been detected as strategic towards CE. Indeed, Product-Service System (PSS)-based CBMs have been proposed as the most suitable strategy towards CE [23]–[25]. Classified in three main categories (product-, use-, and result-oriented), PSSs are split in eight archetypes [18]. However, the big research gap remained to understand how to practically translate a linear BM into a circular one, since very few research actually implemented CE into practice. In addition, CE benefits were also associated with the set of relevant PSS-based CBMs in the WEEE sector, trying to support industrials in i) detecting benefits related with the adoption of CBMs, ii) increasing their awareness on those benefits and iii) reaching them into practice [8]. Finally, it has also been stated that CBMs could bolster companies in the achievement of the Triple Bottom Line (economic, environmental and social) of sustainability [8].

C. CBM mapping methods and models

BMs are usually mapped through the BM Canvas developed by [20], a well-known and recognized framework able to help stakeholders to decode and specify the different components related to the three main value mechanisms characterizing a given business (creation, delivery and transfer). As stated in the previous sub-section, in terms of CMBs, some important steps have been already done to classify them but effort is still needed to map the value of circular solutions and support the shift from linear to CBMs.

Dealing with the mapping of value along CBMs, some attempts were done during the years. [27] aimed to support sustainable BMs development adopting a holistic approach considering all the stakeholders involved and presenting a multi-criteria decision-making analysis for gauging and make a comparison of different decommissioning alternatives. [28] proposed a visualisation tool to map CBMs, offering a standardised representation of their elements and representing the possible cycles of CBMs needed to prolong the useful life of products and components, and manage to close the material loops. Notwithstanding these attempts and the wide adoption of the BM Canvas framework in literature to map value mechanisms in traditional linear BMs, solid applications of this framework to structure these value dynamics in CBMs is still lacking in literature. Therefore, this paper wants to make a first step in this direction, exploring the main characteristics of multiple companies initially implementing a linear BM but, having the opportunity to be involved in a circular SC, willing to turn it in a circular one. The single BM Canvas explored will contribute to define the BM of the future start up involving the business of all the cases analysed in this research.

III. RESEARCH METHOD

Considering the definition of [29], a multiple case study methodology based on a convenient sample of companies has been adopted to develop the research. Three different European Small and Medium Enterprises (SMEs) operating in the manufacturing industry have been selected as case studies. For confidentiality reasons, the three cases are named "Case A", "Case B", "Case C". In addition, a hypothetical company, "Case D", to be created based on the combined circular businesses of the previous three, has been introduced in the analysis. Case D is a hypothetical start-up not only combining the business of the three existing cases but also exploiting a hydrometallurgical process to recover materials from e-wastes. A new startup, i.e. Case D, will present some complementary options in terms of recoverable materials from e-wastes. In addition, all the sampled cases are relevant not only in terms of CE implementation, but also because of the final output they generate. The identification of the cases was based on a convenient sampling criterion, allowing for easy accessibility and availability of information at a given time [30]. Indeed, all the 4 cases come from the same project consortium of a past European H2020 project named FENIX (www.fenix-project.eu).

After performing multiple research investigations about CBMs [7], [8], two researchers brainstormed about the possible CBMs that could be implemented by the new circular supply chain composed by Case A, B and C. All the business complementary options have been considered and detailed. However, the overall scenario to be implemented by the Case D has still to be built based on the research presented in this paper. Therefore, the drafts built by the two researchers were proposed to a wide and heterogeneous group of academics and practitioners (Table 1) to gather more information about the expected CBM Canvases. A workshop was organized. It lasted half a day (around 5 hours) and the interviewed managers were asked to contribute directly on the specific CBM Canvases of their pertinence to define an initial panel of potential CBMs to be considered for Case D, the hypothetical start-up to be constituted to sell integrated solutions in the e-waste management sector. After a first round of interviews, the two researchers verified the results obtained and reviewed them to consolidate them. Finally, specific industrial actors have been involved in identifying the most feasible CBMs among those presented in this paper.

Table 1 Participants to the workshop

ID manager	Expertise	Organization
1	Automated PCB disassembly processes	Consulting
2	Product lifecycle assessment tools	Consulting
3	Additive manufacturing technologies	Research centre
4	Metal powders production processes	Case A
5	3D printing & 3D scanning processes	Case B
6	WEEE treatment processes	WEEE supplier
7	Hydrometallurgical processes	University
8	Social aspects	Research centre
9	Software development	Consulting
10	PSS-based CBMs	University
11	3D printed jewels & artifacts	Case C

A. The use cases

Trying to demonstrate in practice the real benefits a CE can offer, this paper considers a pilot plant aiming to reproduce at small-scale a CE able to reintroduce materials (metal powders, filaments for 3D printing, precious metals) recovered from WEEEs (specifically, from Printed Circuit Boards – PCBs) in different supply chains (e-waste management, jewellery, additive manufacturing) [31]. The related multiple circular supply chain is shown in Figure 1.

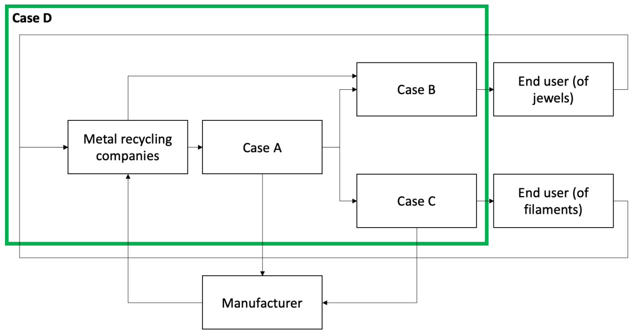

Figure 1: The multiple circular supply chain (adapted by [31]**)**

Considering the delivery of the production plant, different PSS-based CBMs can be identified. First, a product-oriented BM could be adopted if the final aim of the business will be the simple selling of the production plant (or some of its independent modules). Second, a use-oriented BM could be implemented if the final aim will be selling the access to the plant (hypothesizing that final users will have the right skills to exploit it). Finally, a result-oriented BM could be adopted if the final aim will be selling of the several services (e.g., disassembly, materials recovery and additive manufacturing) related to those activities enabled by the plant.

Looking through the final product lenses, it would be possible to adopt as CBMs just two (out of three) PSS-based BMs. These CBMs are the product-oriented and the result-oriented. On one side, a product-oriented BM could be adopted if the final aim is the simple selling of a product (e.g., metal powders, 3D printed jewels, materials for additive manufacturing and 3D printing filaments). On the other side, a result-oriented BM could be adopted if the final aim is the selling of the several services related to those products enabled by the plant.

Case A is a metal powders manufacturer for additive manufacturing processes. Over time, the company developed a portfolio of technologies capable of producing innovative metal powders useful in several industrial sectors (e.g., coatings, composites and materials for energy storages) and suitable to be subsequently transformed into new products. The innovation lies in the initial material from which metal powders are produced. Starting from e-wastes, base metals are extracted from them through a specific hydrometallurgical process. Subsequently, the production process of Case A allows to transform these raw materials into metal powders and characterize them basing on customers' specifics.

Case B is a filament manufacturer for 3D printing processes. This company starts from metal powders developed by Case A and, after an extrusion process, develops metal filaments suitable for common 3D printing processes. Also in this case, the innovation lies in the initial material from which metal powders are produced.

Case C is a 3D-printed jewels manufacturer. This company exploits 3D printing processes to customize wax-based casts and, therefore, produce original-designed jewels. The innovation lies in the initial material from which jewels are manufactured. Starting from e-wastes, precious metals are recovered from them through a specific hydrometallurgical process. Subsequently, precious metals are melted directly in the wax-based cast to obtain the jewel. To better differentiate its business, this company developed also a customized 3D scan able to replicate human faces into a jewel. Through a set of professional webcams, human faces are translated in a digital surface that is, in turn, replicated in the jewel.

Differently from the other cases, Case D is a hypothetical start-up selling integrated solutions (under the form of pilot plants) dedicated to the e-waste management sector. Starting from the technologies developed during the FENIX project, this start-up will sell them in the market thanks to an internal agreement among the different members involved. These solutions consider both PCB disassembly and recycling processes plus additive manufacturing ones. Given the small-scale nature of the considered processes, they could be potentially adopted by SMEs.

IV. RESULTS: CIRCULAR BUSINESS MODEL CANVASES

Hereafter, nine PSS-based CBM Canvases, are reported (Tables I-IX). The amount of CBMs proposed depends on the fact that the two researchers and the participants to the workshop decided to compare specific BMs (not aggregated ones). Depending on both the focus of BMs and the reference PSS adopted, several options have been developed. In general terms, the tree PSS-based options (described in section II.B) have been considered only in the pilot plant case. Otherwise, only two out of three PSS-based options have been taken into account.

Two CBM Canvases are dedicated to metal filaments, two dedicated to metal powders, two are dedicated to 3D printed jewels and three dedicated to pilot plants.

The CBM Canvases reported in Table I and Table II refer to metal filaments. In the first case, a company could follow a product-oriented logic (acting as a producer of green metal filaments made by secondary base metals). In the second case, a company could follow a result-oriented logic (acting as a green metal filaments service provider).

Table III and Table IV refer to metal powders. Again, the followed logics are product-oriented and result-oriented PSSs. Starting from e-wastes (gathered from either private or industrial customers), final products will be metal powders.

Table V and Table VI refer to 3D printed jewels. Even if the followed logics are the same as before, this is the only case were both B2B and B2C markets are considered. This difference with the previous CBM Canvases (B2B-oriented) lies in the way a company could reach its markets through dedicated channels and customer relationships.

Finally, Tables VII, VIII and IX refer to pilot plants. In this last case, all the PSS-based CBM can be adopted. This way, a potential start-up able to exploit the results of the results obtained could function in three (very different) ways. Firstly, a company could decide to sell turn-key modular pilots dedicated to either PCB disassembly, or recycling or additive manufacturing in the market. Each pilot's module could be sold (and function) independently from the others, depending on the market request. Secondly, a company could act as a service provider, by offering to the market a portfolio of services dedicated to either PCB disassembly, or materials recycling or green additive manufacturing. Finally, a company could follow a use-oriented logic, by offering the access to the full set of pilots (like a fab-lab). The hypothesis in background is that customers asking for this access will be sufficiently skilled to manage all the pilots autonomously (or will need the assistance of a dedicated personnel).

Referring to the ReSOLVE framework [32], the three PSS-oriented logics can be grouped together under the "Exchange" class because all of them exploit Key Enabling Technologies (KETs) instead of traditional production processes. This way, they can be classified under the same umbrella.

TABLE I. BUSINESS MODEL CANVAS #1 (FILAMENTS: PRODUCT-ORIENTED)

Key partnerships:	**Key activities:**	**Value proposition:**	**Customer relationship:**	**Customer segments:**
• R&D centres • Universities • Fab-labs • Strategic industrial companies • Binder suppliers	• Material characterization/development • Material production, • Quality check, • Material standardization	• Selling green/recycled materials for additive manufacturing (filaments)	• Dedicated relation with fab-labs/big customers • Common relation with final users (resellers)	• Fab-labs • 3D printing companies • Private customers • SMEs • Prototyping companies • Binder suppliers
	Key resources:		**Channels:**	
	• Dedicated operation site • Proprietary knowledge • Patents • Business / chemical scientists • Sales force • Green raw materials • Extrusion systems		• Dedicated sales force (for big customers) • Web/physical shops	
Cost structure:			**Revenue streams:**	
• Production costs • Transportation costs • Standardization costs (small %) • Marketing costs			• Transaction and recurring revenues from selling materials	

TABLE II. BUSINESS MODEL CANVAS #2 (FILAMENTS: RESULT-ORIENTED)

Key partnerships:	**Key activities:**	**Value proposition:**	**Customer relationship:**	**Customer segments:**
• R&D centres • Universities • Fab-labs • Strategic industrial companies	• Order/sales of 3D printed products • Design of personalized products • 3D printing, • Debinding & Sintering • Polishing/Finishing • Shipping	• Selling services for producing products using green filaments for additive manufacturing	• B2B & B2C relation with customers	• Private customers • Business customers
	Key resources:		**Channels:**	
	• Manufacturing site • Proprietary knowledge • Patents • Legal advisory • Sales/marketing force • Green raw materials		• Internet (website, apps, etc.)	

Cost structure:	**Revenue streams:**
• Production costs • Development costs (R&D, etc.) • Marketing & sales costs • Shipping costs • Administration costs (insurance, certifications, etc.)	• Recurring revenues from selling 3D printed products

TABLE III. BUSINESS MODEL CANVAS #3 (POWDERS: PRODUCT-ORIENTED)

Key partnerships:	**Key activities:**	**Value proposition:**	**Customer relationship:**	**Customer segments:**
• R&D centres • Universities • Fab-labs • Strategic industrial companies	• Material characterization/development • Material production, • Quality check, • Material standardization	• Selling green/recycled materials for additive manufacturing (metal powders)	• Direct relation with customers	• Companies exploiting SLD/MLD/MLS technologies: • Fab-labs • 3D printing companies • SMEs • Prototyping companies
	Key resources:		**Channels:**	
	• Dedicated operation site • Proprietary knowledge • Patents • Business scientists • Sales force • Green raw materials		• Dedicated sales force (for big customers) • Web/physical shops	

Cost structure:	**Revenue streams:**
• Production costs • Transportation costs • Standardization costs (small %) • Marketing costs	• Transaction and recurring revenues from selling materials

TABLE IV. BUSINESS MODEL CANVAS #4 (POWDERS: RESULT-ORIENTED)

Key partnerships:	**Key activities:**	**Value proposition:**	**Customer relationship:**	**Customer segments:**
• R&D centres • Universities • Strategic industrial companies	• Material characterization/development • Material production, • Quality check, • Material standardization	• Selling services producing metal powders for additive manufacturing	• Direct relation with customers	• Companies exploiting SLD/MLD/MLS technologies: • 3D printing companies • SMEs • Prototyping companies
	Key resources:		**Channels:**	
	• Dedicated operation site • Proprietary knowledge • Patents • Business scientists • Sales force		• Dedicated sales force (for big customers) • Web/physical shops	

Cost structure:	**Revenue streams:**
• Production costs • Transportation costs • Standardization costs (small %) • Marketing costs • Characterization costs	• Transaction and recurring revenues from selling production services

TABLE V. BUSINESS MODEL CANVAS #5 (B2B JEWELS (STORES): PRODUCT-ORIENTED)

Key partnerships:	Key activities:	Value proposition:	Customer relationship:	Customer segments:
• Fab-labs • Jewellery manufacturers (forging/casting labs) • Distribution chain (jewellery retailers)	• Order/sales of jewels • Design of personalized jewels (3D scanning, 3D modelling, etc.), • 3D printing, • Casting/creation of jewels, • Polishing/Finishing • Shipping	• Selling personalized (e.g., human face)/green 3D printed jewels	• B2B Direct relation with retailers • B2C relation with customers • B2B2C relation with customers and retailers	• Jewellery stores • Wholesalers • Private customers
	Key resources: • Manufacturing site • Proprietary knowledge • Patents • Legal advisory • Sales/marketing force • Green raw materials		**Channels:** • Internet (website, apps, etc.) • Retailer shops	

Cost structure:	Revenue streams:
• Production costs • Development costs (R&D, etc.) • Technical support costs (after-sales, etc.) • Marketing & sales costs • Transportation costs • Administration costs (insurance, certifications, etc.)	• Recurring revenues from selling jewels (for retailers and manufacturers) • Royalty revenues • Profit margin for manufacturer • Profit margin for retailer • Revenue from selling scanner machine • Recurring license/maintenance fees

TABLE VI. BUSINESS MODEL CANVAS #6 (B2C JEWELS (ONLINE) RESULT-ORIENTED)

Key partnerships:	Key activities:	Value proposition:	Customer relationship:	Customer segments:
• Fab-labs • Jewellery manufacturers (forging/casting labs)	• Order/sales of jewels • Design of personalized jewels (3D scanning, 3D modelling, etc.), • 3D printing, • Casting/creation of jewels, • Polishing/Finishing • Shipping	• Selling 3D printing services of green/personalized metal products (jewels, etc.)	• B2C relation with customers	• Private customers
	Key resources: • Manufacturing site • Proprietary knowledge • Patents • Legal advisory • Sales/marketing force • Green raw materials		**Channels:** • Internet (website, apps, etc.)	

Cost structure:	Revenue streams:
• Production costs • Development costs (R&D, etc.) • Marketing & sales costs • Shipping costs • Administration costs (insurance, certifications, etc.)	• Recurring revenues from selling jewels (for consumers) • Royalty revenues • Profit margin for manufacturer • Profit margin for retailer

TABLE VII. BUSINESS MODEL CANVAS #7 (PLANT: PRODUCT-ORIENTED)

Key partnerships:	Key activities:	Value proposition:	Customer relationship:	Customer segments:
• R&D centres • Universities • Chemical equipment suppliers • Engineering companies • OEMs, • Industrial associations • Governments • Consumer associations • Public/local administrations	• Technological/Sustainability assessment, • Pilot plant design/ engineering/construction/testing /validation/start-up • Standardization, • Transport, • Installation, • Maintenance • Problem solving • Consulting	• Selling pilot plants	• Dedicated/personal assistance when purchasing a plant	• OEMs • Powder-metallurgy companies • Metal traders
	Key resources: • Dedicated operation site • Proprietary knowledge • Patents • Business/chemical scientists		**Channels:** • Sales force (for big customers) • Web sales (for small/one-shot customers)	

	• Sales force			

Cost structure:	Revenue streams:
• Production costs • Transportation costs • Installation costs • Standardization costs • Data management costs • After-sales service costs	• Transaction and recurring revenues from selling plants • Asset sales • Product volume-/pilot feature-dependent pricing strategy

TABLE VIII. BUSINESS MODEL CANVAS #8 (PLANT (FAB-LAB LIKE) USE-ORIENTED)

Key partnerships:	Key activities:	Value proposition:	Customer relationship:	Customer segments:
• R&D centres • Universities • Chemical equipment suppliers • Engineering companies • OEMs • Industrial associations • Governments • Consumer associations • Public/local administrations • Training centres • Fab-labs network	• Technological/Sustainability assessment, • Pilot plant training, • Standardization, • Product distribution - Transport, • Set-up, • Maintenance • Problem solving • Consulting **Key resources:** • Dedicated operation site • Proprietary knowledge • Patents • Business/chemical scientists • Sales force	• Selling pay-per-use services	• Dedicated/personal assistance when using the plants (fab-labs style) **Channels:** • Sales force (for big customers) • Web sales (for small/one-shot customers) • Fab-labs network	• OEMs • CEMs • Powder-metallurgy companies • Metal traders • Fab-labs

Cost structure:	Revenue streams:
• Operational costs • Transportation costs (additional service) • Maintenance costs • Training and supervising costs • Data management costs • Marketing costs	• Fees from renting plants • Asset sales • Product volume-/pilot feature-dependent pricing strategy

TABLE IX. BUSINESS MODEL CANVAS #9 (RESULT-ORIENTED)

Key partnerships:	Key activities:	Value proposition:	Customer relationship:	Customer segments:
• R&D centres • Universities • Chemical equipment suppliers • Engineering companies • OEMs • Industrial associations • Governments • Consumer associations • Public/local administrations • Training centres • Customer/user network	• Technological/Sustainability assessment, • Pilot plant training and support, • Operational services • Consulting **Key resources:** • Dedicated operation site • Operational staff • Proprietary knowledge • Sales force	• Selling refining services • Experimentation as business development	• Dedicated/personal assistance when delivering the service **Channels:** • Web sales (web portal) • Customer/user network	• OEMs • CEMs • Powder-metallurgy companies • Material traders & Recyclers

Cost structure:	Revenue streams:
• Operational costs • Overhead costs • Marketing costs • Depreciation costs	• Service recurring fees • Revenue share (provider/customer) • Product volume-/pilot feature-dependent pricing strategy

V. DISCUSSIONS

For each of the PSS-based CBM Canvases developed, typical characteristics can be unveiled. Indeed, based on the PSS archetype (product-, use-, or result-oriented) chosen, the dimensions of the BM canvas are composed of different set of assets.

In this discussion, it can be useful to remember the two sides of the BM Canvas that is composed on the left by the efficiency related dimension and on the right by the value-related one.

Looking at the Business Model Canvases and grouping them based on the type of output delivered (i.e., products or plants and their and related services), different proper characteristics can be evidenced. Indeed, when product are delivered, on the left (efficiency-related) side of the BMC, key partnerships and activities are very different compared to the case of plants delivering while key resources are quite similar. In particular, key partnerships with R&D centres and universities are occurring for the delivery of both product and plants. Fab-labs, strategic industrial companies, binder suppliers, jewellery manufacturers, distribution chain

Key activities are very specific depending on both the output delivered (product or plant) and type of PSS chosen as BM strategy. When filaments are sold as product-oriented PSS and in the case of powders, the main activities needed are material characterization and development, material production, quality check and material standardization. In the case of filaments, if sold as result-oriented PSS, different activities are needed: order and sales management of 3D printed products, design of personalized products, 3D printing operations, debinding and sintering of filaments and polishing and finishing of final products. Instead, in the case of jewels, besides the common management of orders of personalized products, the design of personalized jewels (in this case through 3D scanning and modelling), the 3D printing and finishing operations, the key further activity detected is the casting of jewels.

Finally in the case of plants delivery, activities are very different. Technological/sustainability assessment should be performed, together with the development of the plants and consultancy on its usage. Standardization, maintenance, and problem solving should be ensured in production operations, especially when the plant is sold according to product- and use-oriented PSS models. When the plant is sold according to product-oriented PSS models, transportation and installation costs need to be considered, while in the use-oriented model plant set-up and product distribution need to be managed. Finally, in the case of result-oriented PSS, plants need to be always flanked by operational services.

Key resources are instead very similar in the different cases of products and plants delivery: dedicated operation site, proprietary knowledge, patents, business and chemical scientists, sales force are in common to both of them. Operational staff is something needed only in the case of plants delivered with result-oriented CBM, while legal advisory and marketing forces are needed in the product cases (mostly when delivered with result-oriented CBMs).

In terms of costs, the plant solution has some elements in common (production, transportation, standardization and marketing costs), neglects other costs related with products (development, sales, shipping, administration and characterization costs) but adds also new elements (as operational, maintenance training and supervising, overhead and depreciation costs).

Some patterns for the right (value-related) side of the BM Canvas can be also detected. Customer relationship is a dimension changing not only depending on the type of output delivered (products or plants) but also on the type of industry/supply chain characterising each case (filaments, powders, jewels, plants) and the PSS-based approach assumed (product-, use-, result-oriented).

In terms of channels, dedicated sales force for big customers and web shops are considered in both product and plant cases. While physical and retailers shops are considered only for delivering products, fab-labs networks and customer/user networks are exploited as channels in plants delivery.

Concerning customers, 3D printing companies can be an option for both the case of product and plant delivery, while a quite heterogeneous list of customers varies in the case of products delivery depending on the industry and PSS-based approach (fab-labs, private customers, SMEs, prototyping companies, binder suppliers, business customers, companies exploiting SLD/MLD/MLS, jewellery stores and wholesalers) and in the case of plants delivery based on the PSS-based approach (OEMs, CEMs, Powder-metallurgy companies, metal and materials traders and recyclers).

Finally, these three elements convey in revenue streams. In this dimension of the BM Canvas, a strong differentiation between the product and the plant view is clear looking at the different options. While in the case of delivery of products there are streams of revenue related with the selling of materials, of 3D printed products, of jewels and of production services, in the case of plants the main sources are transactions related with selling of plants and their assets, fees from plant renting and service recurring fees, keeping a pricing strategy based on volumes and features of the products to be produced.

VI. Conclusions

This paper presented and discussed CBM canvases related to the multiple and complementary options of business to recover materials from e-wastes. The Canvases are related to the three linear supply chains of the case studies analysed (i.e. Cases A, B and C) and will be in the future used to ground the development of a unique business model related to a circular extended supply chain (to be materialized in Case D, the new start up to be developed to provide an overall solution able to exploit and sell an extended circular offer in the WEEE industry). As suggested by the literature, the CBMs explored are PSS-based (product-, use-, or result-oriented). The CBM Canvases presented are related to metal filaments, metal powders and jewels production (using the pilot plant of the reference project exploited to conduct this research) and to the delivery and operation of the entire pilot plant (composed of three pilots able to disassemble PCBs, recycle materials from them and transform secondary materials in additive manufacturing-ready consumables). For each of them, a set of typical characteristics have been evidenced. Indeed, there are some dimensions of the CBM Canvases that are more dependent on the PSS orientation (product, use, or result), others that instead are characterizing the specific industries and linear supply chains (e-waste management, jewellery, additive manufacturing) constituting the extended multiple circular supply chain enabled by WEEE recovery, and others that are related to the type of output delivered (products or plants) through the CBM.

In addition, this work opens rooms for further analysis on the results obtained. Indeed, first, it would be interesting to investigate how to select and prioritize, through the involvement of experts of the WEEE industry, the most suitable and convenient CBM Canvases among the nine developed. Alternatively, a unique BM Canvas including all the cases presented in this paper could be developed to support the business of the new start-up to be funded (i.e.

Case D). Second, an economic evaluation of the most important CBMs selected can be made to practically figure out the costs and revenue streams and assess their actual feasibility.

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