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Enabling cross-sectorial, circular economy transition in SME via digital platform integrated operational services

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Abstract

Circular Economy (CE) is an emerging paradigm aiming at establishing a new sustainable development path by decoupling economic growth and resource consumption. The main limitation in current production models is that manufacturing and de-and remanufacturing operations are carried out independently and without sharing information and economic benefits. This can be overcome by rethinking the current European industrial system into new collaborative and sustainable value networks. New business cases can be generated also for individual Small and Medium Enterprises (SME) by taking advantage of the connection with the Industry 4.0 opportunities and by building on cross-sectorial markets and the potential of digital solutions. The operational services (DOS) presented in this paper are the key part of a novel digital platform called DigiPrime, whose aim is to provide SME with a federated service infrastructure that help overcome the current information asymmetry and explore the possibility to access and transit towards a CE cross-sectorial value-chain. The manuscript presents a selection of DOS considered fundamental for an SME in such a process, through a relevant exploitation use-case scenario. The combination of such DOS has been validated within the project for the case of an electric car repair-shop network and the preliminary outcome of their integration process is also outlined.

Keywords: Circular Economy; Industry 4.0; Service-oriented Platform; Operational Services as a Service; Small and Mid-size Enterprise

1. Introduction

The EU Circular Economy Action Plan for a cleaner and more competitive Europe (one of the main blocks of the European Green Deal) clearly states how there is only one planet Earth, yet by 2050, the world will be consuming as if there were three [3]. Global consumption of materials such as biomass, fossil fuels, metals and minerals is expected to double in the next forty years, while annual waste generation is projected to increase by 70% by 2050. Circular Economy (CE), on the contrary, is an emerging paradigm aiming at establishing a new sustainable development path by decoupling economic growth and resource consumption, also in manufacturing [1]. CE shows potentials to generate new business opportunities in worldwide economies and significantly increase resource efficiency in industrial systems, thanks to the vision to change dramatically the current linear "take–make–dispose" economic approach. In contrast, the CE paradigm brings restorative and regenerative approaches by intention and design [2]. Recent studies show that a transition to CE may represent a new sustainable growth path as well as a business opportunity for the worldwide industry [10, 18]. In a world of close to 9 billion people expected by 2030 the challenges of expanding resource supply to meet future demand are unprecedented. Without rethinking of how society uses materials in the linear economy, resources that are vital for industry could be depleted within the next 5–50 years, reaching the planetary boundaries with irreversible effects [19]. A new industrial model that decouples revenues from material input, and production from resource consumption is needed for achieving a sustainable development path [6]. However, a structural gap between this CE vision and the current industrial practices exists. CE is implemented by collecting post-use products from the market through reverse logistics systems, by performing de- and remanufacturing operations to recover re-usable materials and components from the product, and by selling them back to the manufacturing industry for reuse in new products or in spare parts for the after-

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market services. Such model is effective and economically sustainable mainly for simple products and for specific classes of materials (steel and techno-polymers, for example) but the current trend of smart products with embedded intelligence poses significant challenges to the implementation of sustainable CE practices. The main limitation of current model is that manufacturing and de-and remanufacturing operations are carried out independently in an isolated manner, without sharing information and economic benefits: this can be overcome by rethinking the current European industrial system into new collaborative and sustainable value networks. There is a business case also for individual Small and Medium Enterprises (SME), which derives from Industry 4.0 opportunities [11]: since manufacturing firms in the EU spend on average about 40% on materials [3], closed loop models can increase their profitability and networking strategies, while sheltering them from resource price fluctuations. Building on cross-sectorial markets and the potential of digital solutions, the CE can strengthen EU's industrial base and foster business creation among SME, with the idea of promoting the creation of cross-sectorial circular value-chains. In such a manner, the residual value of a product in its post-use phase could be maximized by establishing alliances between stakeholders in different sectors. In the automotive sector, for instance, one of the most interesting strategies is centred around the lithium batteries and relates to the remanufacturing and reuse of the disassembled cells with proper residual characteristics into multi-life applications (back in the automotive sector or in customized cross-sectorial stationary applications, dedicated for example to the storage in renewable energy installations). On the contrary, the implementation of these promising cross-sectorial value-chain opportunities is strongly bounded by several factors, such as: i) the lack of product data and knowledge transfer from manufacturers to de-and remanufacturers and vice-versa; ii) no exchange of information about recovered component and materials among sectors; iii) the lack of certification data and protocols for secure transfer of recovered materials and components among sectors, and iv) a poor acceptability of products embedding recycled materials by end-customers. There are also SME specific barriers to the adoption of CE business practices, both from the market chain in which the SME operates and from the lack of technical skills and finance to invest in innovation: the cost of "green" innovation and business models is reported in literature as one of the major barriers to sustainability practices by SME [15]. Even from the perspective of the Industry 4.0, its positive but limited impact on SME is still due to key factors in organization and management (i.e. operational control) and the digitization of production processes [9].

2. Related work

Production digitalization matters and industrialized countries now have their own initiatives to support it. In this scenario, the relevance of IT-based platforms and digital technologies supporting CE aspects have been demonstrated in a variety of supply chain applications, also related to SME [8]. Digital platforms developed under the call FoF-11-2016 for instance aim at supporting the horizontal and vertical integration of processes within a factory or along a value-chain but cannot support the leap to "external" value-chain in different sectors (Fig. 1). For this reason, they are not sufficient for overcoming the limitations in the establishment of cross-sectorial circular value-chains.

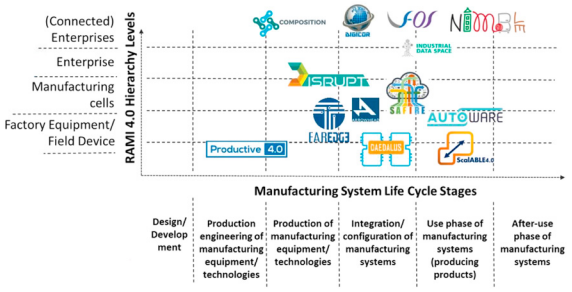

Fig. 1. Positioning of FoF-11-2016 projects on RAMI 4.0 cross-section [5]

The European Circular Economy Stakeholder Platform provides a list of specific CE oriented digital initiatives for SME in the EU [4], but without focusing on cross-sectorial applications. Authors in [7] provide a survey on the roles of online platforms in enabling a more sustainable production and CE. From a more general point of view of the living and sustainable manufacturing, the work presented in [10] helps understand how manufacturing interacts with the overall ecosystem and suggests resolutions for the dilemma of competitive and sustainable manufacturing. This paradigm shift also requires the industrial sector to prioritize sustainable business models and create their own CE strategies, which has to be supported by such digital platforms [12, 16]. Remarkably interesting contributions also show how CE applications can indirectly benefit from concepts such as *resource sharing* and *reverse logistics* in manufacturing environments, in which trust and reputation are the leading concepts of the underlying collaboration and information sharing among the players of the federation [17].

2.1. Contribution

The digitization of information and technology is the very first step for SME to unlock the potential of its operational assets in CE production environments. This process needs to be supported by the proper digital infrastructure, offering the right services. The goal of the DigiPrime platform is the development of a CE enabling federated digital infrastructure, whose aim is to overcome the current information asymmetry and lack of access among value-chain stakeholders. The platform will integrate and offer a portfolio of service applications, also at operational level. These services are usually neither accessible nor (at least technologically) affordable in a typical SME environment [9]. Aim of this manuscript is to propose a selection of DigiPrime Operational Services (DOS) identified as fundamental for an SME in such a process, and a typical exploitation use-case scenario for them. The combination of these added-value

DOS can enable and support a CE oriented transition for the company, which would be improbable otherwise without such a digital solution. DOS represent the common element in three major driving dimensions: SME, I4.0 and and CE (further details in Section 3).The presented approach have been validated within the project (73%, of the industrial partners are SME) for the case of an electric car repair-shop network.

3. Integrated Operational Software Solutions as Services

The DOS embody the convergence of the three major factors and their driving forces: SME (organizational shift requirements), I4.0 (digitization and virtualization of processes and technology via CPPS) and CE (new manufacturing paradigm and business models), as illustrated in Fig. 2.

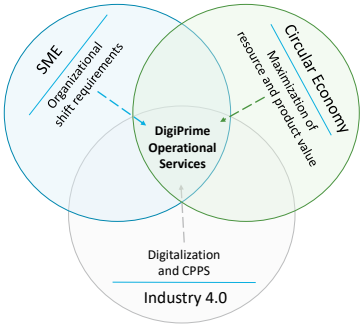

Fig. 2. Convergence of SME, I4.0 and CE driving forces in the DOS

DOS are *vertical services* provided by nodes of the platform and used by SME companies mainly to support their decision making. Their objective is to help improve the effectiveness and the profitability of the circular business processes.

3.1. DigiPrime platform piloting

The DigiPrime platform aims at tackling those factors that bound the transition to a CE for high added-value components in very strategic sectors (such e-mobility), divided into 4 Pilots for application and demonstration: battery, mechatronics, composite materials and textile. The battery system, for instance, constitutes 35%-50% of the cost of current electric vehicles (EV). By demonstrating new cross-sectorial reuse options of EV battery systems, the battery cost can decrease with a rate higher than the existing trend. This in turn can decrease the price of new EV battery systems in the market, due to the residual value gains, thus accelerating the market penetration of EV [13]. Differences with respect to traditional vehicles can be observed in EV in terms of material composition, with a higher concentration of engineering polymers and lightweight composites to compensate the weight increase due to battery systems.

3.1.1. Use case

Here we present the case of an independent electric car repair-shop network. This network consists of multiple repair shops in five different countries around the Alps and they have high-level expertise in e-car disassembly and repair. However they lack of experience in re- and demanufacturing processes and also in the operational logic of related supply-chain network. The example aims at demonstrating how the leading drivers of an SME can converge to a CE transition by means of the DOS. One of the main barriers for SME to join such platforms are the lack of digitalization or the low level of digital integration in between the shop-floor and the management software tools. The platform aims at filling this gap trough seven selected DOS that can support the vertical integration ladder and compensate the missing steps, if required. A SME joining the platform can take advantage of these service solutions and create their own integration chain. The ecosystem of such platform is usually based on standards, which increase the technological entry level of new partners to significant heights. By providing solutions at the operational level, these reporting and data provisioning protocols can be adopted in a native and reliable manner without the need of complex API developments. Every opportunity to discover relevant and necessary services can assist in identifying the lacing re- and demanufacturing aspects. Connection to new stakeholders will be dynamic and immediate, so the SME can focus on the business side of CE. Nevertheless, it is worth to remark how sustainability is a leading trend characterizing new customers habits: by joining a CE platform, a company could potentially acquire new customers while securely retaining the existing ones.

3.2. Operational Services as a Service for CE

One aim of the platform is to deliver software applications as supporting services to each federation node at operational level. The development of these services is focused on targets determined by cross-sectorial use-cases defined by industrial partner expectations toward the CE paradigm. Seven functionality has been selected as barrier breaking operational services, to support the digital transition requested for joining the CE network. These seven DOS together provide a new, higher level of service synergy, which can improve the sustainability of the manufacturing at operational level. The selected DOS are presented in the following subsections.

3.2.1. Product use-phase data acquisition

Data acquisition is one of the most crucial part of any digitalization approach. With the rise of IoT, more and more products became smart products. Simply put, smart means there is digital data collected and stored about the product, however for quality assurance and user data security reasons they are difficult to access. Nevertheless a trusted platform can rise above such constraints, but still large volume of data can be difficult to handle without the right tools. For this purpose/Based on these, one of the most crucial service is the one that is responsible to provide a polymorphic approach to conduct the data acquisition management. This goes together with data enrichment by visualisation tools.

3.2.2. Product condition prediction

One cannot take a good economical decision on CE-related product life-cycle without a trustworthy assessment of each product separately. Nowadays this assessment is mostly done by human experts with visual inspection, and sometimes by means of rapid instrumental measurements. However to tackle the economical challenges of CE, one have to do this assessment fast with determinable precision without continuous human intervention. For this the second proposed service is an artificial intelligence (AI) based product condition prediction, which can perform a State of Health (SoH) check on each product based on the use-phase data (Fig.3). The prediction accuracy is highly depending on the accessible data for which it is crucial to highlight the utility of available data sets.

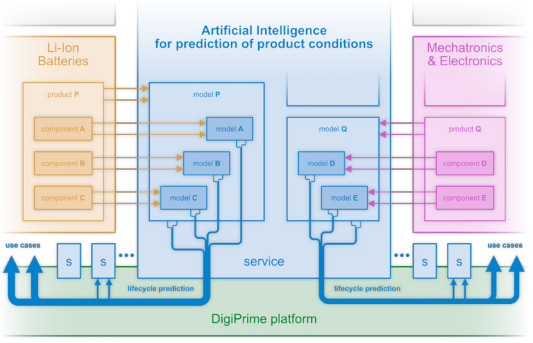

Fig. 3. Artificial intelligence based service model for product condition prediction

3.2.3. Decision Support System for CE

Even for a mature participant in the CE ecosystem it can be challenging to make an appropriate decision based on the SoH prediction. To help both mature and newcomer stakeholders a Decision Support System (DSS) is requested. The DSS service can guide the user to make an economically responsible judgement on what to do with the current product based on a data-driven assistance. Nevertheless, the possibility of automation is highly dependent on the available decision support tools. This service ground on DSS methodologies for battery packs/modules remanufacturing, for glass fibers reinforced plastics (GFRP) recycling and for automotive mechatronics remanufacturing. These methods, integrated and upgraded in a comprehensive DSS, can define a specific end-of-life strategy.

3.2.4. Digital Twin-based simulation for disassembly

The Digital Twin (DT) of the physical de- and remanufacturing process-chain is fundamental in order to support operators in adapting their processing strategy to the conditions of the system and of the returning post-use products. This DT based service offers the computerized counterpart of the physical assets and uses data from sensors, actuators, power supply and network interfaces installed on physical objects to represent their near real-time status, working conditions or position. This service offers a huge benefit in the process planning process when different scenarios or many dynamic influencing factors are present. The DT will be able to determine for a given product condition (e.g. a certain gear is broken), the detailed description of possible process alternatives (e.g. disassemble the gear housing) that are required to realize the remanufacturing of the component.

3.2.5. Demand and Supply Forecast

This service supports de- and remanufacturers in the medium-term production planning, the long-term capacity planning activities, and the economic assessment of circular business cases on new products and second-life material/product pricing. On the basis of product sales data, statistical methods, e.g. time series analysis, regression analysis and seasonal factors, in combination with stochastic product life cycle models, can be used to forecast the expected quantity and quality of returned products or their components. By using actual data of returning products, these statistical models and the forecast can be refined, in order to forecast also the quantity of the demanded remanufactured products. Multi-method simulation is developed to model the stock and flows for de- and remanufacturing, for example by system dynamics, and to capture the user behaviour towards the second-life products, for example by agent-based simulation.

3.2.6. Circular Production Planning and Control

The aim of this service is to provide a simulation software supporting production planning and control in circular value-chains, with the possibility to match the value stream of the production system with the de- and remanufacturing system implications. Challenging factors, such as the high volatility of the returned cores, the non-deterministic production process due to products state variability, and the uncertain demand from the aftermarket have to be analysed and included for a correct and comprehensive simulation model. Existing production planning and digital technologies are integrated in this service, resulting in economical and strategic recommendations for the planning of remanufacturing and new product production. The robustness of the implemented algorithms take into account typical uncertainties in cyclic material flows, such as instability in post-use product quantity and quality and demand turbulence.

3.2.7. Testing and Certification Services

Economically sustainable remanufacturing and recycling can be achieved only with the availability of sufficient information regarding the composition of components and the materials, and the production processes. The lack of knowledge can make perfectly appropriate reusable material unusable scrap. To prevent such occurrence a portion of every new supplied goods need to go over a lot of chemical and mechanical testing. Digitalization is the key to spare remanufacturing and recycling companies form more and more repetitive testing. A service, which collects relevant information from the producer and accommodates external independent experts' reports, can serve as a shared datasource for CE stakeholders and interested new-

comers. Certifications are a promising aspect of such service too, to propagate the vision of CE.

4. CE transition use-case

To address information asymmetry among value-chain stakeholders DigiPrime implements the list of DOS presented in previous Section 3. In this section we explain in more details how such a service oriented system can assist an electric-car repair network in setting-up their reorganization and so gain relevant CE value-chain partnerships. To help understanding the utility and effectiveness of such approach, we present a service exploration experiment with its relative step-by-step service use scenario. Fig. 4 illustrates the current positioning of the stakeholder within the CE, whereas Fig. 5 visually depicts the service journey explored by the repair-shop through the DOS, in order to transit and expand to a CE cross-sectorial value-chain (boxes reported in gray refer to horizontal services of the DigiPrime platform published separately and are out of scope in this manuscript).

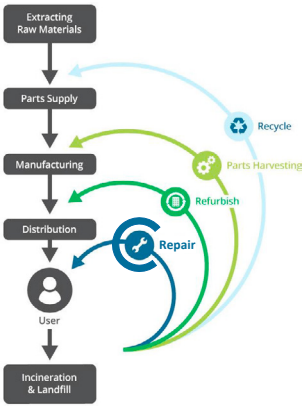

Fig. 4. Repair-shop current positioning in the CE [14]

Step 1: During the maintenance of EV multiple parts need to be assessed. One of the most crucial ones is the battery. The repair shop has access to the battery management system, so the digital use-phase logs are there to help determine the SoH of the battery. However evaluating the raw digital data can be challenging. For this purpose the monitoring service's data enrichment feature is a necessary first step. Whereupon the next service's duty is to check the health condition with artificial intelligence tools. Based on this assessment the decision support system will guide the mechanic to give a thoughtful estimation on the battery and convey this to the customer. This is a digital support from the platform at operational level for assessing and sorting parts under maintenance.

Step 2: After this first basic exploitation of the platform, the next progressive step is to join the CE ecosystem by means of the provided tools. This step is more of a horizontal connection with other participants, than the in-house vertical integration supported by the DOS. Therefore this has less relevance in this publication. In brief, a discovery service is mandatory to match the supply and demand requirements. Based on this matching, the repair-shop network can establish a long lasting partnership by joining the reverse logistic chain as disassembled parts supplier and a customer for recovered parts.

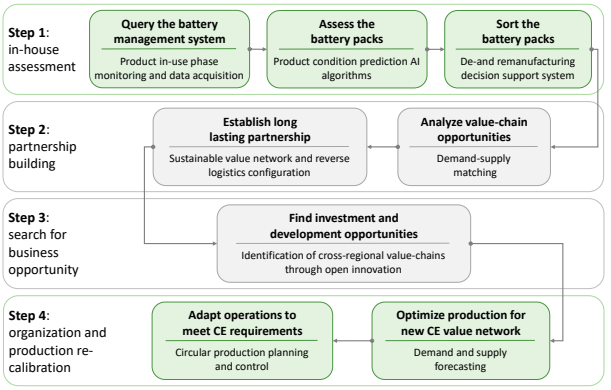

Fig. 5. Possible service link sequence in the repair-shop CE use-case

Step 3: For a company aiming for prosperity, the next economical step probably is to invest profit in new potential business perspectives and sustainability, which is one of the most promising dynamically growing trends today. The DigiPrime platform provides services that identify value-chains through open innovations, which can highlight the potential of the investment. For example new automation technology for battery disassembly can be a good developmental opportunity even for a repair shop network. In this manner they can increase their engagement in the CE supply-chain network.

Step 4: Once a new CE business direction is finalized, it is vital for a company to align the traditional organization with the new business sector's requirements. Hence new operation services are required: a forecasting tool to predict the demand for disassembled battery parts can help to gauge the volume they have to supply. Business is driven by deadlines and one company needs to schedule their processes to meet the customers orders. For a repair shop network, this can be a relatively new situation and the DigiPrime platform provides the necessary production planning and controlling tool to meet the deadlines. Thanks to these operational improvements a mature CE stakeholder can play an active role for a sustainable economy.

5. Preliminary realization and integration

DOS providers of the federation offer services and data that can be accessed by other nodes, combined with optional added-value and sector-specific functions and data, provided by third parties. The inter-operation among nodes is ensured by an OpenAPI based set of functionality that the platform offers (profile registration, circular entity management, material/product data publication, matchmaking and negotiation, and so forth). Stakeholders will be able to publish their offer from one node and then the federation will make them visible for searches, analytics and other information discovery. Each DigiPrime service

is developed in compliance with the twelve-factor methodology for building software-as-a-service apps, and packaged and delivered using the Docker containerization technology. Different types of integration mechanism are provided by the platform, according to each DOS specific disclosing requirements and the pilot data confidentiality: fully integrated in the platform (deployment + circular data sharing), partially integrated (deployment on the DOS provider's premises but with circular entity data sharing with the platform) and stand-alone (in this last case, the DOS does not share service logic nor CE related data with the platform but it is connected for user identification and service provision tracking functionality). DOS are tightly connected to the concept of data sharing by means of smart contracts, which define who can access the data and under what conditions. Through a data channel, only specific business entities (organizations, companies, etc.) will have access to specific datasets. It is a contract between the data owner entity and the authorized entities that can retrieve those datasets. The goal is to secure the trust among all stakeholders.

6. Conclusion

SME willing to enter CE value-chains need practical and technical advice, as well as the proper support. This can be facilitated by digital platforms such as DigiPrime, which offers a step-by-step service mechanism and helps evaluate the feasibility and profitability of CE enabling business scenarios for SME. Showcasing these use-scenario success stories from SME with international experience would intensify the exchange of experience between SME and facilitate the creation of partnerships. In order to have a functioning digital platform, it is essential that SME end-users provide minimal but trustful information on their company, their services, their products and their innovations, without revealing trade secrets that give them a competitive advantage. Fundamental is the role played by the presented DOS for SME: highlighting the financial advantages of resource and energy efficiency, the access to innovative manufacturing services, as well as mentioning the potential for improving competitiveness in a cross-sectorial environment appears to be promising in attracting SME toward CE supporting digital services.

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