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Information flows supporting Circular Economy adoption in the manufacturing sector

Federica Acerbi[1[0000-0002-0818-4620]] and Marco Taisch[1[0000-0003-2016-3571]]

[1] Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milan, Italy
federica.acerbi@polimi.it
marco.taisch@polimi.it

Abstract. Circular economy (CE) is considered one of the drivers pushing towards sustainable development. Indeed, this economy is defined as an "industrial economy that is regenerative and restorative by intention and design" and thus, it boosts responsible consumption and production which is one the sustainable goals promoted by policymakers. In particular, from the extant literature emerged that to pursue the transition towards CE, manufacturers adopt different CE strategies. Their implementation implies to have a clear vision about stakeholders involved along product life cycle and about the implications that are encountered during the decision process of the producer thus, by its companies' functions. Indeed, all the actors involved should operate concurrently for a single and common direction. For this reason, the objective of the present work is to investigate the vertical information flow within a manufacturing company at strategic, tactical and operational levels while adopting CE strategies to appropriately manage product lifecycle. The paper objective is pursued through a literature review on Scopus together with practitioners' interviews. The outcome is the development of a conceptual framework to support the decision process. The framework structures the information flow for adopting CE across the three levels above mentioned. Indeed, the main finding of this research is the key role of information as a facilitator for the adoption of circular economy strategies in manufacturing.

Keywords: Circular Economy, Manufacturing, Information Flow

1 Introduction

Nowadays, the limited resource availability of our planet is one of the main criticalities that our society is facing [1]. For this reason, sustainable objectives have been proposed to be fulfilled by people in their daily activities and by companies while running their industrial activities, among which production and transportation. These are commonly

called "*sustainable development goals*" and, they promote sustainable development in respect of planet resources generation such as "responsible consumption and production" [2]. In order to achieve these goals, structured guidelines should be promoted, and specific sustainable strategies should be designed. A first attempt has been done by The Ellen MacArthur Foundation, which promoted the adoption of circular economy (CE). This economy is defined as "*an industrial economy that is restorative and regenerative by intention and design*" [3] and it might be used as mean towards sustainable development by the society as a whole, but especially by manufacturers. Indeed, considering the prominent position of manufacturers in consuming resources generated by natural systems, in the extant literature more than one CE strategy has been studied as a possible application boosting the sustainable development of this sector. More in detail, different research streams have been identified and what they all have in common is the need to define a structured decision process supporting the adoption of CE [4]. Indeed, manufacturers usually are forced by internal rigidity, and this limits them to efficiently undertake the transition from a linear economy towards a circular one.

Indeed, the objective of this~~e~~ paper~~present work~~ is to develop a conceptual framework aiming to facilitate this transition by structuring the vertical information flows of the company's functions, (i.e. the one occurring among the strategic, tactical and operational hierarchical levels), that ~~of the main company's functions~~ emerged to be the most affected during the transition~~involved in it~~, by allocating to each ~~hierarchical~~ level the corresponding decisions and related information required to manage the product along its life cycle with a circular vision. This has been partially proposed in the extant literature to design the right reverse logistics network [5]. Nevertheless, the perspective of the focal firm has been neglected in the extant literature, and whenever present, it has been tackled only from the strategical perspective. Therefore, this paper aims to cover this lack, by including in the analysis the strategic, tactical and operational perspectives ~~, the three main hierarchical levels,~~ through ~~the lenses of~~ the producer's lenses to facilitate the adoption of CE.

The structure of the present work is the following: (2) "Methodology" to explain how the research has been conducted~~developed~~, (3) "Theoretical background" to elucidate both the CE concept and the traditional decision process of manufacturers, in order to put the basis of this research~~to integrate them into a unique framework~~, (4) "Practitioners' interviews" to add value and validate the literature findings by observing the industrial field, (5) The section "Information flow for circular economy adoption" in which results and discussions are reported~~,~~ relying on both scientific literature and practitioners' interviews. In this section, ~~,~~ it is presented the conceptual framework to structure the vertical information flow of the different company' functions involved in the transition, (6) "Conclusions" to elucidate and discuss the main findings and limitations of the work.

2 Methodology

To create the ground for this research, a first overview of CE strategies adoption in the manufacturing sector has been provided, together with an overview of manufacturers'

organization structure and internal decision process. ThenTherefore, a literature review has been performed to envisage the main information required to take adequate decisions to manage the product along its life cycle under CE. The main findings from the review have been benchmarked and validated through practitioners' interviews. Indeed, lLeveraging on both scientific literature and practitioners' interview, a conceptual framework has been developed. This aims to clear-out the main information flows required, in a structured manufacturing company, to facilitate the transition from a linear economy towards CE of the company itself enabling to appropriately manage the product along its life cycle. In particular, the vertical information flow regards the three main hierarchical levels related to the company's functions mainly involved in the transition towards CE.

The literature review has been developed by using Scopus as search engine that was queried with the following keywords: (i) (("circular economy" AND "manufacturing") OR "circular manufacturing") AND ("decision*" OR "data" OR "information"); (ii) ("decision process" AND "Strategic*" AND "tactic*" AND "operat*"). These two strings of keywords were first used separately in parallel and then together. The literature review developed, together with the experts' interviews, enabled to classify the main issues faced by the manufacturer during the transition, and the information required according to the level of responsibility, in order to establish the right information flow through the strategic, tactical and operational levels while adopting CE strategies.

3 Theoretical background

3.1 Circular economy

During the '90s, to pursue a sustainable development path, the concept of CE started to arise [6]. As previously mentioned this economy aims to ensure resource regeneration and restoration and. In particular, it is characterized by three main pillars: (i) preserve and enhance natural capital, (ii) optimize resource yields, (iii) foster system effectiveness [3]. ; which are reflected in more exhaustive principles: (i) *Design out waste* by limiting waste generation from the design stage of product and systems, (ii) *Build resilience through diversity* by boosting modularity, versatility and flexibility of the systems, (iii) *Rely on energy from renewable sources* by making them running relying on only these types of resources that are easily accessible, (iv) *Think in systems* by understanding how different parts of the system and actors influence one each other and the types of relationships they have, (v) *Waste is food* by reusing as a resource for another system [7].

These pillarsrinciples have been adopted by manufacturers and created the ground for the development of several different types of CE strategies [6]. Among the possible CE strategies adopted by manufacturers, there are: circular design practices [7], remanufacturing, recycling, reuse [8], closed-loop supply chain [9], industrial symbiosis [10] and others. Moreover, the transition from a linear economy towards CE modifies the internal structure of companies since new stakeholders are involved and different activities are undertaken [10]. According to the extant scientific literature, the companies' functions most involved while adopting these CE strategies are procurement (e.g. [11]),

product design (e.g. [7]), production (e.g. [12]), logistics (e.g. [13]) and customer care (e.g. [14]) and they all require specific sets of information. Actually, the most challenging barrier in adopting CE strategies ~~, according to the extant scientific literature,~~ is information management and sharing [15]. It emerged the need to have a structured decision-making process relying on an adequate information management ~~process~~ [4]. Therefore, to embrace CE, it is required to manage information about the entire product life cycle[16], which exits companies' boundaries and requires the firm to gather and manage information not only referred to internal processes, but also referred to other actors' behaviours, both internal and external to the supply chain, which are involved along circular product life cycle [13].

3.2 Decision process within a manufacturing company

According to the extant literature, the main barrier to adopt CE in manufacturing companies is information management, which becomes a challenge for the decision process. Indeed, the structure of manufacturing companies usually leads towards a high level of rigidity especially whenever the dimensions in terms of human resources and plants are huge. Therefore, companies require to coordinate their internal activities both among functions, thus horizontally, but also vertically among different levels of responsibility. Actually, managers, in this context, hold a relevant position to guide their companies in moving towards CE adoption [17]. T~~In order t~~o streamline the vertical information flow and to facilitate the decision process to efficiently manage enterprises, the distinction among strategic, tactical and operational levels, that are the three major hierarchical levels, has been proposed for years [18]. I~~The i~~nformation granularity is different according to the levels, which are~~is~~ characterized by specific responsibilities. T~~Indeed, t~~hese are reflected in determined decisions to be taken and required information whose aggregation level increases in line with the augment of the responsibility. In particular, the strategic level requires aggregated information to make decisions covering the longest time horizon thus, these are the most difficult to be changed and impact the entire organization's main direction. The tactical one must be highly integrated and aligned with the strategic level to pursue a common and shared direction. The time horizon characterizing this level is ~~a little bit~~ shorter and its role is to guide the operational level, in charge of making daily decisions covering a limited time horizon, towards the concrete adoption of the general guidelines proposed at the strategic level [5]. The major barrier stands into gathering the right information according to the level, to appropriately take decisions by streamlining the vertical flow of information, and push the entire company in embracing CE pillars.

4 Practitioners' interviews

Practitioners' interviews were conducted~~performed~~ with Italian manufacturing companies characterized by one of the two following issues: (i) they have~~e~~ the intention to undertake the transition, (ii) they have~~e~~ already put in place specific actions towards CE.

The interviews were developed ~~in order~~ to understand in practical terms the main issues regarding the decision process encountered in adopting CE strategies. The main barriersfindings~~, which were~~ highlighted by most of them, are reported below and they all agreed that the enabler would be the adequate information sharing and management. The decisions to be made and the required information are reported in sub-section 5.1 together with literature findings.~~.~~

The first obstacle is to educate final users to prevent the product from becoming waste and to enable its restoration. This is possible only if the product itself is designed to allow its disassembly and reusability or the recyclability of its components and materials. Therefore, to educate end-users, once the product has been designed with circular characteristics, adequate information should be given to them to avoid the final landfill. Once the product becomes "waste" its juridical status changes and it cannot be anymore restored as a resource. Thus, in this latter case, all the circular end-of-life practices cannot be adopted and, the disposal becomes the only action to be undertaken.

Second, they observed difficulties in managing products end-of-life whenever they do not own all the information related to product components and materials. This becomes a problem especially when the producer is not the same actor managing product end-of-life, thus it should be promoted the tracking of the product information.

Third, they observed the need to structure the information flow across the organization value chain since they consider essential to provide a common direction. Indeed, being already many the trade-offs to be balanced, even without the introduction of CE adoption, it would be difficult to efficiently move the entire organization towards CE. For this reason, the integration must be done not only horizontally but also vertically starting from the strategic level.

5 Information flow in circular economy adoption

According to the findings in the scientific literature regarding the CE adoption in the manufacturing sector, there is still not an overall framework enabling the structured vertical information management flow within the company, even though the transition towards CE impacts the entire company and all its internal activities. This is the reason why the unique direction must be given first by the highest level of responsibility, in order to ensure awareness in the entire company about the transition [17]. Moreover, this direction must be translated into guidelines and more operative tasks to be assigned at lower levels in the company hierarchy. Nevertheless, in the extant literature, the CE concept has been usually tackled from a strategic point of view. Since, both from the scientific literature and also from practitioners~~,~~ emerged the need to integrate the entire vertical structure of manufacturing companies with the CE pillars~~rinciples~~ to efficiently undertake the transition ~~towards CE~~, the two concepts and the results from the field and from the literature have been merged into a unique framework. ~~The framework was developed merging what arose both from the scientific literature and the practitioners' experience.~~ The explanation is reported in section 5.1.

5.1 Strategic, Tactical and Operational decisions towards CE adoption in a manufacturing company

The decision process supporting the transition towards CE is quite complex being it impacted by heterogeneous stakeholders affecting ~~influencing~~ the product life cycle, and for this reason, ~~and, as reported in the theoretical background section, there are~~ some functions' decisions ~~that~~ are highly~~mostly~~ impacted during this transition by external actors and need to coordinate themselves. Moreover, all t~~Moreover,~~he decisions are governed by CE principles, sustainable government regulations, and sustainable-related standards, and ~~these~~ are characterised by three levels as reported in the framework in .

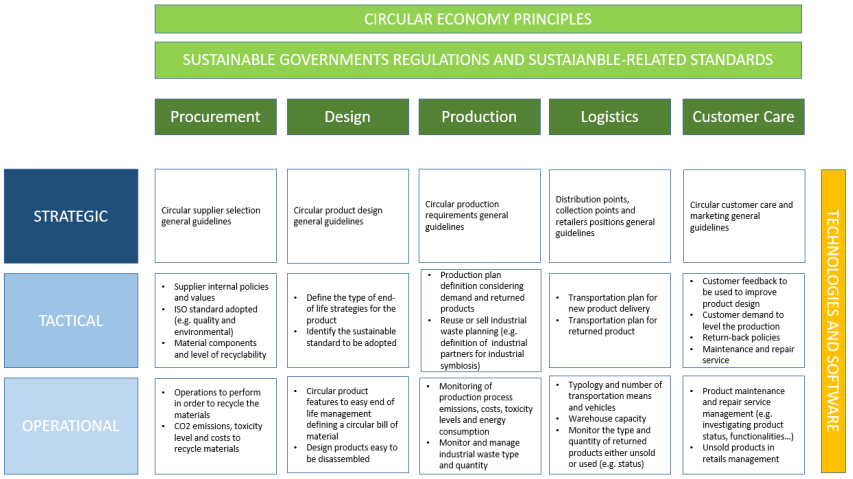


Fig. 1 Information flow framework for circular economy adoption in manufacturing

T~~As stated before, t~~he strategic level is the one that guides the entire company by taking decisions that cover a longer time horizon and it requires a low level of information granularity [5]. This level owns the responsibility to clearly state in the mission of the company the willingness to adopt CE principles, thus the information to be managed are at firm level with a general overview of the external context in which the company operates. In this way, the company can both show to the external stakeholders its "circular values", while simultaneously make aware of these values the company's internal stakeholders. This concerns also the definition of new strategies and overall principles to be followed for the single company's area. Moreover, at this level should be defined as the capital allocated for the investments in technologies and software that enable to efficiently support the transition [19]. The technology type is defined at the tactical level since the needs are ~~required technologies are~~ different according to the area ~~and, the typology is defined at the tactical level~~. The~~ir~~ functionalities are defined at the operational one where ~~since at this level~~ the requirements necessary to conduct daily activities are well known.

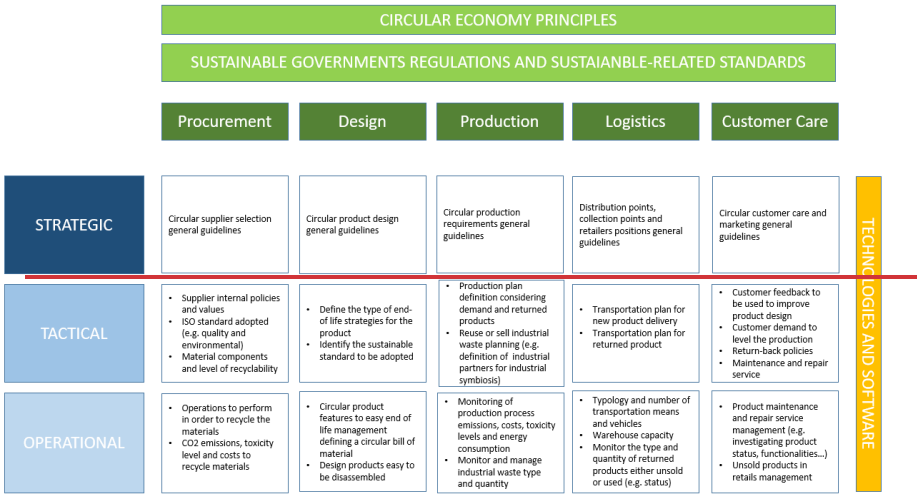
T~~In order t~~o manage more concretely the transition, the tactical level must be involved. At the tactical level, managers must concurrently operate to build systems in

line with the overall mission. They need to put in place the general guidelines proposed by the strategic level. Concerning the selection of suppliers, their benchmark should be done by investigating the standards adopted, the internal policies with the related values and the materials supplied. In particular, there should be information about the material components and the possibility to recycle them [20]. Moreover, designers should consider the circular end-of-life management practices the product should be able to perform and the sustainable standard to be used, both affecting product features. The production plan should be defined according to market demand and sustainable standards. Moreover, during the production process, industrial waste might be generated and, the tactical level should define either the policies to reuse that scrap or industrial partner to sell the waste. According to the demand, returned products, distribution points, and retailers' localization, the definition of transportation plan should be defined for the logistic [21]. For customer care, they should manage their feedbacks to improve product design and monitor the demand to align the production. Moreover, they should define returned-back policies and maintenance and repair service [22]. Therefore, at tactical level, the information required is focused on the firm's functions, and on the basis of internal general information such as on product characteristics and processes ones, the information to be gathered need to be extended also over external actors belonging to the supply chain. This requires to better understand customers' behaviours and suppliers' characteristics and thus to be able to gather this type of information.

Last, at the operational level, all these decisions must be translated into concrete information and data. Considering the procurement of materials and components, at this level must be gathered information about the operations to be done in order to recycle the materials and the relative costs and CO2 emissions. For the design area, the information required is related to the definition of a circular bill of material. This is reflected in the definition of circular product features that must facilitate the circular product life cycle, among which the possibility to easily disassemble the product. Indeed, it is required to ensure easy product maintenance, reparability, reuse, remanufacturing and recycling. Regarding the production, the information gathered should enable the monitoring of production process costs, CO2 emissions, toxicity level, and energy consumption, but also information regarding the type and quantity of industrial waste created during the production process [12]. The logistic should have the information required to monitor the type and quantities of returned products (both used and unsold products), to manage the warehouse capacity and the transportation in terms of localization and quantity. Customer care should be devoted to understand the main issues regarding unsold products in the retailers and to manage the product maintenance and repair service by investigating for each product the status and functionalities. At this level, product-related information must be gathered and managed to take right operational decisions.

~~To conclude, the decisions, taken by each function, are governed by CE principles, sustainable government regulations, and sustainable-related standards.~~

~~The integrated framework is reported in **Figure 1**.~~



~~Figfure 1~~ ~~Information flow framework for circular economy adoption in manufacturing~~

~~10~~6 Conclusion

To efficiently undertake the transition towards CE and thus, to appropriately manage the entire product life cycle, different companies' functions should be involved at all the hierarchical levels. In particular, those highly affected are procurement, design, production, logistics and customer care. These need to be guided starting from the top management, thus the strategic level, to then translate the overall strategy into more operational tasks, passing through the tactical level. Indeed, the company must be cohesive both horizontally and vertically to face this challenging transition.

The framework proposed in the present work aims to cover the lack identified in the extant literature regarding the need to study the adoption of CE, through the lenses of the focal firm, not only with a strategical perspective, but by digging deeper also in the other levels to operationalize the transition. In future researches, this framework should be applied to a case study and it should be extended by studying in detail all the information and data required. Data management is the core aspect of this context. Indeed, to make the right decisions, the information must be gathered carefully and should rely on adequate data, whose collection might be done either though software or other technologies. Indeed, data management systems should be adopted, and their functionalities and characteristics should be defined in future researches. A conceptual data model could be developed in order to define the required classes of data and their relationships.~~.~~

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