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LEADING QUESTIONS TOWARDS BUILDING A DIGITAL COCKPIT FOR CIRCULARITY IN THE HEALTHCARE INDUSTRY

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Abstract:

Transitioning from a linear economy to a circular economy (CE) in healthcare is essential for reducing human-induced environmental impacts and promoting sustainability. However, this shift is challenged by a lack of standardization in circular procedures. This article identifies key elements and challenges to implementing CE in complex industrial environments, with the use case of medical systems. These entail complex devices, such as Magnetic Resonance Imaging systems or Computed Tomography scanners. While CE principles have emerged in the medical industry, they must be improved and optimized especially in repair, maintenance and reuse processes, to support the decarbonization of healthcare. In the industrial case study, this is illustrated by the implementation of opportunistic maintenance for a spare part supply chain, or the use of a PSS-like (product-service system) model. In this context, literature is studied by focusing on three axes: (1) academic articles, (2) sustainability standards and frameworks for industrials, and (3) grey literature in a healthcare case study. This article aims to answer the following question: *What are the main identifiable challenges to a circular economy in the medical system value chain, looking at a complex industrial environment case study?* To better implement and evaluate CE in an industrial setting, companies need to reevaluate their business models and follow the 4.0 digital technology wave by augmenting or redesigning their ecosystems, facilitating the computation of circularity indicators. These metrics could provide more visibility and traceability on material flows, notably open & closed loop recycling, product returns, waste management and packaging loops. Additional constraints to achieve CE can be pinpointed by studying existing sustainability standards and policies on European or international levels. The results of the research identify twelve leading questions tackling CE reporting and evaluation, the digitalization of industrial ecosystems, and the identification of the initial steps to develop a Circular Digital Cockpit (CDC). Hence, four research themes are identified: (1) updating industrial paradigms for CE, (2) defining means for transitioning from LE to CE, (3) studying the status of CE in the healthcare industry, and (4) developing a CDC. The identified questions will guide ensued research and potentially discern gaps and hotspots for evaluating and monitoring CE practices, to ultimately create a comprehensive multi-faceted platform. Such a tool would bring decision aid to all steps in the medical device value chain, from product design to its end-of-life. Looking at the industrial use case, a preliminary framework to design this platform is proposed, with four structuring and interlinked pillars: robust data definition, circularity metrics, analytics & optimization, and models & simulation.

Keywords: circular economy, circularity indicators, data science, medical systems, product-service system

1 INTRODUCTION

The circular economy (CE) aims to minimize waste and maximize resource efficiency by designing out waste and pollution [1] and keeping products and materials in use for as long as possible [2]. In such a system, resources follow a continuous cycle, where products are reused, repaired, remanufactured, and recycled rather than discarded after a single use, as in a linear economy [3].

In this objective, the proposed research topic revolves around the sustainability of medical systems, such as magnetic resonance imaging and computed tomography scanners, specifically focusing on integrating eco-circularity through data science. The motivation for this research stems from the need to consider CE principles and environmental impacts in repairing, maintaining, and reusing medical devices, as these activities are a significant contributor to pollution. In 2023, the French healthcare sector represented 8% of its GHG emissions nationwide, approximating 49 million tons of CO₂ [4]. Scope 3 emissions associated to healthcare activities, such as purchasing medical devices, transport, and waste management, make up 87% of these emissions [4]. Additionally, for international scope 3 emissions, Healthcare Without Harm declares an essential action towards climate-smart healthcare: "Set and implement criteria for low-carbon or zero-emissions procurement so as to begin to decarbonize the supply chain" [5].

Hence, the research will address various challenges, such as the complexity of medical systems, regulatory requirements, and the trade-offs between environmental, technological, and economic performance. In this objective, the research aims to answer the following question: *What are the main identifiable challenges to a circular economy in the medical system value chain, looking at a complex industrial environment case study?*

2 METHODOLOGY

To answer the research question, three axes for literature selection are identified, enclosing multiple relevant facets of CE:

1. An academic publication database – Google Scholar
2. Sustainability policies and standards used by industrial firms
3. Our use case, GE HealthCare (GEHC)

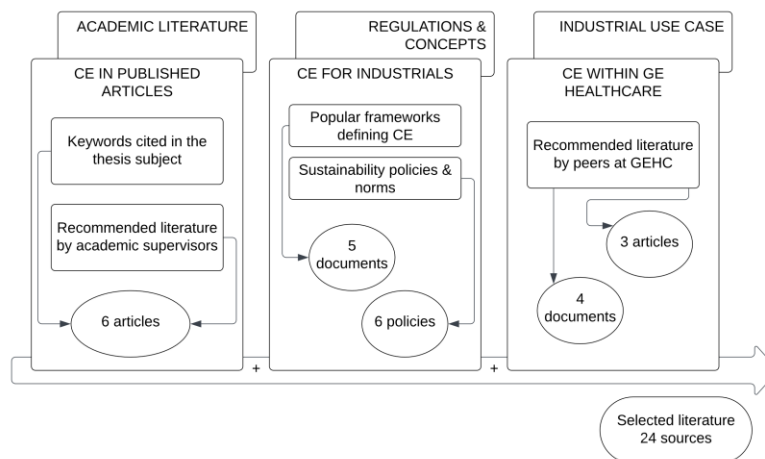


Figure 1. Resource selection workflow

The methodology workflow is detailed in Figure 1. Three types of accessed sources can be distinguished: academic articles, industrial/business documents, and official regulations and policies. These sources were selected opportunistically, considering citations, recency, or relevance of abstracts/summaries to the research question.

Six initial academic articles [6, 7, 8, 9, 10, 11] were accessed through either recommendations from academic supervisors or arbitrary combinations of a few keywords associated with the thesis subject: circularity indicators, carbon footprint, medical systems, CE, product-service system, and waste reduction. Then, focusing on the definition of CE for industrials, public resources such as regulations and popular frameworks defining standards and CE concepts were accessed. This concluded in selecting eleven documents, including six policies [12, 13, 14, 15, 16, 17] and five grey literature documents [1, 2, 3, 5, 18]. Lastly, peers and supervisors at GE HealthCare recommended three articles they had personally published [19, 20, 21] and documents they found relevant to the subject [4, 22, 23, 24].

3 RESULTS

3.1. Implementing and evaluating eco-circular initiatives in industrial environments

A seamless transition to the CE for businesses is not evident, as this change of paradigm requires firm-scale changes and optimization. Means to reach this can interfere with adjacent themes, such as environmental and socioeconomic impacts. This is prominent if firms have not implemented solutions regarding their sustainable impact from the get-go, as integrating eco-conscious tools from the start of product development is fundamental to evaluating their sustainability [11]. *How can industries update their business models to help this transition?*

In a strict linear economy (LE), products are directly sold from the business to the client, leading to excessive waste due to a lack of recycling, reuse, or repair. An important part of CE, as defined as one of its seven pillars by the Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME) [24], is “a functional economy” i.e., product-service systems (PSS). Instead of, or in addition to selling products, companies sell services associated with a commodity, with the customer purchasing a guarantee of repair within a limited timeframe and maintenance to ensure both continuity of service and extended service life. *What tools can be successfully implemented to aid this transition?*

Digital Technologies (DT), notably linked to the industry 4.0 wave, are increasingly identified as essential to solving this problem. DT, such as artificial intelligence, data science, digital twins, highly impact the mindsets of corporate boards and their businesses [6]. In a survey of 250 executives conducted by Subramoniam et al [6], 75% thought that AI would change their business in the next three years. However, the literature does not necessarily provide detailed frameworks for their implementation [10]. An initial response could be a model in which precise objectives are defined and should be fulfilled by implementing DT, e.g., better resource management, extending product lifespan, and closing the supply chain loop. These objectives correspond to the main phases of the product lifecycle: product design, use, and recovery. As this theme gains traction in the academic scene, researchers explore various tools to measure circularity in manufacturing systems, introducing circularity indicators (c-indicators) applied to different axes, such as sustainability assessment and effective decision-making [3, 7]. Such indicators have great potential to effectively measure the circularity over entire supply chain processes, especially if they encompass impacts on recycling, resource efficiency, waste management, as well as carbon emissions, water usage, and energy consumption. Compared to recycling indicators, they would not neglect certain aspects and trade-offs. This poses the question, *How does one define the scope of a circularity indicator – what are the appropriate data, facets, systemic levels, impacts, processes, and actors to comprehend?*

3.2. Reporting sustainability in industrial environments

As carbon emissions produced by supply chains have a significant weight globally e.g., 8 supply chains represent 50% of global emissions [18], standards and regulations are being developed to hold manufacturers accountable and incentivize them to take initiative towards eco-circular practices. *What are the existing norms for industrials regarding sustainability and circularity?*

The World Business Council for Sustainable Development (WBCSD) is on the industrial forefront, offering insight into corporate sustainability. This entity encompasses a broad international range of businesses and industries, with over 255 members in different sectors, aiming to shape their strategies and align them with global environmental goals. This translates through one of their considerable contributions, their yearly iterations of Circularity Transition Indicators - Metrics for Business by Business since 2020 [17]. Internationally, the ISO 14000 family of standards [12], established in 1996, provides a structured approach to environmental management for businesses and organizations. They aid in minimizing ecological footprints, highlighting the importance of systematic environmental management and sustainability approaches. In line with these environmental practices, the upcoming ISO 59000 series [13] clearly states the need to transition from a linear to a circular economy. This series focuses on measuring and assessing circularity, standardizing data for products, and implementing traceability of materials.

The Sustainability Accounting Standards Board (SASB), founded in 2011, tackles the financial facet of sustainability, emphasizing the importance of transparent reporting. It marks a significant shift in how businesses account for and communicate their environmental impact. In Europe, corporate sustainability reporting has become mandatory for fiscal year 2024. The EU Taxonomy, published in 2020 [16], provides a clear and standardized definition of sustainable economic activities focusing on climate change. This classification aims to help companies and their financial counterparties in their decision-making toward more sustainable choices. The EU taxonomy is crucial for the EU's sustainable finance framework and market transparency. This framework is a backbone of the Corporate Sustainability Reporting Directive (CSRD) [14], proposed in 2021 and implemented in the financial year 2024. It comprehends more themes than the taxonomy – pollution, water management, CE, workforce, governance, value chain, etc. – but still uses its eligibility and alignment criteria for its reporting.

There is an outlook for a more robust European standard at the scope of the product. The adoption of the Digital Product Passport (DPP) in 2022 [15] demonstrates how technology can enhance transparency and sustainability throughout the product lifecycle. The digitalization wave will help provide, for each product, a comprehensive and detailed rundown of its materials, usage, and end-of-life possible outcomes. Hopefully, most industries will be subject to the DPP by 2030.

3.3. Implementing and evaluating eco-circular initiatives in industrial environments

As the CE theme gains popularity, certain industries are more advanced than others in making sustainable changes. *What are the biggest current challenges regarding circularity in the healthcare industry?* The healthcare industry is often overlooked regarding its potential in CE transition due to its single-use mindset and the infectious, toxic nature of healthcare waste (HCW). HCW is growing rapidly, impacting environmental sustainability and public health. Research has identified four axes to handle this problem: (1) HCW minimization, sustainable management, and policy-making; (2) HCW incineration and environmental impacts; (3) hazardous HCW management practices; (4) and HCW handling, occupational safety, and training [9].

This change can be accelerated if corporate businesses set standards for their industrial processes. *What strategies are taken by leaders in the healthcare industry regarding the CE?*

4 DISCUSSION

4.1. The circular economy at GE HealthCare

In this context, the end goal is an application and decision support tool for transitioning to a CE within GE HealthCare. To identify what is missing, GEHC's status and strategies regarding CE must be understood. *What are the existing measures taken at GEHC?*

Given the criticality of their products i.e., medical systems, GEHC has already implemented a CE model for years to maintain those of their customers in operational conditions. Indeed, GEHC offers maintenance services for their customers. The main objective of this PSS-like model is to ensure the reliability of their products i.e., reducing the occurrence rates of breakdowns, and to minimize their downtime along with all costs associated with their interventions. All these elements are linked with the eco-design of the product to ensure product reliability, remote control, diagnostics, reparability, life extension programs for products, and spare parts. In the spirit of increasing the circularity of products and spare parts and extending the system's life, GEHC has a program to buyback uninstalled equipment during socket replacement. The equipment can be sold back to a new customer after refurbishment or disassembled to recover critical spare parts to maintain the remaining installed base. For certain products or spare parts, when the lifetime of a critical component is significantly longer than a product's and under very strict quality and regulatory requirements, there are programs to collect and reuse these components in a new product, qualified as new. In the same way, recycling programs are conducted to maximize valorization [22]. *For a manufacturer and maintenance provider like GEHC, what organization, indicators and decision-support tools should be adopted to successfully implement the transition from LE to CE?*

Furthermore, a couple of PhD theses have been initiated to contribute to significant identified problems in the medical system manufacturing process. A model study was conducted in 2022 [19] to forecast spare part harvesting for GEHC. This is defined as the retrieval and extraction of product components at the end-of-life phase and is a crucial element in the reverse supply chain. This process complements the repair supply chain, which remanufactures products to give them a second life. The forecast of harvested spare parts was successful, using statistical tools. In 2023, internal research tackled opportunistic maintenance in multi-component systems to reduce operational costs and improve reliability. The research introduces a model that accounts for components' structural and economic interdependencies and employs a genetic algorithm to optimize maintenance strategies [20]. Opportunistic maintenance enables targeted repair and replacement of spare parts, which is key to CE, as it makes the system more reliable overtime and limits the frequency of such interventions in the long run. Lastly, a circularity metric adapted from the COCIR model [23] has been successfully applied to a specific imaging system [21]. This metric consists in evaluating the ratio of recycled medical devices compared to the total placed on the market.

4.2. The Circular Digital Cockpit

GE HealthCare has expressed the need for a tool that would aid decision-making in all steps of the product value chain. Indeed, it is stated by Subramoniam et al. [6] that digitalizing systems could benefit businesses by helping them become more sustainable and profitable. To this effect, an architecture for a Circular Digital Cockpit (CDC) is proposed, emulating a digital twin for the whole design process, supply chain, and product lifecycles. This tool would integrate c-indicators, as Saidani et al. [8] show their importance for evaluating the circularity of said processes, as well as developing a decision-making model. *What role would the CDC play at GEHC?*

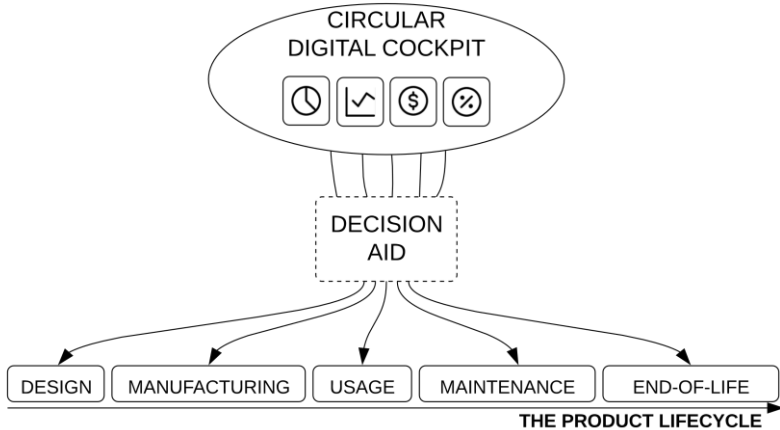


Figure 2. Role of the CDC in GEHC's product lifecycle

Ideally, the CDC will touch all phases of the life cycle (Figure 2), as none can be excluded from progressing towards the CE; therefore, an interesting and significant part of the cockpit would be a view of the step-by-step of the supply chain. Concerned teams, such as – but not limited to – designers, manufacturers, and maintenance, would use the CDC's global view, integrated models, and c-indicators as tools for aiding their day-to-day decisions.

Looking at the design and development of such a framework ensues multiple questions regarding its feasibility: *Today, what are the biggest challenges to this implementation? Within GEHC, to what extent is each step of the supply chain digitalized? Lastly, what are the first steps to developing the CDC?*

Currently, two main pillars that will feed the cockpit can be distinguished: data and simulation models (Figure 3). Data is truly the backbone of this project; its quality must be pristine and its scope well-defined, as it will provide circularity measures within GEHC today and help develop forecasting models to guide decision-makers.

4.3 Preliminary framework to developing the CDC

To develop the CDC, four main sections of ensued research are defined as seen in Figure 3: data (1), metrics (2), analytics & optimization (3), and models & simulation (4). From accessed data, c-indicators and metrics shall be computed (1 & 2), aiding in analyzing and optimizing circular processes within GEHC (2 & 3). This analysis will also help selecting which metrics are relevant to include in the final cockpit (3 & 2).

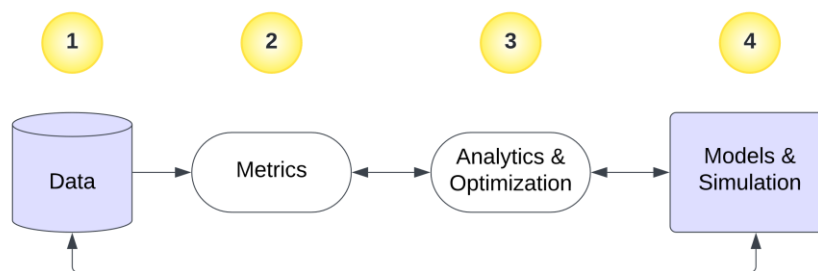


Figure 3. Generalized framework towards building the CDC

In addition to the prominent data pillar, a second is interlinked: models & simulations, as stated in the previous section. It aims to model the product value chain and simulate different scenarios for optimization (4 & 3). An inseparable double-sided relationship exists between these two pillars (1 & 2): as data will feed these models, the latter will also supplement missing values.

5 CONCLUSION

To answer the question: *What are the main identifiable challenges to a circular economy in the medical system value chain, looking at a complex industrial environment case study?*, twelve leading questions have been identified in the results and discussion (sections 3 & 4):

1. How can industries update their business models to help [the transition to CE]?
2. What tools can be successfully implemented to aid [the transition to CE]?
3. How does one define the scope of a circularity indicator – what are the appropriate data, facets, systemic levels, impacts, processes, and actors to comprehend?
4. What are the existing norms for industrials regarding sustainability and circularity?
5. What are the biggest current challenges regarding circularity in the healthcare industry?
6. What strategies are taken by leaders in the healthcare industry regarding the CE?
7. What are the existing [circularity] measures taken at GEHC?

8. For a manufacturer and maintenance provider like GEHC, what organization, indicators and decision-support tools should be adopted to successfully implement the transition from LE to CE?
9. Within GEHC, to what extent is each step of the supply chain digitalized?
10. What role would the CDC play at GEHC?
11. Today, what are the biggest challenges to [the implementation of the CDC]?
12. What are the first steps to developing the CDC?

Raised challenges can be categorized into four themes: updating industrial paradigms for CE (quest. 1 & 4), defining means for transitioning from LE to CE (quest. 2, 3, and 8), studying the status of CE in the healthcare industry (quest 5, 6, 7, and 9), and developing the CDC (quest. 10, 11, and 12).

It is important to note that these questions were identified in a limited amount of time and should be complemented with an extensive/systematic literature review and internal audit, to better understand the given context. Ensued works will take this into account to properly identify research gaps and precise steps to this implementation.

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