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# From Linear to Circular: A Diagnostic Tool for Circular Economy Skills in Industrial Manufacturing.

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**Author: July Fernanda Romero Figueroa**

Student ID: 10902843

Advisor: Name Surname

Co-advisor: Prof. Marta Pinzone

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# Abstract

The transition to a circular economy (CE) is reshaping the manufacturing sector by redefining how resources are consumed, reused, and managed. While technical innovations and closed-loop models are well-documented, the role of human capital—specifically the green and circular skills required to drive this transition—remains underexplored. This thesis addresses this critical gap by developing a comprehensive assessment tool designed to evaluate CE-related competencies among manufacturing professionals. The model is grounded in an extensive literature review, incorporating green, digital, and transversal skill sets, and aligns them with job archetypes across the sector. Drawing from frameworks like the Green Skills Framework, DigComp, and the Worker Profiler tool, the assessment instrument maps individual competencies against ideal job profiles to identify skill gaps and propose targeted upskilling pathways. A radar chart visualization was also integrated to enhance result interpretation. This research contributes to both academic and industry needs by offering a replicable, scalable tool to guide workforce development strategies, policy planning, and organizational transformation toward a sustainable industrial future. The results advocate for a human-centric approach to circular transformation—where innovation is not only technological but also deeply embedded in the capabilities and growth of the workforce.

**Key-words:** Circular Economy, Green skills, Circular Economy skills, Skills assessment, sustainability transition, workforce competencies, Manufacturing sector.



## Abstract in Italiano

La transizione verso un'economia circolare (CE) sta ridisegnando il settore manifatturiero ridefinendo le modalità di consumo, riutilizzo e gestione delle risorse. Mentre le innovazioni tecniche e i modelli a ciclo chiuso sono ben documentati, il ruolo del capitale umano - in particolare le competenze verdi e circolari necessarie per guidare questa transizione - rimane poco esplorato. Questa tesi affronta questa lacuna critica sviluppando uno strumento di valutazione completo progettato per valutare le competenze legate alla CE tra i professionisti del settore manifatturiero. Il modello si basa su un'ampia revisione della letteratura, incorpora le competenze verdi, digitali e trasversali e le allinea con gli archetipi di lavoro del settore. Attingendo a framework come il Green Skills Framework, DigComp e lo strumento Worker Profiler, lo strumento di valutazione mappa le competenze individuali rispetto ai profili professionali ideali per identificare le carenze di competenze e proporre percorsi di riqualificazione mirati. Per migliorare l'interpretazione dei risultati è stata integrata anche la visualizzazione di un grafico radar. Questa ricerca contribuisce alle esigenze del mondo accademico e industriale, offrendo uno strumento replicabile e scalabile per guidare le strategie di sviluppo della forza lavoro, la pianificazione politica e la trasformazione organizzativa verso un futuro industriale sostenibile. I risultati sostengono un approccio umano-centrico alla trasformazione circolare, in cui l'innovazione non è solo tecnologica, ma anche profondamente radicata nelle capacità e nella crescita della forza lavoro.

**Parole chiave:** Economia circolare, competenze verdi, competenze dell'economia circolare, valutazione delle competenze, transizione verso la sostenibilità, competenze della forza lavoro, settore manifatturiero.

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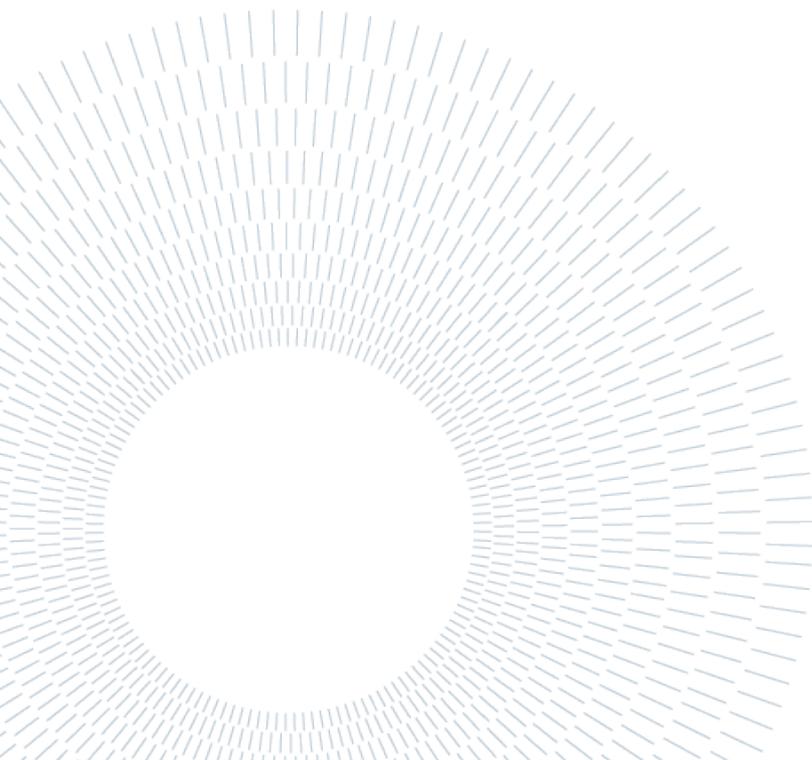
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# 1 Introduction

The global manufacturing industry is undergoing a profound transformation as the urgency of addressing climate change, resource scarcity, and environmental degradation becomes increasingly evident. In response, the circular economy (CE) has emerged as a guiding paradigm—a model that reimagines production and consumption systems to eliminate waste, extend product lifecycles, and regenerate natural systems. For manufacturing companies, adopting CE principles is no longer a matter of corporate responsibility alone; it is rapidly becoming a strategic necessity for long-term competitiveness, resilience, and regulatory compliance.

Despite the growing body of research on CE processes, business models, and technologies, a significant gap remains in understanding the human dimension of this transition. Technological readiness is often prioritized, yet the shift to a circular manufacturing model requires a workforce equipped with specific green, digital, and transversal competencies. These include not only technical knowledge but also systems thinking, collaboration, adaptability, and a strategic mindset capable of navigating complex, multi-stakeholder environments.

While the concept of "green skills" has gained prominence in policy and academic discourse, few tools exist to systematically assess these skills at the firm or industry level—especially in the context of CE. Most existing tools either narrowly focus on digital proficiency or generic employability traits, neglecting the interdisciplinary and future-facing nature of CE competencies. Consequently, organizations face challenges in identifying skill gaps, designing effective training programs, and aligning talent development with sustainability goals.

This thesis proposes a novel assessment tool tailored to evaluate the CE-related competencies of professionals in the manufacturing sector. It begins with a comprehensive mapping of the green, circular, and digital skills needed across various occupational roles, from operations managers to engineers and remanufacturing operators. These are then used to create archetypal job profiles, serving as benchmarks for the tool's self-assessment feature. Drawing from established models

such as the Worker Profiler and DigCompSAT, the tool incorporates a user-friendly interface and data visualization elements (e.g., radar charts) to facilitate intuitive interpretation of results and personalized learning trajectories.

## 2 Literature review

All identified academic articles for the review were evaluated in order to identify gaps and areas requiring further research regarding the given goal to developing a conceptual model and a functional and systematic assessment tool to evaluate the circular economy competences of managers, engineers and operators in the manufacturing sector by pursuing a formal methodological approach in order to reduce distortions by an overly restrictive selection of the available literature and to increase the reliability of the literature selected. The objective of the literature review is also to provide an overview of the current state of knowledge within the domain, highlighting gaps and suggesting avenues for future research to make the strategic planning on human capital more effective.

The scope of the literature review of published research on skills assessment models was limited for relevant articles that explicitly discuss the relationship between the skills that are considered as a fundamental for the transitioning to the CE in the manufacturing sector and the models and platforms that intentionally recognize them and enable the mapping, processing and Analysis of skills. Thus, to develop a model to evaluate the workforce's readiness for demands of Industry 4.0 that considers hard and soft skills focusing on circular and sustainable discourse had to be conducted using multiple approaches at the beginning to identify consistent articles and journal publications. First, a manual search was conducted of sustainability, skills in manufacturing and digital and green behavior challenges in the manufacturing industry that was identified based on the prior research of crucial capacities in the workforce for the transition to the CE. To keep the search manageable, a list of keywords and conceptual frameworks were pinpointed. This resulted in a list of articles that were manually examined and are representative of the main body of research in this domain.

Second, to complement the initial list with papers and studies, a search in online databases was carried including Google Scholar, Research Gate, EBSCO, JSTOR and ProQuest, using many variations of skills tracking applications, frameworks and

mapping digital tools systems, such as “Mapping competencies”, “Measuring skills”, “human capital indicators”, “green skills in Manufacturing” and “cognitive assessment”. Third, the article search was expanded by using forward-and backward-looking references of different models already used in the assessment of skills in the manufacturing that are not directly related to the aim of this research but may be used as some aggregation for the construction of the model, for example, articles for the digital skills management were explored and cited as suggested potential for a review.

All initial articles were scrutinized by the author of the thesis along with the tutor to ascertain whether they might be appropriate for the literature review and the development of the diagnostic tool. For all the potential papers, a full-text examination was conducted to determine the ultimate status of the articles. Only a few ambiguous studies were discussed to be excluded depending on the final purpose. This systematic search resulted in a final of 60 articles that were considered appropriate for the model construction.

Consequently, the theoretical review was structured around the fourth key areas that provide theoretical foundations for further research. First, the transition to the Circular Economy in the Manufacturing Industry is examined, walking through the literature that explains the different stages of the industrial evolution and its consequences in the resource availability, and the underlying necessity of a sustainable economic model [33] [30] [31]. Second, the workforce in the Circular Economy and the rethinking of how products are manufactured is explored and analyzed [10]. Third, in inspection of the green skills in Manufacturing, conceived the skills that involves the capacities required to support and participate in a society that actively seeks to lessen the ecological footprint of human activities [84] [18]. And finally, the identification of the different existing skills profiling tools drawing on research about labour market trends and human capital growth [14].

## 2.1. The Circular Economy in Manufacturing Industry

The interplay between industrial activity and the environment plays a vital role in determining the success of industrial enterprises. Over time, the growing environmental consequences of industrial operations have intensified the pressure on these businesses. Since the onset of the Industrial Revolution, innovations in manufacturing have enabled mass production, making goods widely accessible and

affordable. However, the resulting surge in industrial output, driven by emerging consumer cultures and expanding markets, has led to increasingly serious environmental issues, rising emissions, growing volumes of solid waste, and the widespread use of landfills. Moreover, the global population continues to grow, with a particularly rapid expansion of the middle class, significantly boosting the demand for raw materials. This accelerating consumption of natural resources raises concerns, especially given the planet's finite capacity to supply them [33]. Thus, companies face mounting pressure to comply with environmental regulations while also navigating unpredictable resource prices and supply chain uncertainties. These challenges directly affect their competitiveness and place them in an increasingly unstable position regarding resource availability.

In view of the mentioned series of challenges and highlighted limitations of a linear economy, the perception of a CE is conceived as a solution for a conciliation between the ambitious of a global economy growth and the environmental protection [30]. In terms of production, Geng and Doberstein have used the definition of realization of closed loop material flow in the whole economic system" to refer of the circularity in terms of circular (closed) flows of materials in association with the so called 3R; Reduction, Reduce and Recycling through multiple phases [85]. But for purposes of this paper, the definition more comprehensive is the one of "an industrial economy that is restorative or regenerative by intention and design" by Ellen Macarthur, as it considers the economic and environmental advantages but under the light of regenerative performance requiring high quality circulation while ensuring safe entry of bio nutrients in the biological sphere [26].

Since traditional approaches to business models, product design, and supply chain management have been predominantly shaped by the principles of linear economic systems, these models are frequently ill-suited for addressing the complexities and feedback loops inherent in circular or closed-loop systems. To overcome these limitations, an emerging perspective advocates for a more holistic integration of key business elements—including product development, supply chain dynamics, business models, and customer engagement. Rather than treating these components as separate entities, this perspective views them as interrelated elements that must evolve in tandem to meet the demands of sustainable manufacturing [52].

The Resource Conservative Manufacturing (ResCoM) concept exemplifies this integrated approach. It introduces the idea of designing products for extended

lifecycles, incorporating strategies that prioritize the efficient use of materials and energy, the preservation of economic value, and the reduction of waste. Environmental considerations are embedded directly into the early stages of product development, making sustainability a core principle rather than an afterthought. Research suggests that manufacturing systems grounded in the ResCoM framework tend to be more operationally resilient [9].

Collaterally, the extension of product lifespans and the recovery of end-of-life goods are largely facilitated through the practice of remanufacturing. Although the origins of remanufacturing can be traced back to the early stages of industrialization, it gained substantial traction within the automotive industry during the 1940s, particularly in the aftermath of World War II. The scarcity of raw materials during that period created a compelling need to reuse and refurbish components such as automobile and truck parts. But remanufacturing did not emerge as a distinct area of academic inquiry until the late 1990s. It was during this time that the process began to be conceptualized as "recycling through manufacturing," a term coined by Steinhilper [76]. This approach involves restoring used, durable products to a condition comparable to their original state. The core stages of the remanufacturing process include disassembly, thorough cleaning, inspection and classification of components, reconditioning, and final reassembly.

Parallel to the industrial adoption of remanufacturing, the field of closed-loop supply chain management began to gain academic recognition in the mid-1990s. Today, it is established as a vital sub-discipline within supply chain research. Closed-loop supply chains account not only for the traditional forward flow of materials—from suppliers through manufacturers, distributors, and retailers to end consumers—but also for the reverse logistics involved in the collection and reintegration of used products into the production cycle [74].

In other words, CE makes adequate use of raw materials that we already have and provides a holistic solution to the growing global problem that comes from a linear 'take-make-waste' According to the Ellen MacArthur Foundation, the CE aims to design waste while keeping products and materials in use for as long as possible, thereby minimizing the need for virgin resources. From this foundational perspective, four key strategies can be identified that facilitate the transition from linear to circular systems [26]. These strategic pathways recur consistently across the CE literature and align closely with the elements outlined in the various "R" frameworks, which serve as practical guides for CE implementation and these frameworks provide structured

methodologies for operationalizing circular principles within different sectors [28] [72] [81] [62].

Table 2.1: R Strategies in the Circular Economy Ordered by Degree of Circularity [54]

| <b>R strategy</b> | <b>Description</b>  |
|-------------------|---|
| 0. Refuse         | Make product reductant by offering same function with different product           |
| 1. Rethink        | Make product use more intensive (e.g. sharing)                                    |
| 2. Reduce         | Increase efficiency in manufacturing by consuming less resources and materials    |
| 3. Reuse          | Reuse by another consumer of a discarded product that is in good condition        |
| 4. Repair         | Repair and maintenance of a defective product                                     |
| 5. Refurbish      | Restoring an old product and bring it up to date                                  |
| 6. Remanufacture  | Using (parts of a) discarded product in a new product with the same function      |
| 7. Repurpose      | Using (parts of a) discarded product in a new product with the different function |
| 8. Recycle        | Processing materials to obtain the same (or lower quality)                        |
| 9. Recover        | Incineration of material with energy recovery                                     |

From the table 2.1 it is appreciated that the 9 strategies reflect the increasing degrees of circularity and resource conservation. Positioned at the core of circular economy principles, these strategies serve as a practical guide for minimizing the waste and for extending the product life cycles. The hierarchy begins with Refuse, the most proactive approach, that involves the unnecessary consumption. Rethink follows, encouraging a redesign of systems and products to optimize utility with minimal environmental impact. Reduce focuses on efficient resource use by lowering material and energy inputs. The next ones composed by Reuse, Repair and Refurbish, promote extending the functional life of products through direct application or minimal intervention. Remanufacture and Repurpose involve more transformative processes, where products or components are restored or adapted for new uses. Finally, Recycle, often mistaken as the most sustainable strategy, is placed lowest in circularity as it typically involves energy-intensive processes and a loss of material quality [54]. Understanding and applying the 9R hierarchy is crucial not only for designing circular business models but also for upskilling. Its importance lies in shifting the focus from

end-of-pipe solutions to systemic change—where prevention, intelligent design, and value retention are prioritized over disposal. This structured approach supports a more sustainable manufacturing ecosystem, aligning environmental goals with economic resilience.

These four strategic pillars form the foundation of economic activity within the CE. The next focus is on how employment is defined and measured within the context of the CE framework.

### 2.1.1. The Circular business Models

In response to the growing interest in green business models and innovation, both scholars and industry professionals have increasingly turned to visualization tools as a means to articulate complex concepts. These tools serve multiple purposes: they assist in the design, refinement, communication, and critical evaluation of business models. By illustrating how various components of a business model interact, visual tools make implicit connections more visible, thereby transforming them into tangible opportunities for strategic discussion and improvement [60].

From the analysis of literature two Circular Business Model visualization tools are considered and listed below.

#### 2.1.1.1. The Circular Business Model (CBM) Patterns

Ludeke, Gold and Bocken have conducted a morphological review of 26 current Circular Economy Business Models (CEBMs) from the literature, allowing the identification of specific characteristics and dimensions of each one. Based on this review and analysis, they have proposed six major CBM patterns with the strength to support the closing of resource flows that are categorized in repair and maintenance; reuse and redistribution; refurbishment and remanufacturing; recycling; cascading and repurposing; and organic feedstock business model patterns [54].

Recent frameworks centered on the CE emphasize the need for innovative business models that fundamentally reconfigure how organizations generate and deliver value in alignment with circular principles [70]. A review of contemporary literature reveals recurring patterns in the types of business models proposed. For instance, performance-based and service-oriented models are frequently cited [61], while others appear to be specific to individual frameworks—such as the "hybrid model" and the

"gap-exploiter model" introduced by Bakker [11]. Additionally, similar concepts are often described using different terminologies, such as "product-as-a-service" and "product-service systems" [48].

This conceptual fragmentation underscores the need for a more unified and coherent structure that can support both academic analysis and practical application. In response, we propose the development of a comprehensive morphology that synthesizes and integrates the diverse array of CEBMs currently present in the literature. This unified framework is intended to enhance conceptual clarity and serve as a robust foundation for further research, analysis, and model implementation within the academic field but also within companies.

In order to build a proposal for the six patterns gathering all the literature for the Business Models, the authors started with a comprehensive examination of a database of circular economy business models (CEBMs) to identify possible configurations for business model design, serving as a foundation for a systematically method to explore complex, multi-dimensional problems that are not readily quantifiable aimed at structuring the major design options for circular business models [67]. Adopting this approach, it was possible to define relevant business model dimensions and then identify prominent attributes within those dimensions. After that, the analysis involved the derivation of six principal patterns of circular economy business models based on the identified design features. These patterns are then used to propose targeted design strategies that can inform the development and implementation of effective circular business models within diverse industrial contexts.

Patterns are commonly defined as recurring configurations of problems and their corresponding solutions, often abstracted from practice to support knowledge transfer across contexts [52]. Originating in the disciplines of design theory and architecture, Alexander et al. (1977) described a pattern as a solution framework addressing a specific problem that consistently emerges within a particular environment. This framework is articulated in a way that allows the solution to be applied repeatedly, yet flexibility to adapt to different circumstances each time.

In the figure below can be seen the six patterns subtracted and proposed by the authors based on the extensive literature collected and carefully selected for the elaboration of their paper.

Table 2-1: Major CEBM\* patterns [54]

| Major CEBM patterns             | Reviewed CEBMs supporting the patterns  |
|---------------------------------|---|
| Repair & maintenance            | "Repair"; "product life extension"; "classic long-life model"   |
| Reuse & redistribution          | "Reuse / refurbish / maintain / redistribute / next-life sales"; "reuse"; "product life extension"    |
| Refurbishment & remanufacturing | "Remanufacturing / next-life sales"; "upgrading"; "product life extension"; "extending product value" |
| Recycling                       | "Closed-loop production"; "rematerialization"; "recycling and waste management"                       |
| Cascading and repurposing       | "Multiple cash flows / multiple revenues"; "co-product generation from waste"                         |
| Organic feedstock               | "Co-product generation from waste"; "circular supplies"; "resource recovery"; "industrial symbiosis"  |

\*CEBMs= Circular Economy Business Models.

This framework not only facilitates innovation in business model creation but also serves as a valuable reference for circular economy practitioners, product developers, and service designers. Its comprehensive structure allows users to explore existing patterns and invent new configurations that are contextually appropriate. Through this process, the morphological box can act as a foundation for the creation of future business modeling instruments tailored to the unique needs of the circular economy.

One key insight from the analysis is the difficulty of establishing a single, unified CEBM typology. The sheer volume of potential model configurations—estimated to exceed four million theoretical combinations—underscores the impracticality of capturing the entire landscape within a single framework or academic study. Nonetheless, this estimation suggests that a much wider range of applicable CEBMs exists in practice than is currently reflected in the literature. In addition to cataloging the diversity of CEBMs, the study also outlines several strategic design approaches aimed at supporting their implementation. These include extending product life cycles, promoting durability, and facilitating the separation of biological and technical

materials in products. When these strategies are combined with specific CEBM design elements, they offer enhanced clarity for researchers seeking to investigate circular practices through empirical analysis.

### 2.1.1.2. The Circular Economy Butterfly Diagram

Among the foundational conceptual frameworks within circular economy discourse, the Butterfly Diagram—introduced by the Ellen MacArthur Foundation - stands for its clarity and widespread influence [26]. This model conceptualizes the circular economy as a regenerative system in which both biological and technical materials flow through restorative processes such as reuse, repair, refurbishment, and recycling. By distinguishing between biological cycles (e.g., composting organic matter) and technical cycles (e.g., remanufacturing industrial products), the diagram provides manufacturing organizations with a tangible reference for designing systems that minimize waste and extend material life cycles.

Below is the butterfly Diagram for a visual representation of the Circular economy, helping to illustrate the continue flow of materials composed by two main circles, the technical and the biological. The technical circle the products and materials are retained in circulation by processes like reuse, repair, remanufacturing and recycling. In the biological one, the nutrients obtained from biodegradable materials are returned to the earth [26].

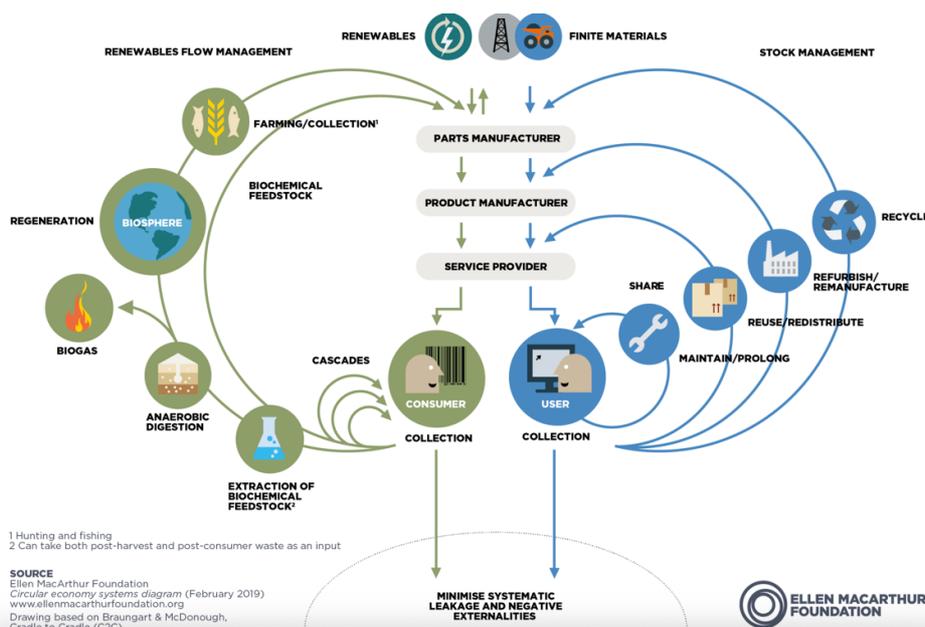


Figure 2-1: The butterfly Diagram [26]

The technical component of the CE is characterized by a closed-loop system, wherein materials and products circulate through strategies such as sharing, maintenance, reuse, remanufacturing, and recycling. In contrast, the biological cycle pertains to renewable resources that function within an open-loop system. This biological flow moves through stages of extraction, production of bio-based materials, energy recovery, and ultimately, the return of nutrients to the biosphere, facilitating the regeneration of primary natural resources.

This cyclical model allows industrial operations to emulate the regenerative principles of natural ecosystems, thereby minimizing the reliance on virgin raw materials, lowering energy usage, and reducing waste generation. As a result, it supports both environmental preservation and enhanced economic performance [44].

Furthermore, products and services are intentionally developed to remain in circulation for as long as possible, thereby decreasing the demand for additional resources and minimizing waste. When specific components within a product can no longer be reused by the original manufacturer, they may still retain value [73]. These components can be repurposed or reengineered by suppliers or third-party enterprises, contributing not only to resource efficiency but also to the creation of alternative income opportunities [10].

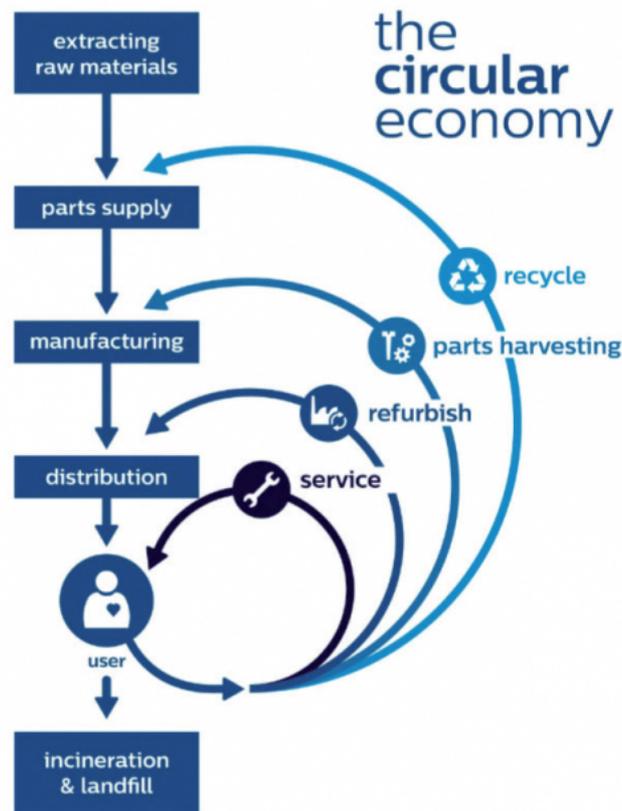


Figure 2-2: The model from the production perspective [26]

The implications of this model for the manufacturing workforce are substantial. Transitioning from traditional linear production to circular approaches necessitates a comprehensive shift in operational strategies, which in turn demands the development of both technical and interpersonal competencies. Employees must be proficient in designing products with disassembly in mind, evaluating sustainable end-of-life pathways, and coordinating effectively within circular supply chains. This paradigm shift involves more than procedural changes—it requires a fundamental transformation mindset from prioritizing efficiency and throughput to emphasizing material recovery and environmental stewardship.

As such, the Butterfly Diagram serves not only as a strategic tool for operational design but also as a diagnostic lens through which workforce competencies can be assessed. It provides a foundation for identifying skills that are critical in circular manufacturing environments and informs the development of targeted training and assessment methodologies aimed at bridging existing capability gaps.

## 2.2. The workforce transformation and the emerging competencies driven by the Circular Economy

### 2.2.1. The human capital in the CE

Shifting toward a CE framework necessitates the development of comprehensive policy and business strategies capable of overcoming entrenched linear economic models. This transition entails a fundamental rethinking of how products are conceived, designed, and manufactured [10]. The process of breaking free from the constraints of linear systems is deeply rooted in innovation dynamics, highlighting the critical role of transformative change.

In light of this, scholars have increasingly emphasized the relevance of expanding the conceptual and empirical scope of eco-innovation to better understand the factors driving the CE transition and its broader implications [23]. From an economic perspective, research has examined how adopting CE-oriented innovations influences firm performance, providing insights into competitive advantages and operational efficiency gains [36].

Recent empirical research conducted at both firm and regional levels has highlighted the complex employment implications associated with the transition to a CE. While enhanced resource efficiency—a central pillar of CE—can potentially lead to a reduction in labor demand, particularly in resource-intensive operations, the shift also creates opportunities for job growth in other areas. Specifically, the adoption of innovation-driven CE strategies often necessitates a workforce with more specialized skills and higher qualifications. This transition may simultaneously result in the displacement of lower-skilled labor, making the overall employment impact dependent on the interplay between job creation in emerging areas and job losses in traditional sectors [37] [63] [58] [66].

Moreover, the classical discourse on the net employment effects of innovation introduces the concept of compensation mechanisms, which can mediate these transitions. On the demand side, lower production costs, the emergence of new products, and broader market penetration may drive increased labor demand. On the supply side, internal shifts within firms and changes across value chains—such as the reallocation of tasks and optimization of resources—can also affect labor dynamics [1] [2] [64].

Despite indications that CE-oriented innovation may favor a more qualified workforce, the academic literature has largely overlooked the qualitative aspects of employment within the CE framework [10]. The distribution of skills and knowledge required to support the transition remains underexplored, even as numerous reports and policy documents in the grey literature emphasize the critical importance of workforce capabilities for enabling a sustainable CE transition [20] [38] [7] [50].

### 2.2.2. The CE skills in Manufacturing

Green skills are broadly understood as the competencies that underpin sustainability across environmental, economic, and social domains. These encompass a combination of technical expertise, knowledge, attitudes, and values essential for individuals in the workforce to effectively contribute to sustainable practices within business, industry, and the wider community. According to the European Centre for the Development of Vocational Training [18] green skills involve the capacities required to support and participate in a society that actively seeks to lessen the ecological footprint of human activities.

These competencies are typically conceptualized across three interrelated dimensions: cognitive, psychomotor, and affective. The cognitive dimension pertains to environmental knowledge—such as understanding ecological principles or the impact of industrial processes on the environment [84]. The psychomotor dimension involves practical abilities, including actions like optimizing energy use or implementing measures to lower greenhouse gas emissions. Finally, the affective dimension reflects personal attitudes and values, such as an individual's commitment to conserving natural resources or their willingness to engage in environmentally responsible behavior [49]. Together, these dimensions highlight that green skills are not confined to technical know-how but extend to behavioral and value-driven aspects that are vital for fostering sustainable development across various sectors of society [18].

However, there remains a lack of clear and consistent definition surrounding the term. Public understanding of green skills tends to be limited, with most individuals primarily familiar with broad categories such as generic skills, technical competencies, and employability attributes. In contrast, awareness and comprehension of what specifically constitutes green skills—those directly linked to environmental sustainability and circular economic practices—remain relatively underdeveloped [84].

The shift toward a greener economy is expected to significantly reshape the skill requirements and responsibilities associated with numerous existing occupations. As noted by Bowen [15], this transition will not only alter the nature of work but also demand the acquisition of new capabilities. In this context, the cultivation of relevant knowledge, skills, and competencies becomes a central pillar in supporting the movement toward a low-carbon economy. These green skills are essential for both businesses and individual consumers, as they underpin the implementation and effective utilization of resource-efficient and environmentally sustainable technologies and processes [19].

Moreover, the evolving skill landscape must be considered within the wider framework of transformative global trends, particularly those defining the 21st century. Among these are the emergence of the Fourth Industrial Revolution—characterized by digital innovation and the integration of smart manufacturing systems, commonly referred to as Industry 4.0. Considering these developments, there is a growing need to ensure that green skills are developed in conjunction with digital competencies. This is especially important given the increasing convergence of digitalization and sustainable industrial practices, which collectively shape the future of work and production [82].

### 2.2.3. The skills measurement approach

The concept of green employment has become a focal point in both scholarly discussions and policy development arenas, but while a universally accepted definition or standardized metric for measuring green jobs has yet to emerge, there is broad agreement on their central purpose. Since the CE models have been developed in a way that the Human Capital is one of the most valuable assets to invest in and the workers are increasingly confronted with more complex responsibilities that demand both adaptability and resilience, the evolving Manufacturing landscape necessitates a workforce that is not only proficient in managing sophisticated systems but also agile in responding to rapidly changing conditions [53].

Before discussing the different frameworks and tools of skills classification, it is necessary differentiate between green skills and CE skills and the importance of digital skills in the relation between those two. While *green skills* and *CE skills* are closely related in their shared goal of promoting environmental sustainability, they differ in scope, emphasis, and operational application. Green skills broadly refer to the

knowledge, abilities, values, and attitudes needed to support environmental sustainability across sectors. These include competencies in environmental management, energy efficiency, pollution prevention, and general sustainability literacy [36].

Green skills are often seen as cross-sectoral and foundational, equipping workers with an overall understanding of environmental impacts and the practices required to reduce them, these skills are often categorized into general awareness (e.g., understanding climate change), technical knowledge (e.g., energy efficiency, waste reduction), and behavioral competencies (e.g., sustainable decision-making) [19]. On the other hand, digital skills refer to the capacity to work with digital tools, data, and systems—ranging from basic ICT literacy to advanced competencies in automation, IoT, AI, and data analytics, all of which are core enablers of Industry 4.0 [19]. While traditionally treated as separate domains, both green and digital skills increasingly intersect, especially in smart manufacturing environments where digital tools are leveraged to improve environmental performance.

CE skills represent a hybrid category that blends green and digital competencies with systems thinking and design-oriented innovation. These skills are more specific and systemic, focusing on the design and implementation of circular strategies such as reuse, remanufacturing, repair, and recycling, as well as business model innovation for closed-loop systems where green skills might emphasize reducing negative impacts, CE skills aim at regenerating value and fundamentally redesigning production-consumption systems to keep resources in use for as long as possible [32]. As such, benchmarking these three categories reveals a progressive competency scale, where digital skills provide the tools, green skills the guiding principles, and circular economy skills the strategic and systemic mindset needed for a sustainable industrial future.

The relationship between green skills and CE skills is therefore one of overlap but also specialization. CE skills can be viewed as a subset of green skills, distinguished by their need for interdisciplinary integration—combining environmental knowledge with technical, design, and business competencies to enable circular models [25]. For instance, a technician with green skills might know how to reduce energy use, but a technician with CE skills would also know how to design for disassembly or facilitate product life extension. This difference has significant implications for workforce

development, as training for CE requires not only environmental awareness but also systems thinking, innovation, and collaboration across value chains as industries move toward circular strategies, the demand for these integrated, role-specific competencies underscores the need for targeted assessment and training frameworks that go beyond general environmental literacy to address the practical challenges of implementing a circular economy [15].

Employees are no longer viewed merely as functional components of production processes but as key enablers of innovation and long-term organizational success. This recognition emphasizes the importance of continuous upskilling and a people-centered approach to sustainable industrial transformation; hence, a skills requirement approach can help to identify the competencies required to shape the industry into a greener economy. Consistent with this, the below overview presents an extensive literature review in how to map the CE skills required in the Manufacturing industry, and the different assessment models, tools and practices and how each of them contributes to the evaluation of the performance metrics. It should be noted that there is no CE skills assessment tool yet, which is the reason for developing this paper.

#### 2.2.3.1. The Green Skills Framework

The European Centre for the Development of Vocational Training (Cedefop) has developed a comprehensive framework to identify and categorize the skills essential for the transition to a green economy. This framework, detailed in their 2018 synthesis report, classifies green skills into three primary categories: generic, technical, and transversal. Generic green skills encompass broad competencies such as environmental awareness and sustainable development principles, which are applicable across various sectors. Technical green skills refer to occupation-specific abilities required to perform tasks that directly impact environmental sustainability, such as operating renewable energy equipment or implementing energy-efficient processes. Transversal green skills are those that support adaptability and lifelong learning, enabling workers to transition across different roles and sectors as the green economy evolves [18].

The integration of these skill categories into vocational education and training (VET) systems is crucial for preparing the workforce to meet the demands of a sustainable economy. Cedefop emphasizes the importance of embedding green skills into curricula and training programs to ensure that workers are equipped with the necessary competencies to support environmental objectives. This approach not only

addresses current skill gaps but also anticipates future needs, aligning workforce development with environmental policies and labor market demands [18].

## Green skills framework

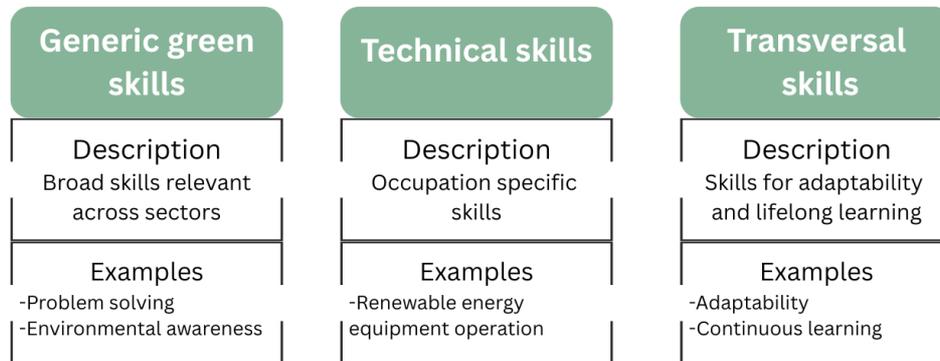


Figure 2-3: The green skills framework, author elaboration based on Cedefop [18]

Moreover, the framework underscores the role of continuous learning and adaptability in the face of evolving green technologies and practices. By fostering a culture of lifelong learning, the framework aims to enhance the resilience of the workforce, enabling individuals to navigate the dynamic landscape of green jobs effectively. This holistic approach to skill development is essential for achieving sustainable growth and supporting the broader objectives of the green transition.

The below table summarizes the analysis of skills implications developed in the UK report called *Working for a green Britain and Northern Ireland* in 2013, where the definition of green skills was developed [68].

Table 2-2: Official definition of skills for a green economy in England, 2011 [18]

| Skills for a green economy                  | Skill needs  |
|---|--|
| Skills supporting resource efficiency       | <ul style="list-style-type: none"> <li>• Strategic business management to build resource-efficient business models leading to bottom line benefits and in preparation for new regulations</li> <li>• Business/financial accounting services around carbon and natural environment accounting</li> <li>• Skills to design and adopt technologies, products and processes increasing resource efficiency, including lean manufacturing</li> <li>• Project management skills with clear understanding of resource efficiency</li> <li>• Operator level actions to maximise resource efficiency (e.g. reducing waste in production)</li> </ul> |
| Skills supporting low-carbon industry       | <ul style="list-style-type: none"> <li>• Scientists and engineers with training or transferable knowledge for nuclear and renewable energy (including wind and marine)</li> <li>• Technicians with training or transferable knowledge to install energy efficiency measures and retrofit at a household and business premises level</li> <li>• Skills to design and adopt technologies, products and processes to minimise carbon emissions</li> <li>• Operator level actions to minimise carbon emissions (e.g. driving in a fuel efficient manner)</li> </ul>  |
| Skills supporting climate resilience        | <ul style="list-style-type: none"> <li>• Scientific and technical skills such as modelling and interpreting climate change projections</li> <li>• Risk management such as assessments of future resource availability</li> <li>• Skills to design and adopt technologies, products and processes to improve climate resilience</li> <li>• Operator level actions to improve climate resilience (e.g. retrofitting water efficient technologies in households and business premises)</li> </ul>   |
| Skills to protect and manage natural assets | <ul style="list-style-type: none"> <li>• Accounting services for the natural environment</li> <li>• Understanding of environmental impact assessments</li> <li>• Understanding and interpretation of environmental legislation targets, ecosystem services design and management and land use planning</li> <li>• Skills to design and adopt technologies, products and processes to manage natural assets</li> </ul>  |

In manufacturing, machine operators, engineers, designers, and managers all require different types of green skills depending on their functions. For instance, an operator may need skills in efficient resource handling and emissions monitoring, while an engineer must master sustainable design and lifecycle analysis. Cedefop's framework helps delineate these skill profiles and informs the creation of occupational maps—tools essential for developing a tailored assessment model. Additionally, it emphasizes the importance of integrating green skills into education and training systems, reinforcing the thesis call for an assessment-based approach to sustainable workforce development.

Notably, identifying what constitutes a green job presents a complex challenge, primarily because it involves analyzing two distinct but interconnected dimensions: the organizational (or firm-level) perspective and the individual (or worker-level) role.

These dimensions are complementary and, while they often intersect, they do not necessarily align in every instance [40]. From this perspective, a job may be classified as green if it involves performing duties that directly support environmental goals, such as developing green products or reducing organizational emissions. Additionally, it considers whether the role requires competencies specifically linked to environmental knowledge or practices.

### 2.2.3.2. The essential Circular Skills using the Relative Skill Advantage Matrix (RSA)

The Relative Skill Advantage (RSA) is a quantitative indicator designed to evaluate the relative importance of a specific skill within a given industry, especially in comparison to its relevance across other industries. This measure shares its conceptual roots with the Balassa Index—commonly referred to as the Location Quotient (LQ) or Revealed Comparative Advantage (RCA)—which has long been utilized in economic geography and regional economic studies [12]. Unlike LQ and RCA, which typically rely on employment data, RSA is grounded in skill intensity scores, offering a more nuanced perspective on the role of skills within industrial sectors.

RSA is computed as the ratio of the relative presence of a particular skill  $s$  in industry  $i$  within region  $p$  at time  $t$ , compared to its relative presence across all industries in the same region and time frame. Mathematically, this relationship is expressed as:

$$RSA^{p,t}(i, s) = \frac{icp(i, s) \setminus \sum_{s' \in S} icp(i, s')}{\sum_{i' \in I} icp(i', s) \setminus \sum_{i' \in I, s' \in S} icp(i', s')}$$

Equation 2-1: The RSA equation

Where  $icp(i, s)$  represents the intensity of skill  $s$  in industry  $i$  in region  $p$  at time  $t$ , derived from ICP and ILFS datasets. An RSA value greater than 1 indicates that a given industry utilizes a particular skill more intensively than the average across all industries, suggesting a comparative skill advantage.

Duygu Buyukyazici and Francesco Quatraro in their paper *The skill requirements of the circular economy*, have applied the formula using binary RSA matrices to reveal the skills advantages for an industry by taking into account the skills advantages of other industries data, computing the RSA values of the diverse economic activities that require heterogeneous skill sets, named CI's with all the industries in the sample [16].

The findings indicate the value of adopting a more detailed, micro-level perspective when examining specific aspects of CE practices. This nuanced approach emphasizes

the need for disaggregated analysis, which can serve as a critical input for shaping policy measures intended to mitigate potential negative consequences of the transition to circularity on labor markets. By focusing on individual components rather than broad generalizations, policymakers can better understand the complex dynamics at play and formulate interventions that are both targeted and effective. The results have been gathered, analyzed, and categorized in the table below.

Table 2-3: Top 20 most important skills for Circular industries [16]

| Core CIs   |                   |                 | Enabling CIs  |                  |                 |
|--|-------------------|-----------------|---|------------------|-----------------|
| Skill  | ICP Descriptor    | Non-Bin.<br>RSA | Skill   | ICP Descriptor   | Non-Bin.<br>RSA |
| (B13) Mechanical   | Knowledge         | 3.63            | (C22) Programming   | Technical Skills | 3.95            |
| (G22) Repairing and Maintaining Mechanical Equipment       | Work Output       | 3.62            | (B10) Engineering and Technology  | Knowledge        | 3.71            |
| (C28) Repairing  | Technical Skills  | 3.47            | (B11) Technical Design  | Knowledge        | 3.60            |
| (G23) Repairing and Maintaining Electronic Equipment       | Work Output       | 3.42            | (B15) Physics   | Knowledge        | 2.70            |
| (C26) Equipment Maintenance                                | Technical Skills  | 2.48            | (G21) Drafting, Laying Out, and Specifying Technical Devices, Parts, and Equipment, | Work Output      | 2.66            |
| (C27) Troubleshooting                                      | Technical Skills  | 2.22            | (C19) Technology Design   | Technical Skills | 2.62            |
| (D25) Control Precision                                    | Psychomotor       | 2.10            | (B9) IT and Electronics   | Knowledge        | 2.42            |
| (G18) Controlling Machines and Processes                   | Work Output       | 2.07            | (B12) Building and Construction   | Knowledge        | 2.27            |
| (C25) Operation and Control                                | Technical Skills  | 2.02            | (C6) Science  | Technical Skills | 2.05            |
| (G20) Operating Vehicles, Mechanised Devices, or Equipment | Work Output       | 2.00            | (C30) Systems Evaluation  | Technical Skills | 1.99            |
| (C21) Installation   | Technical Skills  | 1.97            | (C21) Installation  | Technical Skills | 1.91            |
| (G4) Inspecting Equipment, Structures or Materials         | Work Output       | 1.95            | (B31) Telecommunications  | Knowledge        | 1.91            |
| (C24) Operation Monitoring                                 | Technical Skills  | 1.85            | (C18) Operations Analysis   | Technical Skills | 1.88            |
| (D24) Finger Dexterity                                     | Psychomotor       | 1.84            | (C23) Quality Control Analysis  | Technical Skills | 1.88            |
| (D41) Near Vision  | Sensory           | 1.79            | (C29) Systems Analysis  | Technical Skills | 1.85            |
| (B15) Physics  | Knowledge         | 1.76            | (D12) Math Reasoning  | Cognitive        | 1.82            |
| (G3) Monitor Processes, Materials or Surroundings          | Information Input | 1.71            | (C31) Judgement and Decision Making   | Technical Skills | 1.81            |
| (C34) Management of Material Resources                     | Technical Skills  | 1.70            | (G19) Interacting With Computers  | Work Output      | 1.78            |
| (D32) Static Strength                                      | Psychical         | 1.64            | (B14) Mathematics   | Knowledge        | 1.71            |
| (C29) Systems Analysis                                     | Technical Skills  | 1.62            | (G38) Provide Consultation and Advice to Others                                     | Work Output      | 1.69            |

Note: The table reports the highest non-binary RSA scores as the most important skills for the core and enabling CIs.

The table is organized into two distinct sections, one focusing on core critical industries (CIs) and the other on enabling CIs. Each section presents the 20 most significant skill categories, determined by identifying the competencies for which each CI demonstrates the highest non-binary Relative Skill Advantage (RSA) scores.

In the first section, which pertains to core industries, the data highlights the predominance of mechanical knowledge as well as associated competencies in technical execution, psychomotor abilities, and work output. These skill types are identified as particularly vital. Conversely, the second section, which addresses enabling industries, portrays a more knowledge-centric skills landscape. Here, the emphasis is on specialized domains such as engineering, technical design, physics, and telecommunications, which are reinforced by related technical proficiencies. Although certain skill sets are more relevant to sectors, all industries depend on a broader skill spectrum that supports and enhances their foundational capabilities.

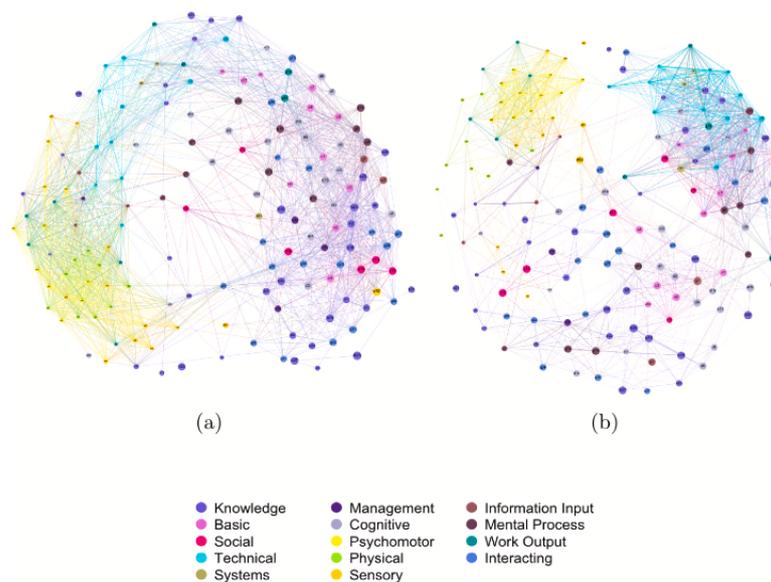


Fig. 3. The Skill Spaces of the Core (a) Enabling (b) Circular Industries (2013–2019). Nodes represent skills. The size of each node is proportional to the complexity level of the skill the node represents. Nodes are coloured to the subcategories of skills. Edge lengths show the degree of relatedness between skill pairs.

Figure 2-4: The skill spaces of the core enabling in Circular Industries [16]

The above illustrates the distribution of skill utilization among the central core industrial sectors (CIs). A clear bifurcation in skill patterns is noticeable, forming two distinct clusters. The first cluster, positioned on the left side of the figure, includes physical, psychomotor, sensory, systems, and technical competencies. These are frequently employed in conjunction with specific domains of knowledge—depicted in purple—such as Production and Processing (B7), Building and Construction (B12), and Transportation (B33). This configuration suggests a tendency for these skill types to be utilized simultaneously across the core CIs.

Conversely, the right side of the figure reveals a second cluster that emphasizes foundational, interpersonal, managerial, interactive, and cognitive skills, along with general knowledge areas. Linking these two clusters is a transitional set of competencies—particularly in the domains of information technology, engineering, and cognitive reasoning—which play an integrative role across both skill sets. Notable examples include IT and Electronics (B9), Engineering and Technology (B10), Telecommunications (B31), Programming (C22), Complex Problem Solving (C17), Originality (D6), and Mathematical Reasoning (D12) [18].

### 2.3. The skills assessment methods and tools

Assessing workforce skills is a crucial step in understanding readiness for new industrial demands such as the circular economy transition. Different methods offer varying levels of precision, scalability, and applicability, and each brings its own advantages and limitations depending on the context of use. In workforce development and research, these methods are often categorized into proxy indicators, objective measures, and subjective measures. The following table, adapted from authors of the paper “The Role of Self-Assessment in Measuring Skills”, Allen Rolf and Van Der Velden, summarizes common approaches to skills assessment and the level of analysis at which they typically operate [47].

Table 2-4: Methods to assess acquired skills [47]

| <i>Method</i>  | <i>Level</i>                                    |
|--|---|
| <b>Proxy:</b> <ul style="list-style-type: none"> <li>• by education</li> </ul>   | Aggregate of educational groups: level or field |
| <b>Objective measures:</b> <ul style="list-style-type: none"> <li>• Assessment</li> <li>• Testing</li> </ul>   | Individuals<br>Individuals                      |
| <b>Subjective measures</b> <ul style="list-style-type: none"> <li>• Supervisor rating</li> <li>• Individual self-assessment</li> <li>• Proxy by required skills</li> </ul> | Individuals<br>Individuals<br>Individuals       |

Proxy measures, such as education level or field of study, are among the most widely used methods for assessing skills at an aggregate level. These indicators rely on the assumption that formal educational attainment serves as a reasonable proxy for skill possession. For example, policymakers or researchers may estimate the availability of engineering skills in a region by counting graduates from engineering programs.

While this approach is efficient for large-scale analyses, it can oversimplify the diversity of individual competencies, as educational credentials do not always perfectly align with the actual skills required in specific jobs [47]. Moreover, such proxies often overlook informal learning, on-the-job training, or evolving industry needs, making them less precise for planning targeted workforce interventions.

Objective measures offer a more direct way to evaluate skills at the individual level through structured assessments and testing. These tools aim to measure actual competence rather than relying on background characteristics like education. Assessments can include standardized tests, practical tasks, or simulations designed to evaluate specific knowledge, technical abilities, or cognitive skills. For instance, in the context of circular economy skills, objective testing might involve evaluating a worker's ability to apply lifecycle assessment methods or design for disassembly principles. While objective measures tend to have higher validity and reliability, they can be resource-intensive to develop and administer and may need regular updating to remain aligned with technological and industrial changes.

Subjective measures involve evaluations based on perceptions and judgments, either by the individuals themselves or by others, such as supervisors. Supervisor ratings can provide valuable insights rooted in real workplace performance and behavior, offering contextual nuance often absent from standardized tests. However, such ratings can be affected by interpersonal biases, inconsistent criteria, or organizational politics. Individual self-assessment is another subjective method where workers rate their own skills, often through surveys or structured questionnaires. Self-assessment is scalable, cost-effective, and can empower workers to reflect on their development needs, but it carries the risk of over- or underestimation due to confidence levels or lack of awareness of industry standards [47].

Finally, the table also includes the "proxy by required skills" approach under subjective measures, which involves inferring individual skill levels by examining the requirements of the role or occupation they hold. This method assumes that workers in certain positions meet the expected skill thresholds, serving as a practical shortcut for workforce planning. However, this assumption may overlook individual variations within job titles or evolving role definitions in dynamic sectors such as manufacturing. Overall, selecting the appropriate assessment method requires balancing precision, feasibility, and the specific goals of the evaluation process—particularly in the context of rapidly changing skill demands linked to the transition to a circular economy.

Actually, the development and application of tools to evaluate both the skills demanded by specific occupations and the competencies possessed by individuals have emerged in response to growing concerns over the declining competitiveness of the North American labor force in a globalized economy [14] [79]. In the United States, this apprehension gave rise to several national initiatives aimed at enhancing workforce capabilities. Among these were the creation of various employability skills frameworks—such as the SCANS (Secretary's Commission on Achieving Necessary Skills) competencies—as well as the formation of the National Skills Standards Board to establish benchmarks for occupational proficiency [79].

Parallel efforts were undertaken in Canada during the same period, reflecting similar anxieties about workforce preparedness. Key developments included the founding of the Canadian Labour Force Development Board, the launch of the Essential Skills Research Project, and a variety of provincial programs aimed at strengthening education and training systems [17]. These concerns were further substantiated by findings from the International Adult Literacy Survey, which revealed significant deficits in foundational skills among working-age Canadians [75]. Collectively, these initiatives illustrate a heightened recognition of the challenges posed by evolving skill requirements in the modern workplace. The increasing complexity of job roles and the pace of technological change have underscored the necessity for continuous skills assessment and upgrading to ensure workforce adaptability and productivity in a knowledge-driven economy [14].

For this reason, the principal aim of work-related skills assessment tools should be to deliver feedback that is both relevant and impactful, thereby supporting informed decision-making and targeted development efforts. According to guidance provided by Acumen International, a company specializing in skills evaluation technologies, a systematic approach should be followed when selecting an appropriate assessment instrument [69].

In the context of an evolving labor market, skills profiling tools have become increasingly significant for organizations seeking to adapt to rapid technological and structural changes. These instruments offer critical insights into the abilities, proficiencies, and strengths of individual employees, serving multiple strategic purposes within workforce management. Such tools allow organizations to systematically evaluate whether employee skill sets align with the demands of specific job roles. This alignment facilitates more informed decision-making around workforce deployment, enabling better resource distribution, team structuring, and ultimately,

improvements in organizational performance. Additionally, skills profiling supports individualized career planning and development [29]. By identifying each worker’s competencies and potential, employers can design targeted training initiatives to address specific deficits, thereby encouraging ongoing professional growth and upskilling [21].

João Mattar, Daniela Karine Ramos and Margarida Rocha Lucas have compared the assessment instruments to assess digital competences in their paper *DigComp-Based Digital Competence Assessment Tools: Literature Review and Instrument Analysis*, illustrated in the below figure, where the categories identified in this typology are not mutually exclusive; a single assessment tool may incorporate multiple types simultaneously [41].

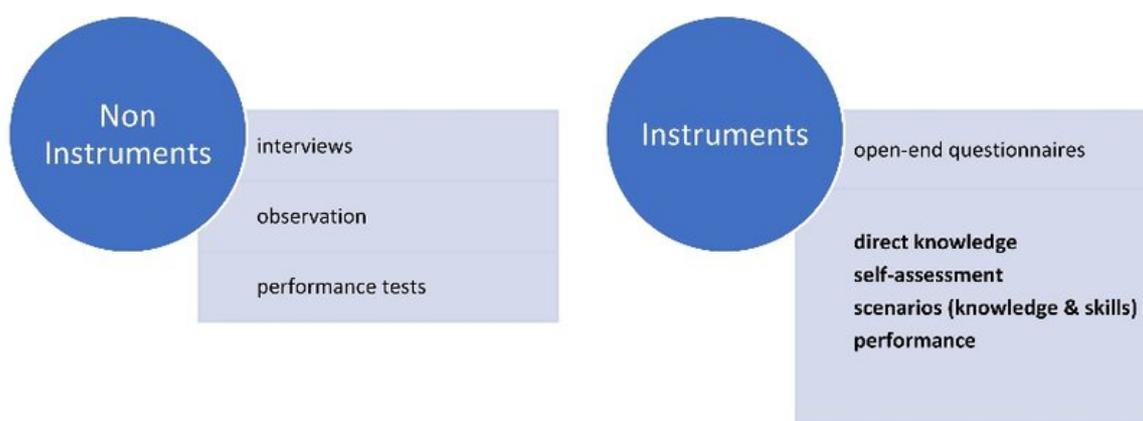


Figure 2-5: Typology of digital competence instruments to assess Digital Competences [41]

Performance-based assessments can be understood in various ways, including structured evaluations conducted in controlled settings for scenario-based simulations [34]. In the context of this discussion, however, the term refers to tasks performed directly by respondents, which are subsequently evaluated through digital tools rather than by human raters—whose involvement, such as in real-time observation or detailed analysis of lesson plans and created artifacts, is often cost-prohibitive.

On the other hand, Silvia Fareri, Riccardo Apreda Valentina Mulas and Ruben Alonso have gathered several profiling tools from the literature review presented in their paper *The worker profiler: Assessing the digital skill gaps for enhancing energy efficiency in manufacturing*, and is presented in the below table with the respectively assessment

methodology, the type of skills assessed, the data source and the use of analytics presented in each model [29].

Table 2-5: Examples of profiling tools from a business and research perspective [29]

| Tool   | Assessment methodology  | Data source or reference  | Type of skills assessed   | Use of analytics   |
|--|---|---|---|--|
| Plum <sup>a</sup> ;<br>Traitify <sup>b</sup><br>Pymetrics <sup>c</sup>   | Behavioral assessments, gamified simulations<br>Gamified neuroscience-based assessments                       | Five-Factor Personality Model<br>Behavioral data, cognitive tests | Cognitive, behavioral, soft skills<br>Cognitive, social, emotional skills | Predictive analytics, machine learning<br>AI, machine learning |
| Baruah et al., 2017  | Reflective Log  | \   | Motivation/transversal skills   | Content Analysis   |
| The Digital Competence Wheel <sup>d</sup><br>Bartolomé et al. (2018); Calatayud et al. (2018)<br>Kuzminska et al. (2019) | Self-Assessment 7-star Scale<br>Self-assessment Likert Scale<br>Scenario based and multiple choices questions | Digicomp 2.1<br><br>(Covello, 2010)                               | Digital skill   | Data visualization   |
| Reddy et al., 2023   | Self-assessment Likert Scale  | (Covello, 2010)   | Digital skills  | Exploratory factor analysis                                    |

Many of these tools tend to focus narrowly on specific competencies, which may restrict their capacity to present a well-rounded evaluation of an individual's overall abilities. This narrow approach can result in a misalignment with the rapidly evolving demands of both industry and the labor market [83].

A further gap identified through literature analysis is the minimal attention given to green skills. Despite the growing emphasis on sustainability and environmental responsibility across sectors, current assessment frameworks rarely incorporate this dimension. Most tools continue to concentrate on either general employability skills or domain-specific expertise, leaving out competencies related to sustainable development [29]. This oversight may impede both individuals and organizations from effectively recognizing and cultivating the green skills increasingly necessary for environmentally responsible practices.

Without integrating insights from emerging technologies and future workforce trends, these tools may fall short in preparing individuals for the skill sets that will be critical in the years to come. This omission is particularly concerning given the pace at which industries are transforming in response to innovation and globalization. While many current assessment tools serve useful purposes, their effectiveness may be undermined by several critical limitations. These include a lack of standardized data sources, insufficient breadth in skill assessment, and an inadequate emphasis on future-oriented competencies, particularly those related to sustainability. Addressing these gaps is essential for creating more robust and comprehensive tools that support both current and future skill development needs.

### 2.3.1. The worker profiler method

The Worker Profiler is an innovative digital tool designed to assess and bridge skill gaps in the workforce, particularly in the context of digital transformation and sustainability within the manufacturing sector. Developed to align workers' existing competencies with the evolving demands of Industry 4.0, the tool facilitates personalized retraining strategies by identifying discrepancies between current skill sets and those required for emerging roles. By leveraging data on technological advancements and green practices, the Worker Profiler aids in mapping out the necessary upskilling pathways for employees to remain competitive and adaptable in a rapidly changing industrial landscape [29].

The developed tool, designed in the format of a user-friendly questionnaire, was constructed using a comprehensive database of occupational profiles and associated skill sets as its foundational input. From the user's perspective, the interaction begins by selecting the professional archetype—one of 87 defined roles—that most closely aligns with their own occupational identity.

The functionality of the Worker Profiler encompasses a comprehensive self-assessment process wherein users evaluate their proficiency across various skill domains, including hard, digital, and soft skills. Following this self-assessment, the system calculates the discrepancy—or "distance"—between the user's current skill portfolio and the optimal skill configuration associated with the chosen professional profile, the ideal occupational archetypes. This approach not only empowers individuals to take charge of their professional growth but also assists organizations in strategic workforce planning by pinpointing collective skill deficiencies and informing targeted training initiatives [29].

The figures below show the flowchart of the model since the user selects the professional profile they identify with to the calculation of the distance between the answers provided by the participant and the ideal skill set of the archetype.

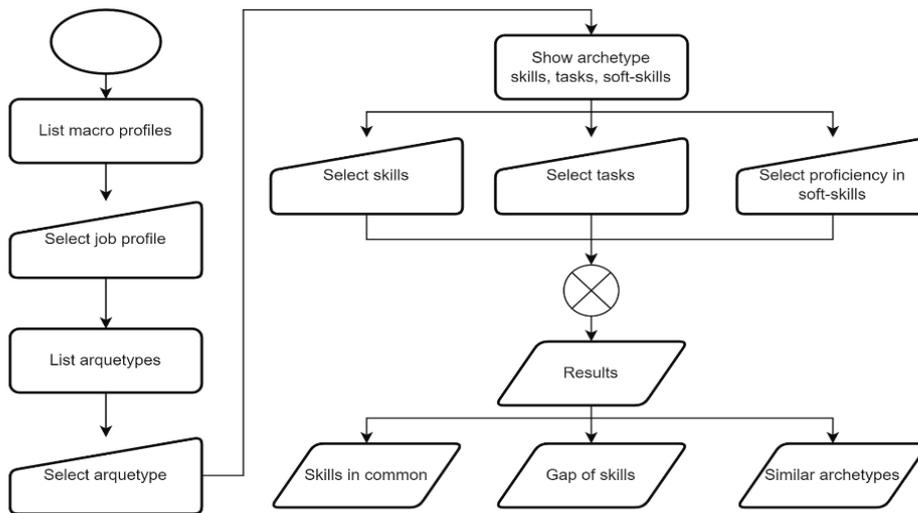


Fig. 5. Flowchart of the worker profiler.

Figure 2-6: Flowchart of the worker profile tool [29]

This analysis yields several outputs: it highlights the soft skills that should be maintained or further developed to remain competitive in the selected occupation, and it offers a detailed evaluation of the technical, digital, and environmental (green/CE) skills that require acquisition or improvement.

Table 2-6: Example of the worker profile outputs (Task selected and task suggested) [29]

**TASKS**

| Selected  | Suggested  |
|---|--|
| <ul style="list-style-type: none"> <li>• Adjust engineering designs</li> <li>• Adjust voltage</li> <li>• Analyse energy consumption</li> <li>• Approve engineering design</li> <li>• Assess environmental impact</li> <li>• Calculate solar panel orientation</li> <li>• Design electric power systems</li> <li>• Maintain concentrated solar power systems</li> <li>• Maintain solar energy systems</li> <li>• Manage environmental impact of operations</li> <li>• Perform scientific research</li> </ul> | <ul style="list-style-type: none"> <li>• Provide information on solar panels</li> <li>• Provide information on wind turbines</li> <li>• Promote environmental awareness</li> <li>• Advise on environmental remediation</li> <li>• Identify energy needs</li> <li>• Create designs for pipeline engineering</li> <li>• Use technical drawing software</li> <li>• Promote sustainable energy</li> <li>• Design solar energy systems</li> </ul> |

Additionally, the system identifies and presents the three occupational archetypes most closely related to the selected profile, providing further career navigation insights

and offering the user a clearer map of those hard, digital and green skills they possess and those to be acquired.

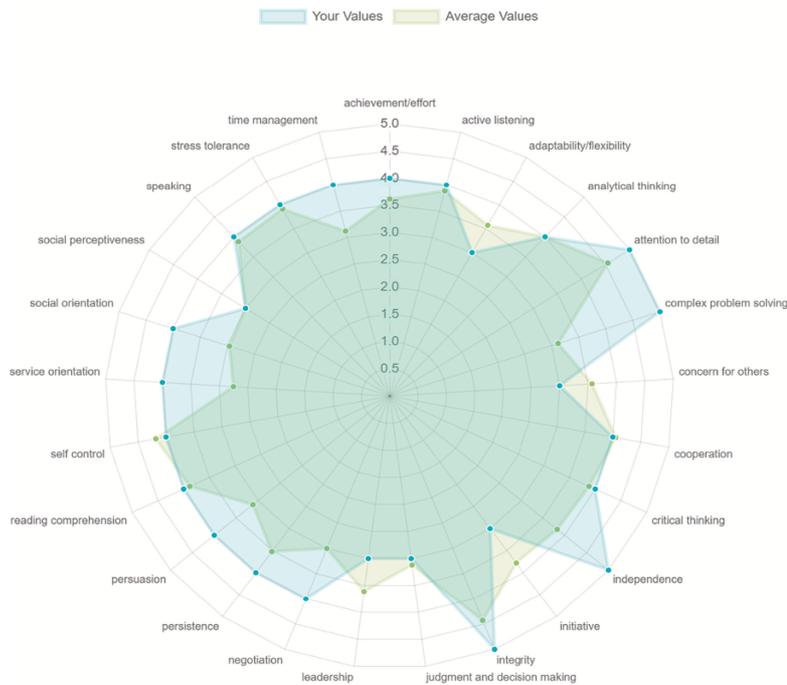


Fig. 7. Soft skill comparison chart.

Figure 2-7: Soft skill comparison chart [29]

In practical applications, the Worker Profiler has demonstrated efficacy in pilot studies across diverse manufacturing enterprises, showcasing its adaptability and user-centric design. The tool's integration into organizational frameworks has facilitated more informed decision-making regarding employee development and resource allocation. Moreover, by emphasizing the acquisition of green skills alongside digital competencies, the Worker Profiler contributes to broader sustainability goals, ensuring that workforce evolution aligns with environmental imperatives and technological progress [29].

### 2.3.2. The self-assessment tool

Among the various approaches to skills assessment presented by Allen and van der Velden, individual self-assessment occupies a particularly important role due to its scalability, cost-effectiveness, and capacity to capture workers' own perceptions of their skills. Self-assessment generally involves individuals rating their own competencies, either through structured surveys or open-ended reflection exercises.

This method has been widely adopted in labor market research and workforce development programs because it enables large-scale data collection at relatively low cost while empowering participants to engage actively with their own skill profiles [47]. By asking individuals to reflect on and evaluate their own abilities, self-assessment can also function as a developmental tool, supporting self-awareness and personal learning planning.

The author emphasize that self-assessment approaches gained traction in European skills research partly due to the limitations of relying solely on proxies like formal education. Educational qualifications often fail to capture the full range of skills workers develop through informal learning, on-the-job experience, or non-traditional training pathways. To address this gap, large-scale surveys such as the European Community Household Panel (ECHP) and the European Social Survey (ESS) included self-reported skill questions, asking respondents to rate the extent to which their jobs required—and they possessed—specific competencies such survey-based self-assessment provides nuanced insights into the alignment between worker skills and job demands, informing labor market policy and vocational education design [32].

Nevertheless, is highlighted that self-assessment methods are not without significant challenges. Chief among these is the issue of measurement bias. Respondents may overestimate or underestimate their abilities due to personality traits (e.g., confidence, humility), social desirability, or misunderstanding of the competencies in question. Research cited by the authors—including work by Falchikov and Boud — demonstrates that accuracy in self-assessment tends to vary depending on the domain, the clarity of criteria provided, and the level of training participants have in self-evaluation. For example, people are often better at judging their concrete technical skills than abstract managerial or soft skills. This variability underscores the need to design self-assessment tools carefully, providing clear, standardized definitions of skills and benchmarks for comparison [88].

To mitigate these limitations, the author proposes embedding self-assessment within broader, mixed-method strategies. For instance, they suggest combining self-reports with supervisor ratings or objective testing to triangulate findings and improve overall measurement validity. This idea is supported by other studies they cite, such as Hartog and Jonker, which show that combining multiple sources of information yields a more reliable picture of workers' skill profiles. Additionally, carefully designed self-assessment surveys can include “anchoring vignettes” or scenario-based questions that help calibrate respondents' interpretations of rating scales). Such methodological refinements seek to preserve the advantages of self-assessment—especially its accessibility and participant-centered design—while addressing its inherent biases [89] [44].

In the context of emerging skill needs such as those linked to the circular economy transition, individual self-assessment remains a particularly valuable tool. The interdisciplinary, evolving nature of CE competencies makes it difficult to rely solely on formal qualifications or standardized tests. Workers themselves are often best positioned to report on their own familiarity with new sustainability practices, design strategies, or digital tools relevant to circular models. However, Allen and van der Velden's insights remind us that effective use of self-assessment requires methodological care, including clear role definitions, well-structured rating instruments, and thoughtful integration with other assessment methods. When applied carefully, self-assessment can empower workers to identify their own skill gaps, support lifelong learning, and enable organizations to design targeted upskilling strategies that align with the goals of a sustainable, circular economy.

### 2.3.3. The self-assessment scale

In research, especially within the fields of behavioral and social sciences, there are challenges of measuring things that aren't directly observable—like attitudes, preferences, or satisfaction. That's where scaling techniques come into play. These are systematic methods used to assign numerical values to qualitative attributes, allowing researchers to interpret, compare, and analyze subjective responses in a structured way [55]. By doing so, they help convert complex human thoughts or emotions into something measurable and meaningful for analysis [54].

There are two primary categories of scales researchers can use: comparative and non-comparative. Comparative scales ask individuals to weigh one item against another—think of ranking or paired comparisons. These tools help establish order but don't give precise distances between choices. Non-comparative scales, on the other hand, allow respondents to evaluate a single item independently, without comparing it to others. These tend to be more flexible in data analysis, offering results that can be used to calculate averages, standard deviations, and correlations [55].

One particularly common form of non-comparative scaling is the itemized rating scale. With this method, respondents choose from a set list of categories, each clearly labeled and often associated with a numerical value. This format improves clarity and consistency in responses. For example, a question might ask how satisfied a customer was with a service, and the answers would range from "Very dissatisfied" to "Very satisfied." Each of those categories would correspond to a specific score on the scale [54].



## 3 Development of the diagnostic tool for CE skills in manufacturing

After the literature review of Chapter 2, in this chapter it is presented the methodology for a creation of a new assessment model of the skills in the upcoming chapters. Although it is well-known that there are existing models that can measure and assess different skills to the employees and operators among transversal tools, it is necessary to develop a tailored tool for the circular economy skills in order to complement it along with the existing models described in the literature review.

### 3.1. Methodology

#### 3.1.1. Mapping the circular and green skills

The initial phase in formulating a CE skills assessment model entailed a detailed competency mapping process, carried out through a spreadsheet-based classification system. This phase was grounded in a thorough review of existing literature, encompassing scholarly publications, sector-specific reports, and established institutional guidelines addressing competencies in green, digital, and circular economy contexts within the manufacturing industry.

To build the classification scheme, several papers and articles were used where the competencies and abilities of the employees were evaluated for a better performance of sustainability inside manufacturing. For the elaboration of the classification in the Basic competencies, articles like *Skills Demand in Energy Intensive Industries Targeting Industrial Symbiosis and Energy Efficiency* [78], *Green Skills and Innovation for Inclusive Growth* [19], *Energy & Utility Skills, Investigating the Skills Required for a Transition to an Advanced Zero-Emission and Circular Economy in Northern Ireland* [7], *The energy worker profiler: From technologies to skills to realize energy efficiency in manufacturing* [29], *Assessing the intangible: Measuring soft skills and emotional intelligence* [32] and *The Remanufacturing Activity: Skills to Develop and Productive Organizations to Rethink* [42] were used to collect the skills requested. Some of the

skills mentioned were subtracted from the paper Key Competencies for circular economy by Marta Pinzone and Marco Taisch [72]. Here are found the different abilities to keep up to date with the regulatory policies but also the ability to understand basic economic concepts and comprehend the different interactions between the actors involved.

In the tables below is shown the skills collected and classified by category and the respectively key abilities after a careful evaluation of their impact on the development of CE in manufacturing. For simplification purposes, they contain the main competencies; the complete selection of skills can be displayed in the Appendix A.

Table 3-1: Matrix of the skills classification

| Basic competencies  |  |
|---|--|
| Competence category   | Key abilities  |
| <b>Fundamentals of sustainable development and the circular economy</b> | Knowledge of the 17 Sustainable Development Goals (SDGs).                                |
|   | Understanding the 3 principles of the circular economy.                                  |
|   | Fundamentals of solid waste streams and the 4Rs: Reject, Reduce, Reuse, Recycle.         |
| <b>System thinking</b>  | Ability to analyze interconnections between economy, environment, and society.           |
|   | Ability to identify components of a system and their roles.                              |
|   | Ability to model interactions within dynamic systems to predict holistic behavior.       |
| <b>Regulatory and economic skills</b>                                   | Ability to track laws, policies, and incentives promoting green industrial practices.    |
|   | Understanding core economic concepts (supply/demand, costs, sustainability, efficiency). |
|   | Ability to apply economic research to forecast trends for green practices.               |

**Technical Management competencies**

| Competence category                          | Key abilities   |
|--|---|
| <p><b>Product Lifecycle Design</b></p>       | <p>Ability to apply modularity, durability, and safety considerations across product lifecycles</p> |
|  | <p>Understanding circular design's impact on supply chain success</p>                               |
|  | <p>Proficiency in Design for Reliability, Multiple Life Cycles, and Sustainability</p>              |
| <p><b>Circular Operations Management</b></p> | <p>Zero-waste manufacturing implementation</p>  |
|  | <p>Resource optimization in production cycles</p>   |
|  | <p>Water/energy management and renewable integration</p>  |
|  | <p>Industrial symbiosis implementation (waste-to-input systems)</p>                                 |
| <p><b>Circular Value Chains</b></p>          | <p>Post-use product recovery strategy development</p>   |
|  | <p>Return flow forecasting and composition analysis</p>   |
|  | <p>Integrated reverse logistics planning</p>  |
| <p><b>Impact Assessment</b></p>              | <p>Life Cycle Assessment (LCA) application</p>  |
|  | <p>Circularity measurement at multiple system levels</p>  |
| <p><b>Sustainable Marketing</b></p>          | <p>Remarketing strategy development for recovered products</p>                                      |
|  | <p>Green/social marketing technique application</p>   |
| <p><b>Business Model Innovation</b></p>      | <p>Circular business model transition planning</p>  |
|  | <p>Cost-benefit analysis for circular investments</p>   |

|                           |  |
|---------------------------|--|
| <b>Digital Enablement</b> | Digital twin and AI applications for CE      |
|                           | Blockchain solutions for material tracking   |
| <b>Energy Systems</b>     | Manufacturing energy efficiency optimization |
|                           | Industrial energy system design              |

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### Transversal competences

| Competence category                | Key abilities   |
|------------------------------------|---|
| <b>Workforce Development</b>       | Upskilling employees to adapt to technological/industry changes   |
| <b>Innovation &amp; Creativity</b> | Out-of-the-box thinking, original problem-solving                 |
| <b>Critical Analysis</b>           | Objective evaluation of information, bias recognition             |
| <b>Entrepreneurial Action</b>      | Transforming ideas into value-generating initiatives              |
| <b>Collaboration</b>               | Multidisciplinary teamwork, negotiation, social perceptiveness    |
| <b>Adaptability</b>                | Resilience in skill development (lifelong learning)               |
| <b>Emotional Intelligence</b>      | Stress/emotion regulation, high-pressure performance              |
| <b>Knowledge Sharing</b>           | Transparent information exchange, fostering collaborative culture |
| <b>Strategic Vision</b>            | Long-term planning aligned with organizational goals              |

Role-specific technical competencies addressed more specialized areas directly linked to operational functions within manufacturing environments. These included expertise in areas such as life cycle analysis, eco-design methodologies, coordination of circular supply chains, and strategies for improving energy efficiency. Such

competencies are closely aligned with the execution of environmentally responsible production processes.

In contrast, cross-functional competencies encompassed a suite of transferable skills essential for fostering adaptability and driving systemic innovation. These included critical reasoning, collaborative problem-solving, systems-oriented thinking, and the ability to initiate and manage change—capacities increasingly important in navigating the complexities of environmental and technological transitions [13] [59].

To improve the practical application of the competency framework, each skill was accompanied by a succinct and standardized definition, laid out in a structured format to promote clarity and usability. This methodological design was intended to support the subsequent phases of tool development, such as crafting self-assessment instruments, conducting empirical validation through surveys, and creating detailed evaluative items.

Organizing the competencies in this systematic manner not only enhanced internal coherence but also allowed for the identification of overlaps and gaps between different skill sets. Additionally, it revealed interdependencies that are critical to designing a more integrated and context-responsive assessment tool. Ultimately, the framework serves both as a theoretical scaffold and a practical guide for constructing tailored evaluation models adapted to specific job profiles within the manufacturing industry.

### 3.1.2. Mapping the assessment models

After establishing the CE skills framework, the subsequent phase of the research methodology focused on a comprehensive examination of existing skills assessment methodologies. This phase involved gathering and critically evaluating various tools and frameworks sourced from scholarly literature, technical documents, and institutional publications. From this review, six widely recognized assessment models were selected. These models were chosen based on their applicability to skill identification, structural approach to evaluation, and flexibility in addressing both environmental (green/CE) and digital competencies.

Each selected model underwent a detailed comparative analysis using a customized matrix. This analytical tool enabled a systematic comparison across several key dimensions. For each model, sub-categories were created to document aspects such as the conceptual definition, methodological approach, intended purpose, assessment

techniques (qualitative vs. quantitative), and contextual pros and cons. This structured analysis facilitated a nuanced understanding of the practical and theoretical attributes of each model.

The comparative review highlighted notable differences among the models, particularly concerning methods of data collection, assessment format (e.g., self-reporting, expert appraisal, simulations), and the models' responsiveness to evolving or static skill needs. For instance, certain models prioritized qualitative, behavior-based approaches such as interviews or narrative exploration, while others relied on standardized surveys or digital platforms to capture skill profiles. The table below shows the results from the matrix created and modulated with the use of several academic papers and innovative assessment tools by different institutions.

Table 3-2: Comparative analysis of Assessment Skills Models

| Framework Element          | Description   | Advantages   | Limitations  |
|----------------------------|---|--|--|
| <b>The worker profiler</b> | Detection of the 3 archetypes the worker embodies the most, and the differences between the skills they currently possess and the ones that they need to acquire. | <ul style="list-style-type: none"> <li>• Classification of the hard skills, digital skills and soft skills.</li> <li>• Calculates the distance between the answers and the ideal skill set of the profile of interest.</li> <li>• Identify any potential issues or areas of improvement</li> </ul> | <ul style="list-style-type: none"> <li>• May not be able to measure certain aspects of the skill gap, such as the level of knowledge or experience.</li> <li>• May not be able to consider the context of the organization, such as its size, culture, and goals.</li> </ul> |

|  |  |   |   |
|--|--|---|---|
| <p><b>Self-assessment<br/>- Likert Scale/<br/>7-star Scale</b></p> | <p>Psychometric scale to rate their level of agreement or performance on a symmetric scale, typically ranging from Strongly Disagree to Strongly Agree and captures specific attitudes, perceptions, or competences.</p> | <ul style="list-style-type: none"> <li>• Approach is relatively cheap, easy to administer and flexible, making it well suited to large scale application in a range of situations.</li> <li>• Likert scales produce quantitative data that can be easily aggregated, analyzed, and compared.</li> </ul> | <ul style="list-style-type: none"> <li>• Employees might overestimate or underestimate their abilities.</li> <li>• If the skill levels are not well-defined or aligned with job roles, employees may struggle to provide accurate ratings.</li> </ul>   |
| <p><b>Behavioral assessments, gamified simulations</b></p>         | <p>Consisting of evaluating individuals by observing their actions, responses, and decision-making in simulated or real scenarios, focusing on how they behave rather than what they claim to know.</p>                  | <ul style="list-style-type: none"> <li>• Provides a realistic understanding of how they would perform and apply skills in actual manufacturing contexts.</li> <li>• The data collected can help HR and training departments track skill levels and develop targeted learning interventions.</li> </ul>  | <ul style="list-style-type: none"> <li>• Requires extensive resources to create scenarios that accurately represent circular economy challenges, especially in industry-specific contexts</li> <li>• For employees unfamiliar or uncomfortable with gaming elements, there may be a risk of disengagement.</li> </ul> |
| <p><b>DigEuLit</b></p>   | <p>European initiative designed to conceptualize and develop a framework for digital literacy and digital competence.</p>  | <ul style="list-style-type: none"> <li>• Covers a wide range of skills, from basic digital competence to advanced transformative abilities.</li> <li>• Goes beyond operational skills to emphasize critical thinking, problem-solving, and ethical considerations.</li> </ul>                           | <ul style="list-style-type: none"> <li>• As technology and digital skills evolve rapidly, the original framework may become outdated without regular updates.</li> <li>• Translating the framework into concrete curricula or assessment tools requires significant effort, potentially limiting its</li> </ul>       |

|                   |  |   |   |
|-------------------|--|---|---|
|                   |  |   | widespread adoption.  |
| <b>DigCompSAT</b> | Designed to help individuals self-assess their digital competences. Participants answer a series of questions or scenarios based on real-life tasks. Typically, it is accessible online. | <ul style="list-style-type: none"> <li>• Encourages individuals to critically evaluate their digital skills, fostering awareness and motivation for improvement.</li> <li>• The format is intuitive and accessible, requiring no prior technical expertise.</li> </ul>  | <ul style="list-style-type: none"> <li>• The tool measures competences through scenarios and questions, not actual hands-on tasks, which may limit the accuracy of results.</li> <li>• Distinguishing between higher proficiency levels can be challenging in a self-assessment format.</li> </ul>                                    |
| <b>DigComp</b>    | The competences are mapped across different proficiency levels and grouped into fourth overarching categories: Foundation, Intermediate, Advanced, Highly Specialized.                   | <ul style="list-style-type: none"> <li>• Design targeted training programs or personalized learning paths.</li> <li>• Maps job-specific digital requirements and assesses candidate competencies.</li> <li>• Flexible framework allows organizations and educators to design effective assessments and tailor interventions.</li> </ul> | <ul style="list-style-type: none"> <li>• Itself is a framework, not an assessment tool, meaning it provides guidelines rather than ready-to-use instruments for measuring skills.</li> <li>• Does not provide clear guidance on how to prioritize or weight the competences, which can be critical for specific use cases.</li> </ul> |

Through this analysis, it became evident that each approach carries distinct strengths and limitations. Models based predominantly on self-assessment were found to be advantageous in terms of accessibility and scalability; however, they often lacked the capacity to measure skills objectively. In contrast, more rigorously structured frameworks provided in-depth insights but typically required significant resource investments and coordination among multiple stakeholders. This evaluation process was instrumental in identifying which models offer the most appropriate balance between methodological robustness and practical applicability within diverse context.

Triangulating these methods revealed disparities between theoretical models and practical manufacturing needs [4].

These results advocate for hybrid assessment strategies. For instance, integrating Fareri et al.'s profiler with DigEuLit competencies could bridge technical and systemic skill gaps. Where the limitations persist, but the advantages of two or more assessment tools combined can exponentially embrace the efficacy of evaluating CE skills with all the variables and tools together.

Hence, the Worker Profiler Model was identified as the most appropriate foundation for constructing a skills assessment tool tailored to the needs of the circular economy within the manufacturing sector. This selection was informed by the model's modular architecture, which facilitates application across a wide range of occupational profiles, as well as its capacity to integrate both self-assessed perceptions and objective performance metrics. A notable strength of the model lies in its user-centered orientation, enabling the design of individualized assessment pathways and advantageous in manufacturing contexts, where skill demands are often complex and varied. To achieve this, the assessment domains within the model were restructured to reflect the three core categories defined earlier: basic competencies, technical management competencies, and transversal competencies. Furthermore, the model's ability to map existing competencies and identify skill gaps at a role-specific level directly supports the overarching aim of this thesis—namely, to evaluate how well manufacturing professionals are equipped to navigate the transition toward a circular economy.

But also, combined with the DigComp and the DigCompsat both designed as self-assessment frameworks to map the skills through different proficiency levels classified in foundation, intermediate, advance and highly advanced were considered as complementary assessment models to incorporate along with the Worker profiler, in that way, the assessment tool to be created can gather the characteristics of these models to be more precise and tailored for the CE skills valuation, but also for identifying competency gaps that can be targeted with training interventions.

Figures 3-1 and 3-2 are presented as a visual representation of both tools and frameworks for a better understanding.

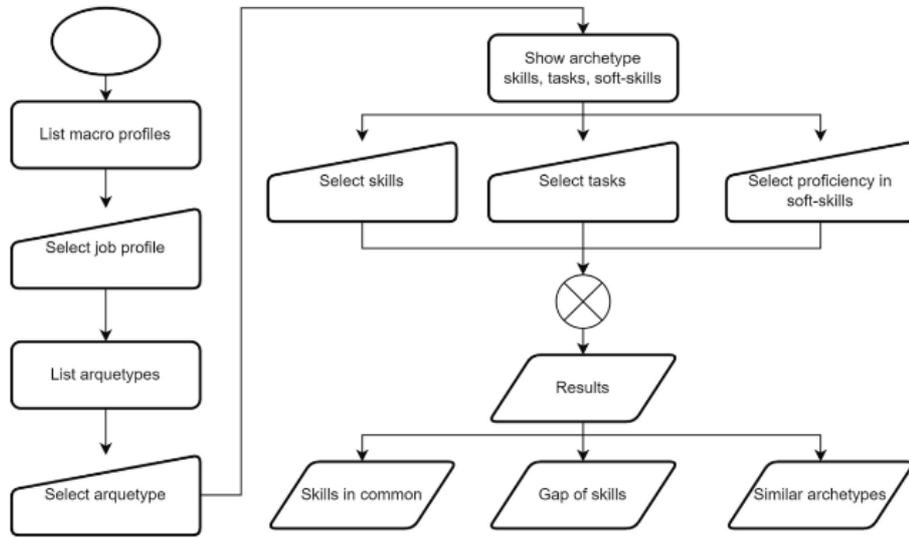


Figure 3-1: The worker profile Model as structure inspiration for the new CE skills assessment model [29]

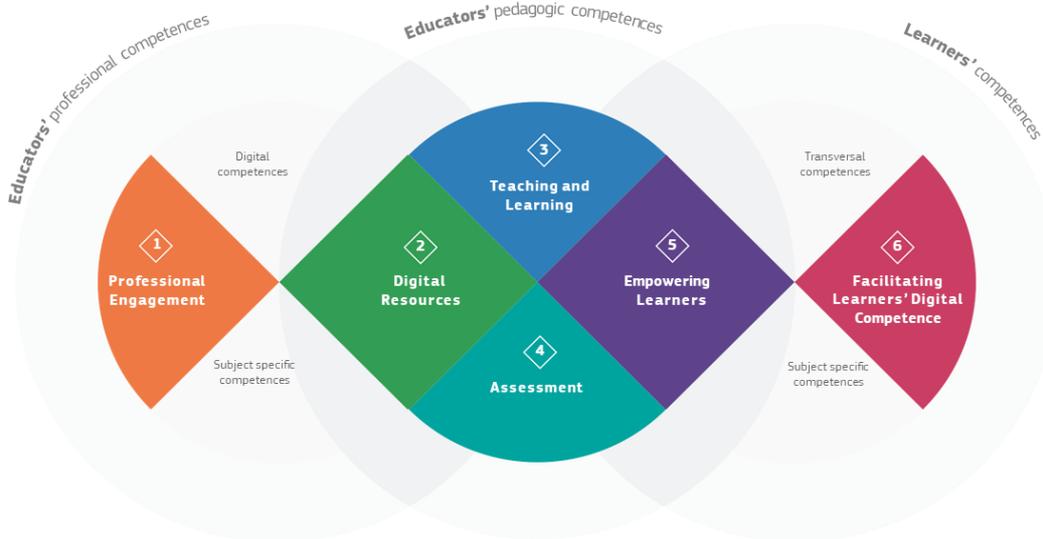


Figure 3-2: The DigComp model as framework inspiration for the new CE skills assessment model [41]

### 3.1.3. Creation of the job profile archetypes

Following the selection and contextual adaptation of the assessment model to capture the CE and transversal competencies relevant to the manufacturing sector, the subsequent methodological phase focused on developing prototypical occupational profiles. These profiles were designed to function as benchmarks within the assessment tool, offering both employees and employers structured role-based criteria for evaluating environmental and cross-cutting skills.

The initial step involved a comprehensive mapping of all relevant actors within a manufacturing organization, encompassing not only central production roles but also supporting functions. This organizational analysis was grounded in established theories of work structure and informed by literature examining the transformation of manufacturing toward sustainable practices [43] [87]. Additionally, targeted research was reviewed to better understand the specific contributions of different roles within manufacturing ecosystems, including product design [25]. The analytical skills for accounting consultants [82] Research consultants [51], Remanufacturing Operators and the skills to develop [42] Energy Manager in Manufacturing [31] maintenance operations in industrial systems [5] and industrial engineering profile and competencies [22].

From this analytical groundwork, a classification framework was formulated to group roles according to their strategic influence and operational involvement in advancing circular economy practices. The identified roles were organized into two principal clusters: Business core, Support Roles.

Table 3-3: Manufacturing roles classification framework

| Business Core roles   | Support roles  |
|---|--|
| <ul style="list-style-type: none"> <li>• Supply chain Manager</li> <li>• Operations/Manufacturing /Production Manager</li> <li>• Environmental/ sustainability/circular economy manager.</li> <li>• Energy engineer</li> <li>• Industrial engineer</li> </ul> | <ul style="list-style-type: none"> <li>• Finance and accounting analyst.</li> <li>• IT engineer.</li> <li>• Impact assessment consultant.</li> </ul> |

|   |  |
|---|--|
| <ul style="list-style-type: none"> <li>• Maintenance and repair engineer/operator</li> <li>• Remanufacturing operator</li> <li>• Product designer/ R&amp;D consultant.</li> </ul> |  |
|---|--|

The Business Core cluster included those responsible for high-level decision-making, strategic oversight, and fostering an organizational culture oriented toward sustainability with engineers and operators’ profiles engaged directly in implementing sustainability through product design, process optimization, and maintenance activities, but also product developers—roles critical to enabling digital innovation, managing data systems, and driving eco-design initiatives. On the other hand, the Support Roles group comprised functions such as IT professionals, impact consultant staff, and finance and accounting job profiles, highly necessary on creating an environment that enables other departments to function effectively and achieve the company goals. This typology highlights the layered nature of circular manufacturing transformation, emphasizing that effective implementation relies on both strategic direction from leadership and the technical competence of operational personnel. It affirms that the transition toward sustainable industry is not solely a managerial challenge, but a cross-functional endeavor requiring coordinated engagement across the organizational hierarchy.

To ensure the relevance and validity of each occupational profile, individual tables were constructed for every role, integrating insights drawn from peer-reviewed literature, official institutional publications, and sector-specific case studies. These tables systematically outline the primary functions associated with each position extracted in the papers mentioned above for each role considered, along with the essential green, CE and digital skills required subtracted from the mapping skills matrix previously elaborated and classified depending on their nature. These skills detailed how each role contributes to broader organizational sustainability objective, for instance, the profile of a product designer was associated with competencies in eco-design and life cycle thinking, emphasizing the integration of environmental considerations into product development. In contrast, roles in Management are related to the awareness of green policies, the familiarity with ESG reporting frameworks, and

the use of economic research to help forecast economic activity and interest rates into green practices. The tables below present 6 profiles archetypes developed and synthesized by cross-sectional information gathered so far. The complete archetype matrix can be found in the Appendix section, necessary to understand the importance of each role described above.

Table 3-4: Extract of job profile archetypes designed for a manufacturing company

| Job Profile   | Responsibilities   | Skills & CE skills  |
|---|--|---|
| <b>Supply Chain manager</b>                         | <ul style="list-style-type: none"> <li>• Strategic supply chain alignment</li> <li>• Procurement, logistics, inventory management</li> <li>• Sustainability and regulatory compliance</li> <li>• Performance metrics and optimization</li> </ul> | <p><b>transversal skills</b></p> <ul style="list-style-type: none"> <li>• Strategic thinking</li> <li>• Leadership for change</li> <li>• Conflict resolution</li> </ul> <p><b>Technical skills</b></p> <ul style="list-style-type: none"> <li>• Ability to understand Circular economy core principles</li> <li>• Ability to identify Closed-loop material reuse systems</li> </ul>               |
| <b>Operations/Manufacturing/ Production Manager</b> | <ul style="list-style-type: none"> <li>• Production oversight and compliance standards</li> <li>• Lean manufacturing and continuous improvement</li> <li>• Circular operations design and management</li> </ul>                                  | <p><b>transversal skills</b></p> <ul style="list-style-type: none"> <li>• Critical thinking</li> <li>• Flexibility and adaptability</li> <li>• Workforce-up skilling</li> </ul> <p><b>Technical skills</b></p> <ul style="list-style-type: none"> <li>• Green forecasting using economic research</li> <li>• Ability for Solid waste and 4Rs approach</li> <li>• Knowledge of UN SDGs.</li> </ul> |
|   | <ul style="list-style-type: none"> <li>• Regulatory alignment and eco-innovation</li> <li>• Green practices training programs</li> </ul>   | <p><b>Transversal skills</b></p> <ul style="list-style-type: none"> <li>• Innovation</li> <li>• Environmental storytelling</li> </ul>   |

|   |  |  |
|---|--|--|
| <b>Environmental/sustainability/circular economy manager.</b> | <ul style="list-style-type: none"> <li>• Resource efficiency and decarbonization planning</li> </ul>   | <p><b>Technical skills</b></p> <ul style="list-style-type: none"> <li>• Understanding of take-back systems</li> <li>• Refurbishment and resale practices</li> <li>• Familiarity with ESG reporting frameworks</li> <li>• Awareness of green policy updates</li> </ul>  |
| <b>Energy engineer</b>  | <ul style="list-style-type: none"> <li>• Energy-efficient manufacturing optimization</li> <li>• Identify and reduce energy waste</li> <li>• GHG reduction and carbon offsets</li> <li>• Energy recovery system design</li> </ul> | <p><b>Transversal skills</b></p> <ul style="list-style-type: none"> <li>• Reskilling for the energy transition</li> <li>• Openness for information sharing</li> <li>• Multidisciplinary Teamwork</li> </ul> <p><b>Technical skills</b></p> <ul style="list-style-type: none"> <li>• Dynamic systems thinking</li> <li>• Knowledge of renewable energy in production</li> <li>• Understand the Life cycle assessment (LCA)</li> </ul> |
| <b>Remanufacturing operator</b>                               | <ul style="list-style-type: none"> <li>• Product disassembly and inspection.</li> <li>• Component wear and reuse assessment.</li> <li>• Part reuse, repair, recycling</li> <li>• Lean, eco-efficient remanufacturing</li> </ul>  | <p><b>Transversal skills</b></p> <ul style="list-style-type: none"> <li>• Attention to detail</li> <li>• Ethical judgment</li> <li>• Active listening</li> </ul> <p><b>Technical skills</b></p> <ul style="list-style-type: none"> <li>• Ability for Zero-defect, zero-waste practices</li> <li>• Mechanical disassembly and reassembly understanding</li> <li>• Resource optimization, environmental management</li> </ul>          |
| <b>R&amp;D/product designer</b>                               |  | <p><b>Transversal skills</b></p>   |

|  |   |   |
|--|---|---|
|  | <ul style="list-style-type: none"> <li>• User-centered ergonomic product design.</li> <li>• Cross-functional design collaboration.</li> <li>• Sustainable and eco-friendly design.</li> <li>• Sustainable materials and processes.</li> </ul> | <ul style="list-style-type: none"> <li>• Creative thinking</li> <li>• Lifelong learning</li> <li>• Change management</li> </ul> <p><b>Technical skills</b></p> <ul style="list-style-type: none"> <li>• Economy-environment-society interconnection understanding</li> <li>• Consumer behavior and needs analysis</li> <li>• Innovative material reuse solutions</li> </ul> |
|--|---|---|

One of the strengths of the Job Profile archetype lies in its capacity to provide visual individualization and tracking of the expected activities and capacities of each profile, enabling users to identify their skill strengths/weaknesses and development areas. In adapting to this model, primary but also assistant roles were introduced to reflect the specific green transition pathways that exist within various manufacturing actors—such as product designers, process engineers, production managers, or accounting specialists. This customization not only makes the tool more context-sensitive but also increases its relevance for both individuals and organizations aiming to benchmark and enhance their workforce capabilities for a circular economy. The resulting model is not merely a diagnostic tool but also a developmental guide, offering insights into potential upskilling trajectories that support sustainable innovation and strategic transformation in the manufacturing industry.

#### 3.1.4. Analytics and data visualization

The diagnostic tool proposed employs advanced data analytics and visualization methodologies to generate detailed insights into existing skill deficiencies. By presenting assessment outcomes in an intuitive and visually engaging format, the tool enhances interpretability and supports decision-makers in pinpointing the most critical areas for strategic intervention, focusing on user-friendly presentation differentiates the tool from traditional assessment platforms, which frequently lack robust or interactive visualization features. For this, the radar chart as a two-dimensional chart was selected due to its easy design to interpret the data recollected and to compare multiple quantitative variables against a baseline. Once the participant has completed their user-journey in the self-assessment tool, the results are displayed

as a series of points connected by lines and forming a polygon shape. This facilitates the holistic assessment of patterns and relationships across several dimensions.

What sets this tool apart is not only its visual interface but also its integrated design, which combines multiple innovative elements into a single cohesive system. These include real-time data tracking, customizable evaluation metrics, and seamless links to tailored training solutions. Collectively, these capabilities represent a significant contribution to the evolving landscape of CE skills assessment. The tool facilitates a more precise, responsive, and effective process for identifying skill gaps and implementing targeted upskilling initiatives—thereby addressing both current workforce needs and future competency demands.

### 3.1.5. Exemplification of the model for the identification of CE skills and gaps

To exemplify the application of the assessment model developed in this research, a complete user journey was constructed using a representative job profile: the Sustainable Manager, this role was selected due to its strategic importance in driving sustainability initiatives and aligning corporate goals with circular economy principles. The journey was designed to simulate a real-world implementation of the assessment tool, demonstrating how a professional occupying this role could interact with the system from initial self-evaluation to the final skill gap analysis. Each step of the process was structured to align with the underlying assessment framework, ensuring consistency between the theoretical model and practical application.

The process begins with a brief explanatory interface that introduces the participant to the symmetric proficiency scale used throughout the assessment process. This scale consists of three clearly defined levels: Basic/Learning, Familiar/Low Knowledge, and Proficient/High Knowledge and the scale was intentionally designed to promote self-awareness without penalizing learning stages, encouraging honest reflection rather than performance-based competition. Before starting the evaluation, the participant is encouraged to understand it, which acts as the basis for interpreting all subsequent inputs and results. This was developed having as a baseline the Digicomp model but also the IYS Skill Tech assessment model developed by the same company [35].

The first phase of the self-assessment focuses on soft skills, which were previously identified and mapped to the Sustainable Manager archetype through literature and academic articles, these include competencies such as innovation and critical thinking—all essential for navigating the complex challenges of circular

transformation. Participants rate their perceived proficiency in each soft skill based on the symmetric scale. The second phase shifts the focus to technical competencies, including interpretation of sustainable reports, design of transition systems to a circular approach, and implementation of product return, reuse and resale. As in the first phase, these skills were carefully matched to the Sustainable Manager archetype to ensure the assessment reflects role-specific expectations.

In the third phase, the participant is presented with a list of concrete activities relevant to the role and the broader context of sustainability in manufacturing. This section uses a multiple-selection format, allowing participants to indicate which of these activities they are currently engaged in, these selections provide additional context for interpreting the skill ratings and offer insight into the alignment between actual job functions and the archetype's ideal responsibilities. This step adds a behavioral layer to the model, going beyond self-perception to account for real practice.

Finally, the system generates a results dashboard that visually distinguishes between areas of strength and areas for development, where the dashboard highlights skills where the participant exceeds the expected level for their role and those where there may be notable gaps. The concluding component is a radar chart, which overlays two visual profiles: the first represents the ideal competency model for a Sustainable Manager, while the second depicts the participant's self-assessed skill levels. This visual juxtaposition allows for intuitive interpretation of alignment, surplus, and deficiencies, and provides a clear foundation for targeted learning paths, internal mobility planning, or external certification efforts. The figure 4-3 represents the exemplification of the assessment model.

# Sustainability Manager Self-Assessment



You will answer questions about your experience across activities, transversal and technical skills. Just select the level that best describes you.

Scale Definition:

- Basic / Learning:** I'm aware of this responsibility/skill but have minimal or no experience.
- Familiar / Low Knowledge:** I understand and have applied this in some contexts.
- Proficient / High Knowledge:** I apply this regularly and confidently, possibly mentor others too.

**Step 1** Transversal skills assessment

| <b>Transversal skills</b>   | Basic/<br>Learning    | Familiar/<br>Low Level<br>Knowledge | Proficient/<br>High Level<br>Knowledge |
|---|-----------------------|-------------------------------------|--|
| How confident are you in bringing forward new ideas that enhance environmental and circular practices?      | <input type="radio"/> | <input type="radio"/>               | <input type="radio"/>                  |
| How skilled are you in analyzing and solving complex environmental or compliance challenges?                | <input type="radio"/> | <input type="radio"/>               | <input type="radio"/>                  |
| How well do you collaborate across departments (e.g., R&D, logistics, production) on sustainability issues? | <input type="radio"/> | <input type="radio"/>               | <input type="radio"/>                  |

**Step 2** Technical skills assessment

| <b>Technical skills</b>  | Basic/<br>Learning    | Familiar/<br>Low Level<br>Knowledge | Proficient/<br>High Level<br>Knowledge |
|--|-----------------------|-------------------------------------|--|
| “How experienced are you in implementing systems for product return, reuse, or resale?”                        | <input type="radio"/> | <input type="radio"/>               | <input type="radio"/>                  |
| “How familiar are you with creating or interpreting sustainability reports using recognized global standards?” | <input type="radio"/> | <input type="radio"/>               | <input type="radio"/>                  |
| “How capable are you in designing and leading transitions to new circular approaches (e.g., servitisation)?”   | <input type="radio"/> | <input type="radio"/>               | <input type="radio"/>                  |

**Step 3** Activities assessment

Please select from the below activities, the ones you take responsibility for in your daily job. You can select several options.

- Ensuring compliance with environmental regulations and standards
- Developing and implementing sustainability strategies
- Leading employee training on green manufacturing practices

**Step 4** Results dashboard**Skills inventory**

Here you will identify the set of skills you have with the respective evaluation in the predefined scale of Basic, familiar, proficient

**Skills you are surplus in****Transversal skills**

Innovation

Proficient / High knowledge



Critical Thinking

Proficient / High knowledge

**Technical skills**Take-back systems  
(reuse/refurbishment)

Proficient / High knowledge



**Skills Gap - Skills you are deficient in**

**Transversal skills**

Multidisciplinary Teamwork **Basic / Learning**

**Technical skills**

Use of sustainability reporting frameworks (GRI, CDP, ESG) **Basic / Learning**

Planning circular transitions **Familiar/ Low Level Knowledge**

**Skills data**

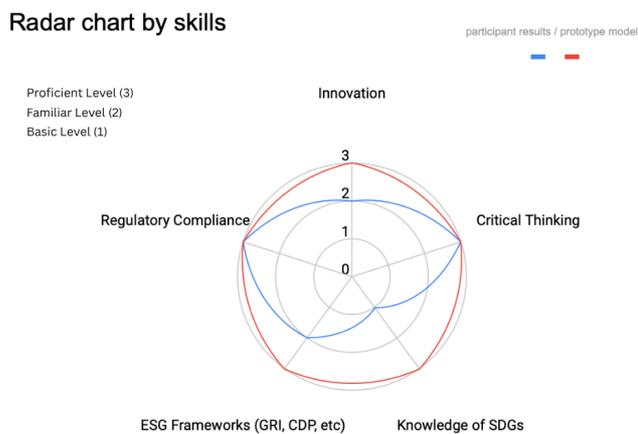


Figure 3-3: Exemplification of the participant journey of the adopted mode



## 4 Discussion and Conclusions

The transition to a CE represents far more than a technological or structural shift; it is fundamentally a human challenge that demands a critical realignment of workforce capabilities. While policy frameworks and industry strategies increasingly highlight circularity as a strategic priority, the practical question of whether the workforce possesses the necessary skills to operationalize these ambitions remains insufficiently addressed. This thesis sought to bridge that gap by developing an assessment tool specifically designed to evaluate CE-related skills in the manufacturing sector, aiming to make the concept of workforce readiness more tangible and actionable.

A central motivation of this research lay in the persistent disconnect between high-level sustainability goals and the concrete instruments available to assess and develop human capital. Too often, existing skills audits are generic, failing to reflect the interdisciplinary demands of CE competencies that blend environmental literacy, technical expertise, strategic thinking, and digital fluency. Through a thorough review and synthesis of academic and policy literature, this work established a structured taxonomy of CE skills, distinguishing among basic, technical, and transversal categories, anchoring these competencies in realistic, role-based archetypes, the model enhances practical relevance, allowing organizations to move beyond abstract commitments to more precise, targeted workforce development strategies.

Equally important was the methodological design of the tool, which sought to balance theoretical rigor with usability. The decision to adopt the Worker Profiler framework as its structural backbone provided a validated, role-based approach that aligns with industry needs while accommodating the complexity of CE transitions, integrating elements of existing digital competency frameworks like DigCompSAT and DigComp ensured analytical robustness and cross-functional adaptability. Notably, the tool's emphasis on self-assessment via a Likert scale offers a user-centered, scalable method for evaluating skills, despite the well-known challenge of subjectivity inherent in self-reported data. By contextualizing self-assessments within clear role definitions and comparing them to "ideal" benchmarks derived from the literature, the model seeks to mitigate this limitation while promoting a dynamic, learner-driven development process.

Beyond its methodological contributions, this research advances the understanding of green human capital by operationalizing how CE readiness can be assessed at the occupational level. Rather than treating the workforce as a passive implementer of sustainability strategies, the model foregrounds its active, transformative role, for instance, remanufacturing operators are reframed not simply as technicians but as stewards of resource efficiency and circular value retention. Similarly, sustainability managers are envisioned as strategic facilitators who must combine regulatory knowledge with storytelling and cross-functional collaboration. Such reframing has significant implications for education and training, suggesting that vocational programs and corporate learning initiatives can be redesigned to target specific, role-based competency gaps rather than relying on generic green training modules.

The practical applications of this tool are considerable, manufacturing firms can use it to identify workforce gaps that might hinder the adoption of circular practices, supporting more strategic investments in training, recruitment, and internal mobility. It offers employees clear, visualized feedback about their current skill levels and personalized development pathways, fostering engagement and ownership of their professional growth. Educational institutions can leverage the model to align curricula with industry demands, thereby enhancing graduates' employability in an evolving labor market. Policymakers may find value in aggregated data produced through large-scale deployment, using it to design targeted interventions, allocate funding more effectively, or inform green job certification frameworks. Moreover, by explicitly linking CE competencies with digital skills, the model reflects the convergence of sustainability and Industry 4.0 transformations, supporting more integrated workforce development strategies suited to contemporary manufacturing contexts.

However, it is important to recognize the limitations inherent in this approach. The reliance on self-assessment inevitably introduces subjectivity, with risks of users overestimating or underestimating their competencies based on confidence levels or familiarity with CE concepts. While the model seeks to address this through clear role definitions and comparative benchmarks, future iterations would benefit from integrating more objective assessment methods such as peer evaluations, behavioral simulations, or real-time task monitoring. Additionally, the archetype-based framework, while offering valuable clarity and comparability, may oversimplify the diversity and nuance of real-world manufacturing roles, which can vary significantly by sector, company size, and geography. A greater customization or sector-specific adaptations will be essential to enhance its accuracy and relevance.

Furthermore, while the model integrates insights from established frameworks and literature, it remains conceptual and has not yet undergone large-scale empirical validation. Pilot testing in actual manufacturing environments is critical to evaluate its usability, reliability, and predictive validity – particularly its capacity to forecast actual

workforce performance or readiness, important to evaluate and validate each profile and skills developed in this paper as it was developed from the understanding of the literature but not tested in a real environment. Another important limitation is the model's current focus on individual competencies in isolation from organizational and systemic factors. True readiness for CE transitions depends not only on the skills of individual workers but also on enabling structures such as leadership commitment, workflow flexibility, technological infrastructure, and supportive policy environments, and therefore future development should consider integrating organizational readiness indicators to provide a more holistic assessment of CE transition capacity.

Looking forward, several pathways for future development emerge from this research. Empirical validation through pilot studies will be essential to refine the skill categories, improve the accuracy of self-assessment data, and test the tool's effectiveness in guiding professional development. Integration with digital learning platforms and HR systems could streamline usage, automate progress tracking, and deliver personalized training content, enhancing both scalability and user engagement. Expanding the range of role archetypes to include additional functions such as logistics, procurement, and quality assurance, as well as developing sector-specific adaptations, would further improve the tool's comprehensiveness. Moreover, incorporating modules that assess organizational enablers—such as leadership buy-in, regulatory compliance, and access to sustainability incentives—would allow for a dual assessment of both individual and systemic readiness. Finally, there is potential for the model to evolve into a formal CE competency certification system, providing recognized credentials that can support workforce mobility, firm-level strategy, and evidence-based policymaking.

In conclusion, this thesis offers an original, practical contribution to the critical question of how manufacturing industries can prepare their workforces for the demands of a circular economy, by centering human capital as a vital enabler of sustainable transformation, not only advances green human capital theory but also provides a tangible, adaptable tool for industry, education, and policy stakeholders. While acknowledging its current limitations and the need for further development and validation, this work lays an important foundation for aligning workforce capabilities with the urgent, complex, and dynamic challenges of achieving circularity in the 21st-century economy.



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# A Appendix A

Appendix A presents two tables. First, the table with the skills recollected from the identified and analysed literature, and second, the table with the accordingly organized skills and classified in transversal, technical and soft skills.

## A.1. The green and CE skills

The list of green skills gathered from literature and considered for the skills matrix.

**Table A-1:** List of green and CE skills identified from the reviewed literature

| The green and CE skills   |
|---|
| <ul style="list-style-type: none"> <li>• Active Listening</li> <li>• Adaptability</li> <li>• Adaptability</li> <li>• Application of innovative management tools to favor the transition to CE</li> <li>• Autonomy</li> <li>• Circular Economy Collaboration</li> <li>• Circular Manufacturing</li> <li>• Cleaner Production Processes</li> <li>• Cleaning Skills</li> <li>• Collaboration</li> <li>• Collaboration in Circular Business Models</li> <li>• Communication</li> <li>• Creativity</li> <li>• Critical Thinking</li> <li>• Critical Thinking</li> <li>• Cross-sectoral Collaboration</li> <li>• Customer Engagement via Digital Platforms</li> <li>• Cybersecurity</li> <li>• Data Management and Analytics</li> <li>• Design for X</li> <li>• Digital Product Lifecycle Tracking</li> <li>• Disassembly and Reassembly</li> <li>• Disassembly Skills</li> <li>• E-commerce and Digital Marketing</li> <li>• Eco-Design</li> <li>• Eco-design - Designing products with environmental impact considerations</li> </ul> |

- Ecosystem Building
- Energy Data Collection & Analysis
- Energy Efficiency
- Energy Efficiency in Production
- Energy Management and Renewable Energy
- Energy Management of Equipment
- Environmental Awareness
- Environmental Storytelling
- Ethical judgement
- Field Experience in IS/EE
- Flexibility and Local Responses
- General Regulatory Awareness
- Industrial Symbiosis
- Industry 4.0 technologies application
- Initiative Taking and Entrepreneurship
- Innovation
- Innovation and Product Development
- IS Basic Understanding
- Knowledge Management and Coaching
- Knowledge of composition and development of products
- Knowledge of energy trading, economics, and financing
- Knowledge of Recycling Technologies
- Knowledge of the 3R Framework
- Leadership
- Lean Manufacturing
- Legislation on CO2 Emissions
- Legislation on Waste Management
- Machine Operation for Recycling and Recovery
- Maintenance of systems operating in green energy environments
- Management of a diversity of tasks
- Market Monitoring
- Master 3D printing and scanning technology
- Master virtual, augmented, and mixed (VAM) realities
- Material Composition Knowledge
- Material Flow Analysis
- Material Innovation
- Material Traceability
- Modular Design
- Mult disciplinarity
- Openness for information sharing
- Policy Monitoring
- Problem-Solving
- Process Optimization
- Product Life Cycle Thinking
- Product Service System (PSS) Design

|  |
|--|
| <ul style="list-style-type: none"> <li>• Production planning</li> <li>• Quality control</li> <li>• Recycling and Waste Recuperation Technologies</li> <li>• Regulatory and Economic Skills</li> <li>• Remanufacturing Skills</li> <li>• Remote Monitoring and Servicing</li> <li>• Repair and Maintenance Skills</li> <li>• Reskilling for the energy transition (?)</li> <li>• Reverse Logistics</li> <li>• Robotics and automation</li> <li>• Servitization Models Development</li> <li>• Software Development for Circular Business Models</li> <li>• Sorting and Grading Skills</li> <li>• Spare Parts Sourcing</li> <li>• Standardized Production and Operations</li> <li>• Storytelling</li> <li>• Strategic Thinking</li> <li>• Strategic Thinking</li> <li>• Stress and emotion management</li> <li>• Supply Chain Management</li> <li>• Sustainability-focused R&amp;D</li> <li>• Sustainable Procurement</li> <li>• Sustainable Resource</li> <li>• System Optimization &amp; Process Analysis</li> <li>• Systems Thinking</li> <li>• Teaming</li> <li>• Teamwork and Self-Efficiency</li> <li>• Technological Adaptation and Implementation</li> <li>• Technological Adaptation and Implementation</li> <li>• Technology Integration</li> <li>• Value Chain Collaboration</li> <li>• Waste Recuperation</li> <li>• Workforce-up skilling</li> </ul> |
|--|

Table A-2: Green and CE skills classified in Basic competencies

**BASIC COMPETENCIES**

|  |  |
|--|--|
|  | <ul style="list-style-type: none"> <li>▪ Knowledge of the 17 Sustainable Development Goals (SDGs).</li> <li>▪ Understanding the 3 principles of the circular economy: Elimination of waste and pollution,</li> </ul> |
|--|--|

|   |   |
|---|---|
| <b>Fundamentals of sustainable development and the circular economy</b> | <p>Circulation of products and materials to their highest value, Regeneration of nature.</p> <ul style="list-style-type: none"> <li>▪ Fundamentals of solid waste streams and their sources and focus on the 4Rs: Reject, Reduce, Reuse, Recycle</li> </ul>   |
| <b>System thinking</b>  | <ul style="list-style-type: none"> <li>▪ Ability to understand the interconnection between economy, environment and society.</li> <li>▪ Ability to identify parts of a system</li> <li>▪ Ability to understand how the parts of a dynamic system interact to produce the behavior of the whole.</li> </ul>  |
| <b>Regulatory and environmental economic Skills</b>                     | <ul style="list-style-type: none"> <li>▪ Ability to keeping up to date with laws, policies, and incentives that promote greener industrial practices.</li> <li>▪ Ability to understand basic economic concepts like supply, demand, costs, benefits, economic sustainability, production, scarcity and efficiency.</li> <li>▪ Ability to use economic research to help forecast economic activity and interest rates into the green practices.</li> </ul> |

Table A-3: Green and CE skills classified in technical competencies

**TECHNICAL MANAGEMENT  
COMPETENCIES**

|  |  |
|--|--|
| <b>Design and management of multiple product-service life cycles</b> | <ul style="list-style-type: none"> <li>▪ Ability to apply multiple lifecycles thinking involving modularity, durability and safety considerations, as well as maintainability, reparability, upgradeability, reusability and recyclability of products and materials.</li> <li>▪ Understanding the influence of circular product design on the success of the circular supply chain.</li> <li>▪ Ability to apply Design approaches that support sustainability and circular economy - such as Design for Reliability, Design for Multiple Life Cycles (Disassembly, Remanufacturing, Recycling), Design for Supply Chain, Design for Sustainability.</li> <li>▪ Ability to develop recyclable, compostable materials.</li> <li>▪ Ability to measure product-service circularity and assess the environmental, economic and social impact of circular design interventions.</li> <li>▪ Ability to implement co-design practices (participatory design/collaborative design) for the circular economy, involving the main actors in the circular product value chain.</li> </ul> |
|--|--|

|   |   |
|---|---|
|   | <ul style="list-style-type: none"> <li>▪ Ability to identify real consumer needs, develop information on consumer behavior towards alternative products and services to conventional ones. Ability to engage users in all aspects of the circular economy, e.g. by enabling them to share and care for products (shared or owned) and encouraging them to return them at the end of a cycle use</li> <li>▪ Ability to develop easily accessible services to extend product life, e.g. product upgrades, predictive maintenance and repair, scalable on attractive economic models for suppliers and consumers</li> <li>▪ Ability to develop innovative solutions to increase the use of recyclable and compostable materials, to increase the use of secondary raw materials with a view to replacing virgin materials with recycled ones, production residues and by-products, and to eliminate, replace or reduce the presence of hazardous substances in products or improve their traceability in order to facilitate recycling.</li> </ul> |
| <p><b>Design and management of circular operations and production systems</b></p> | <ul style="list-style-type: none"> <li>▪ Ability to identify, prevent and correct waste and zero-defect/zero-waste manufacturing</li> <li>▪ Ability to optimise the use of resources in production cycles; and environmental management.</li> <li>▪ Water management: technologies, processes and industrial solutions for the rational use, efficient management, reuse and recycling of water, especially wastewater.</li> <li>▪ Energy management, increased use of renewables and energy efficiency</li> <li>▪ Ability to design, implement and operate process technologies and industrial production systems in which waste or by-products become new inputs</li> <li>▪ Ability to operate and analyze using Computerized Maintenance Management Systems.</li> <li>▪ Ability to design/select, implement and operate "smart" technological systems, innovative processes and flexible, reconfigurable systems for disassembly sorting and recycling (e.g. Hyper-intelligent sorting systems, Learning disassembly robots)</li> </ul>      |

|   |   |
|---|---|
|   | <ul style="list-style-type: none"> <li>▪ Basic understanding of restoring products without original documentation</li> <li>▪ Ability to understand the mechanical systems and components for effective disassembly and reassembly.</li> <li>▪ Ability to design/select, implement and operate "smart" technology systems and innovative processes for Remanufacturing.</li> <li>▪ Ability to operate and manage services to extend product life, e.g. product upgrades, predictive maintenance and repairs.</li> <li>▪ Ability to evaluate different alternatives and identify the best circular strategy for a given product.</li> <li>▪ Ability to plan and control production in systems characterized by high complexity, uncertainty, heterogeneity in material quality and composition (reverse production planning, reverse MRP, Reprocessing Scheduling)</li> </ul> |
| <p><b>Design and management of circular value chains</b></p>                          | <ul style="list-style-type: none"> <li>▪ Long-term Product Returns Management - Ability to select recoverable post-use products and sources, to develop an Acquisition Strategy and a Collection Strategy.</li> <li>▪ Ability to make reliable forecasts of return flows and their composition, qualitative properties etc.</li> <li>▪ Ability to create synergies between direct and reverse logistics, plan the transport and handling of recovered products, optimise the use of multi-directional transport networks.</li> <li>▪ Planning and control of distribution of reprocessed products to consumers. Packaging optimization.</li> </ul>  |
| <p><b>Assessment of circularity and environmental, social and economic impact</b></p> | <ul style="list-style-type: none"> <li>▪ Ability to apply methods for the assessment of ENVIRONMENTAL, ECONOMIC, SOCIAL impacts along the product-service life cycle (e.g. LCA)</li> <li>▪ Ability to apply methods for assessing "circularity" at product, process, enterprise, value chain level (e.g. Circular Economy Maturity Assessment).</li> <li>▪ Ability to define interventions to improve circularity, energy systems and impacts.</li> </ul>   |
| <p><b>Sustainable Marketing,</b></p>  | <ul style="list-style-type: none"> <li>▪ Selection and market segmentation skills</li> <li>▪ Ability to develop and implement remarketing and pricing strategies to increase</li> </ul>   |

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| <p><b>Remarketing and Re-marketing</b></p>  | <p>demand/availability to purchase recovered products and alignment with "primary" product strategies (e.g. manage cannibalization risk)</p> <ul style="list-style-type: none"> <li>▪ Ability to apply green marketing, social marketing approaches and techniques</li> <li>▪ Demand Planning and Fulfilment Capability</li> </ul>   |
| <p><b>Innovation of the value proposition and business model oriented towards circularity</b></p> | <ul style="list-style-type: none"> <li>▪ Circular Economy Storytelling --&gt; Ability to create engaging visions and narratives of the circular economy so that it becomes a shared idea for which support can be garnered among various stakeholders</li> <li>▪ Ability to plan and implement the transition to new circular business models (cross-sectoral / servitisation-based, etc.)</li> <li>▪ Ability to assess costs and benefits and manage risks of possible investments and projects.</li> <li>▪ Circular Economy Collaboration --&gt; facilitating and engaging collaborations through value networks in order to create circular product-service systems and stimulate the transition to a circular economy.</li> <li>▪ Knowledge of the types and characteristics of circular business models, e.g. Circular supply chain "from the beginning", Recovery and recycling, Product life extension, Sharing platform, Product as a service.</li> </ul>                |
| <p><b>External context and trend analysis</b></p>   | <ul style="list-style-type: none"> <li>▪ Knowledge of Standards and Certifications and ability to apply them. Ability to contribute to their creation / evolution.</li> <li>▪ Knowledge of international geo-politics and understanding of implications for business</li> <li>▪ Ability to monitor, select and take advantage of tax incentives and access to credit, funding for R&amp;D&amp;I projects on circular economy/sustainability.</li> <li>▪ Ability to monitor regional, national and international policies, legislation and regulations related to the different areas of the circular economy. Understanding of the implications on business activities and ability to influence their evolution.</li> <li>▪ Ability to create financial modeling for energy efficiency projects, lifecycle costing, ESG metrics.</li> <li>▪ Knowledge of Standards and Certifications and ability to apply them. Ability to contribute to their creation / evolution.</li> </ul> |

|   |   |
|---|---|
|   | <ul style="list-style-type: none"> <li>▪ Ability to monitor, select and take advantage of tax incentives and access to credit, funding for R&amp;D&amp;I projects on circular economy/sustainability.</li> </ul>  |
| <p><b>Development and use of digital solutions as an enabling factor for the circular economy</b></p> | <ul style="list-style-type: none"> <li>▪ Ability to select, implement and use digital platforms for data sharing and integration between multiple actors (Data Spaces)</li> <li>▪ Ability to select and apply solutions based on Distributed Ledger Technologies (e.g. CircularChain, Circularise)</li> <li>▪ Ability to apply modelling and simulation techniques (Digital Twins)</li> <li>▪ Ability to apply supporting hardware lifecycle optimization and e-waste management strategies</li> <li>▪ Ability to select, implement and use artificial intelligence-based applications to support multi-criteria decision-making processes (e.g. design choices, best solution for end-of-life product, etc.)</li> <li>▪ Data management, engineering, analysis and visualization skills</li> </ul> |
| <p><b>Coordination of Circular Logistics</b></p>  | <ul style="list-style-type: none"> <li>▪ Ability to detail transport equipment utilization, improving fill rates and identifying the best modes of transport for the needs to optimizing processes within the given transport network for cost, lead times and CO2.</li> <li>▪ Ability to understand of Take-Back Systems to collect and recycle or properly dispose of products or materials that have reached the end of their useful life.</li> <li>▪ Ability to reduce the distance and number of goods transport operations, especially those that use combustion vehicles, which emit greenhouse gases that are harmful to the environment</li> </ul>   |
| <p><b>Assessment of energy performance and energy efficiency</b></p>                                  | <ul style="list-style-type: none"> <li>▪ Ability to conduct LCA to evaluate environmental impact of energy usage across product/process life cycles.</li> <li>▪ Ability to integrate renewable energy technologies (solar, biomass, etc.) into production systems.</li> <li>▪ Ability to conduct energy assessments and identify inefficiencies in manufacturing processes and infrastructure.</li> <li>▪ Ability to design, analyze, and optimize industrial energy systems, including HVAC, boilers, turbines, and process heating/cooling.</li> </ul>  |

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|  | <ul style="list-style-type: none"> <li>▪ Ability to collaborate with automation engineers to align control systems with energy-saving goals</li> </ul> |
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Table A-4: Green and CE skills classified in transversal competencies

**TRANSVERSAL  
COMPETENCIES**

|                                      |  |
|--------------------------------------|--|
| <b>Workforce-up skilling</b>         | <ul style="list-style-type: none"> <li>▪ Ability to enhancing the existing skills of employees or equipping them with new competencies, to adapt to changing job requirements, industry trends, and technological advancements, ensuring that the workforce remains competitive, productive, and capable of meeting the evolving needs.</li> </ul> |
| <b>Innovation</b>                    | <ul style="list-style-type: none"> <li>▪ Ability to innovate by thinking outside the box, looking out of the ordinary, being able to see situations, objects and problems from another point of view, giving space to one's imagination and making original connections and proposing changes</li> </ul>   |
| <b>Critical thinking</b>             | <ul style="list-style-type: none"> <li>▪ Ability to analyze information, situations and experiences objectively, distinguishing reality from one's own subjective impressions and prejudices, recognizing factors that influence one's own and others' thoughts and behavior</li> </ul>  |
| <b>Entrepreneurial skills</b>        | <ul style="list-style-type: none"> <li>▪ Ability to act on ideas and opportunities and turn them into values for others.</li> </ul>  |
| <b>Multidisciplinary Teamwork</b>    | <ul style="list-style-type: none"> <li>▪ Ability to coordinate, instruct, negotiate, persuade, service orientation, social perceptiveness of several disciplines to achieve a joint goal</li> </ul>  |
| <b>Flexibility and adaptability</b>  | <ul style="list-style-type: none"> <li>▪ Ability to remain resilient and manage skills development.</li> <li>▪ Ability to adapt to a multitude of tasks, changes of scenarios, jobs, means and technologies by adapting to the work environment whatever the task at hand.</li> </ul>  |
| <b>Stress and emotion management</b> | <ul style="list-style-type: none"> <li>▪ Ability to recognize, understand, and regulate one's emotions and stress levels in a healthy and productive way. These skills are crucial for maintaining mental well-being, improving</li> </ul>   |

|   |  |
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|   | relationships, enhancing performance in high-pressure situations, and building resilience in both personal and professional settings.  |
| <b>Openness for information sharing</b>     | <ul style="list-style-type: none"> <li>▪ Ability to freely and transparently exchange relevant knowledge, data, ideas, or insights with others in a collaborative environment. It involves the mindset and practice of making information accessible to colleagues, teams, or stakeholders, fostering a culture of trust, innovation, and teamwork.</li> </ul> |
| <b>Strategic Thinking</b>                   | <ul style="list-style-type: none"> <li>▪ Ability to analyze situations, anticipate future trends, and develop long-term plans that align with an organization's goals and objectives. It involves a high-level, big-picture perspective that helps individuals and teams make decisions that position them for success over time.</li> </ul>                   |
| <b>Environmental Storytelling</b>           | <ul style="list-style-type: none"> <li>▪ Ability to convey a narrative or message through the physical environment, is a powerful tool for creating rich, immersive narratives that rely on the environment itself to communicate meaning, engage audiences, and evoke emotions.</li> </ul>  |
| <b>Leadership for change</b>                | <ul style="list-style-type: none"> <li>▪ Ability to guide, inspire, and influence individuals or teams to achieve shared goals and objectives. It involves a combination of qualities and abilities that enable someone to motivate others, build trust, make decisions, and navigate challenges.</li> </ul>   |
| <b>Knowledge Management and Coaching</b>    | <ul style="list-style-type: none"> <li>▪ Ability to effectively gather, organize, share, and apply knowledge within an organization, while also guiding, mentoring, and developing individuals or teams through coaching practices.</li> </ul>   |
| <b>Reskilling for the energy transition</b> | <ul style="list-style-type: none"> <li>▪ Ability for acquiring new skills to transition into a different job role or training individuals for alternative roles all of this towards the energy transition practice.</li> </ul>   |
| <b>Active Listening</b>                     | <ul style="list-style-type: none"> <li>▪ Ability to actively processing and seeking to understand the meaning and intent behind them. It requires being a mindful and focused participant in the communication process.</li> </ul>   |
| <b>Ethical judgement</b>                    | <ul style="list-style-type: none"> <li>▪ Ability to make effective decisions in critical situations or dilemmas. Use of these skills can include evaluation and prioritization of factors, making a wade decision, arriving at a conclusion and forming subjective opinions.</li> </ul>  |

|                                      |   |
|--------------------------------------|---|
| <p><b>Communication</b></p>          | <ul style="list-style-type: none"> <li>▪ Ability to understand and be understood by others. These can include but are not limited to effectively communicating ideas to others, actively listening in conversations, giving and receiving critical feedback and public speaking.</li> </ul> |
| <p><b>Creative thinking</b></p>      | <ul style="list-style-type: none"> <li>▪ Ability to come up with unique, original solutions.</li> </ul>   |
| <p><b>Project management</b></p>     | <ul style="list-style-type: none"> <li>▪ Ability in planning, executing, and monitoring engineering projects with time and budget constraints.</li> </ul>   |
| <p><b>Change management</b></p>      | <ul style="list-style-type: none"> <li>▪ Ability to adapt to help a company through the process of making organizational changes.</li> </ul>  |
| <p><b>Attention to detail</b></p>    | <ul style="list-style-type: none"> <li>▪ Ability to deliver top quality work and maintain high standards.</li> </ul>  |
| <p><b>Embeddedness</b></p>           | <ul style="list-style-type: none"> <li>▪ Ability to generate trust, developing regional socioeconomic networks, and thus leading to regional innovation and socioeconomic development.</li> </ul>   |
| <p><b>Sustainability mindset</b></p> | <ul style="list-style-type: none"> <li>▪ Ability of thinking and being those results from a broad understanding of the ecosystem's manifestations, and an introspective focus on the personal values and the higher self.</li> </ul>  |



## B Appendix B

Appendix B presents a series of tables where the job profile archetypes are elaborated for the self-assessment tool purposes with the green and CE skills crossed from the tables developed in the Appendix A.

Table B-1: Supply Chain Manager job profile archetype

| Responsibilities   | Skills & CE skills  |
|--|---|
| <p>Develop and implement supply chain strategies aligned with production and business goals.</p> <p>Manage procurement, logistics, and inventory systems</p> <p>Ensure compliance with sustainability, circular economy, and regulatory standards</p> <p>Collaborate with internal teams (production, sales, finance) and external partners (suppliers, logistics providers)</p> <p>Monitor performance metrics (e.g., on-time delivery, cost savings, carbon footprint)</p> | <p><u>Transversal skills</u></p> <ul style="list-style-type: none"> <li>• Strategic thinking</li> <li>• Leadership for change</li> <li>• Knowledge management and coaching</li> <li>• Active listening</li> <li>• Communication</li> <li>• Change management</li> <li>• Embeddeness</li> <li>• Conflict resolution</li> </ul> <p><u>Technical skills</u></p> <ul style="list-style-type: none"> <li>• Understand basic economic concepts like supply, demand, costs, benefits, economic sustainability, production, scarcity and efficiency.</li> <li>• Ability to keeping up to date with laws, policies, and incentives that promote greener industrial practices -</li> <li>• Analyze the relationships between product-service design, supply chain and business model.</li> <li>• Design flexible configurations for circular supply chains, manage and operate circular supply chains to</li> </ul> |

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|  | <p>maximize environmental, economic and social performance</p> <ul style="list-style-type: none"><li>• Design, manage and operate industrial symbiosis systems, local production-distribution-consumption networks.</li><li>• Select recoverable post-use products and sources, to develop an Acquisition Strategy and a Collection Strategy</li><li>• Create synergies between direct and reverse logistics, plan the transport and handling of recovered products, optimise the use of multi-directional transport networks.</li><li>• Ability to understand the interconnection between economy, environment and society.</li><li>• Ability to detail transport equipment utilisation, improving fill rates and identifying the best modes of transport for the needs to optimizing processes within the given transport network for cost, lead times and CO2.</li><li>• Ability to reduce the distance and number of goods transport operations, especially those that use combustion vehicles, which emit greenhouse gases that are harmful to the environment</li><li>• Ability to collect the used but functional products, which can then be refurbished and resold, reducing the need for new production cycles and their associated environmental costs.</li><li>• Ability to understand of Take-Back Systems to collect and recycle or properly dispose of products or materials that have reached the end of their useful life</li></ul> |
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Table B-2: Operations/Manufacturing/production Manager job profile archetype

| Responsibilities   | Skills and CE skills   |
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| <ul style="list-style-type: none"> <li>• Oversee production workflows and ensure alignment with safety, quality, and environmental standards</li> <li>• Implement lean manufacturing and continuous improvement initiatives.</li> <li>• Design and management of circular operations and production systems</li> <li>• Monitor KPIs and production targets, with management of budgets, resource allocation, and cost control.</li> <li>• Ensure the implementation of repair, reuse, and remanufacturing initiatives, optimizing the time and waste in production.</li> <li>• Lead technology adoption and digital transformation initiatives considering environmental impact across product lifecycle.</li> </ul> | <p><i>Transversal skills</i></p> <ul style="list-style-type: none"> <li>• Leadership for change</li> <li>• Stress and emotion management</li> <li>• Openness for information sharing</li> <li>• Knowledge management and coaching</li> <li>• Flexibility and adaptability</li> <li>• Lifelong learning</li> <li>• Critical thinking</li> <li>• Workforce-up skilling</li> <li>• Communication</li> <li>• Change management</li> <li>• Time management</li> </ul> <p><i>Technical skills</i></p> <ul style="list-style-type: none"> <li>• Understand basic economic concepts like supply, demand, costs, benefits, economic sustainability, production, scarcity and efficiency</li> <li>• Identify, prevent and correct waste and zero-defect/zero-waste manufacturing</li> <li>• Optimize the use of resources in production cycles; and environmental management</li> <li>• Increase use of renewables and energy efficiency</li> <li>• Design, implement and operate process technologies and industrial production systems in which waste or by-products become new inputs</li> <li>• Design/select, implement and operate "smart" technological systems, innovative processes and flexible, reconfigurable systems for disassembly sorting and recycling.</li> <li>• Understand the 3 principles of the circular economy: Elimination of waste</li> </ul> |

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|  | <p>and pollution, Circulation of products and materials to their highest value, Regeneration of nature.</p> <ul style="list-style-type: none"> <li>• Use economic research to help forecast economic activity and interest rates into the green practices.</li> <li>• Fundamentals of solid waste streams and their sources and focus on the 4Rs: Reject, Reduce, Reuse, Recycle.</li> <li>• Use <b>closed-loop systems</b> for materials reuse.</li> <li>• Knowledge of the 17 Sustainable Development Goals (SDGs)</li> </ul> |
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Table B-3: Environmental/sustainability/circular economy manager job profile archetype

| Responsibilities   | Skills and CE skills  |
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| <p>Ensures that the organization's operations comply with environmental regulations and standards while developing and implementing strategies that improve sustainability performance.</p> <p>Allow compliance, innovation, and strategic environmental planning.</p> <p>Drives employee training on green manufacturing practices</p> <p>Promote resource efficiency and carbon footprint reduction by developing and executing decarbonization strategies for plants and logistics.</p> | <p><i>Transversal skills</i></p> <ul style="list-style-type: none"> <li>• Innovation</li> <li>• Critical thinking</li> <li>• Multidisciplinary teamwork</li> <li>• Environmental storytelling</li> <li>• Reskilling for the energy transition</li> <li>• Active listening</li> <li>• Ethical judgment</li> <li>• Communication</li> <li>• Embeddedness</li> <li>• Change management</li> <li>• Knowledge management and coaching</li> <li>• Flexibility and adaptability</li> <li>• Leadership for change</li> </ul> <p><i>Technical skills</i></p> |

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|  | <ul style="list-style-type: none"> <li>• Knowledge of the 17 Sustainable Development Goals (SDGs)</li> <li>• Familiarity with Take-Back Systems to collect and recycle or properly dispose of products or materials that have reached the end of their useful life.</li> <li>• Ability to collect the used but functional products, which can then be refurbished and resold, reducing the need for new production cycles and their associated environmental costs</li> <li>• Familiarity with GRI, CDP, or integrated ESG frameworks for reporting sustainability performance.</li> <li>• Ability to monitor regional, national and international policies, legislation and regulations related to the different areas of the circular economy.</li> <li>• Knowledge of the types and characteristics of circular business models, e.g. Circular supply chain "from the beginning", Recovery and recycling, Product life extension, Sharing platform, Product as a service.</li> <li>• Ability to identify problems and challenges of the current business model and suggest improvements and/or new circularity-oriented models, considering the relationship with product design and supply chain</li> <li>• Ability to plan and implement the transition to new circular business models (cross-sectoral / servitisation-based, etc.)</li> <li>• Ability to facilitate and engaging collaborations through value networks in order to create circular product-service systems and stimulate the transition to a circular economy.</li> <li>• Ability to Monitor, select and take advantage of tax incentives and access to credit, funding for R&amp;D&amp;I projects on circular economy/sustainability.</li> <li>• Ability to apply methods for assessing "circularity" at product,</li> </ul> |
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|  | <p>process, enterprise, value chain level (e.g. Circular Economy Maturity Assessment)</p> <ul style="list-style-type: none"> <li>• Ability to measure product-service circularity and assess the environmental, economic and social impact of circular design interventions.</li> <li>• Ability to understand the 3 principles of the circular economy: Elimination of waste and pollution, Circulation of products and materials to their highest value, Regeneration of nature</li> <li>• Ability to keeping up to date with laws, policies, and incentives that promote greener industrial practices.</li> <li>• Ability to use economic research to help forecast economic activity and interest rates into the green practices.</li> </ul> |
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Table B-4: Energy engineer job profile archetype

| Responsibilities  | Skills & CE skills  |
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| <p>Ensure that manufacturing processes optimize energy consumption.</p> <p>Identifies inefficiencies in energy use and implements solutions to reduce waste and costs.</p> <p>Develops and deploys renewable energy sources (solar, wind, biomass) to power manufacturing operations.</p> <p>Works on strategies to lower greenhouse gas (GHG) emissions through clean energy initiatives and carbon offset programs.</p> | <p><i>Transversal skills</i></p> <ul style="list-style-type: none"> <li>• Reskilling for the energy transition</li> <li>• Strategic Thinking</li> <li>• Openness for information sharing</li> <li>• Active Listening</li> <li>• Critical thinking</li> <li>• Communication</li> <li>• Multidisciplinary Teamwork</li> <li>• Flexibility and adaptability</li> <li>• Sustainability mindset</li> <li>• Leadership for change</li> </ul> <p><i>Technical skills</i></p> |

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| <p>Designs and implements energy recovery systems (e.g., heat recovery, cogeneration) to maximize resource use.</p> <p>Ensures adherence to environmental standards (ISO 50001, EU Green Deal, etc.) and provides sustainability reports.</p> <p>Incorporates digital tools like AI-driven energy monitoring and IoT-based smart grids for optimized energy distribution.</p> | <ul style="list-style-type: none"> <li>• Ability to understand how the parts of a dynamic system interact to produce the behavior of the whole.</li> <li>• Ability to understand basic economic concepts like supply, demand, costs, benefits, economic sustainability, production, scarcity and efficiency</li> <li>• Ability to define interventions to improve circularity, energy systems and impacts.</li> <li>• Ability to optimise the use of resources in production cycles; and environmental management.</li> <li>• Ability to conduct energy assessments and identify inefficiencies in manufacturing processes and infrastructure.</li> <li>• Ability to use energy management, increasing the use of renewables and energy efficiency.</li> <li>• Ability to integrate renewable energy technologies (solar, biomass, etc.) into production systems.</li> <li>• Ability to conduct LCA to evaluate environmental impact of energy usage across product/process life cycles.</li> <li>• Ability to design, analyze, and optimize industrial energy systems, including HVAC, boilers, turbines, and process heating/cooling.</li> </ul> |
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Table B-5: Industrial Engineer Job Profile archetype

| Responsibilities   | Skills & CE skills  |
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| <p>Designs and improves manufacturing processes to reduce energy, water, and material waste.</p> <p>Implements lean manufacturing to minimize raw material consumption and maximize reuse.</p> | <p><u>Transversal skills</u></p> <ul style="list-style-type: none"> <li>• Project management</li> <li>• Adaptability and flexibility</li> <li>• Multidisciplinary team work</li> <li>• Workforce-up skilling</li> <li>• Critical thinking</li> <li>• Strategic thinking</li> <li>• Ethical judgment</li> <li>• Change Management</li> </ul> |

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| <p>Evaluates the environmental impact of production processes and recommends improvements.</p> <p>Incorporates Industry 4.0 technologies (AI, IoT, digital twins) to enhance sustainable production and predictive maintenance.</p> <p>Designs, analyzes, and improves manufacturing workflows to enhance productivity and reduce costs.</p> <p>Works with suppliers and logistics teams to optimize inventory management and resource flow.</p> <p>Uses predictive analytics and performance metrics to enhance operational efficiency.</p> | <ul style="list-style-type: none"> <li>• Communication</li> </ul> <p><u>Technical skills</u></p> <ul style="list-style-type: none"> <li>• Understand the 3 principles of the circular economy: Elimination of waste and pollution, Circulation of products and materials to their highest value, Regeneration of nature</li> <li>• Ability to understand the fundamentals of solid waste streams and their sources and focus on the 4Rs: Reject, Reduce, Reuse, Recycle</li> <li>• Ability to identify parts of a system</li> <li>• Ability to understand basic economic concepts like supply, demand, costs, benefits, economic sustainability, production, scarcity and efficiency</li> <li>• Ability to use economic research to help forecast economic activity and interest rates into the green practices.</li> <li>• Ability to design/select, implement and operate "smart" technological systems, innovative processes and flexible, reconfigurable systems for disassembly sorting and recycling (e.g. Hyper-intelligent sorting systems, Learning disassembly robots)</li> <li>• Ability to design/select, implement and operate "smart" technology systems and innovative processes for Remanufacturing</li> <li>• Ability to operate and manage services to extend product life, e.g. product upgrades, predictive maintenance and repairs</li> <li>• Ability to plan and control production in systems</li> </ul> |
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|  | <p>characterized by high complexity, uncertainty, heterogeneity in material quality and composition (reverse production planning, reverse MRP, Reprocessing Scheduling)</p> |
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Table B-6: Maintenance & repair engineer job profile archetype

| Responsibilities  | Skills & CE skills  |
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| <p>Ensures the smooth operation of machinery, equipment, and production systems by implementing preventive maintenance, diagnosing faults, and performing repairs.</p> <p>Quickly identifies, analyzes, and repairs mechanical, electrical, and automated system failures.</p> <p>Uses IoT sensors, AI-driven diagnostics, and data analytics to predict failures before they occur.</p> <p>Recommends and installs new technologies to enhance equipment efficiency and longevity.</p> <p>Ensures all maintenance activities adhere to safety regulations and environmental policies.</p> <p>Works closely with production and engineering teams to align maintenance strategies with operational goals</p> <p>Works collaboratively with operators, engineers, and management to maintain seamless operations.</p> <p>Experience with hydraulic circuits, pneumatic systems, and programmable logic controllers (PLCs).</p> | <p><u>Transversal Skills</u></p> <ul style="list-style-type: none"> <li>• Attention to detail</li> <li>• Communication</li> <li>• Critical thinking</li> <li>• Lifelong learning</li> <li>• Stress and emotion management</li> <li>• Strategic thinking</li> <li>• Openness for information sharing</li> <li>• Active listening</li> </ul> <p><u>Technical skills</u></p> <ul style="list-style-type: none"> <li>• Ability to design/select, implement and operate "smart" technological systems, innovative processes and flexible, reconfigurable systems for disassembly sorting and recycling (e.g. Hyper-intelligent sorting systems, Learning disassembly robots)</li> <li>• Ability to design/select, implement and operate "smart" technology systems and innovative processes for Remanufacturing</li> <li>• Ability to operate and manage services to extend product life, e.g. product upgrades, predictive maintenance and repairs</li> </ul> |

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|  | <ul style="list-style-type: none"> <li>• Ability to identify, prevent and correct waste and zero-defect/zero-waste manufacturing</li> <li>• Ability to operate and analyze using Computerized Maintenance Management Systems.</li> </ul> |
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Table B-7: Remanufacturing operator Job profile archetype

| Responsibilities   | Skills & CE skills   |
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| <p>Disassembling, inspecting, refurbishing, and reassembling used products or components to restore them to like-new condition.</p> <p>Carefully dismantles products and components to assess wear, damage, and potential for reuse.</p> <p>Restores components through cleaning, machining, reconditioning, and applying coatings or surface treatments.</p> <p>Ensures remanufactured parts meet original equipment manufacturer (OEM) specifications through rigorous testing.</p> <p>Identifies which parts can be reused, repaired, or recycled to minimize waste.</p> <p>Implements lean remanufacturing techniques to improve efficiency and reduce environmental impact.</p> <p>Operates CNC machines, laser scanning tools, and additive manufacturing (3D printing) to restore precision components.</p> | <p><u>Transversal skills</u></p> <ul style="list-style-type: none"> <li>• Attention to detail</li> <li>• Flexibility and adaptability</li> <li>• Communication</li> <li>• Teamwork</li> <li>• Ethical judgment</li> <li>• Active listening</li> </ul> <p><u>Technical skills</u></p> <ul style="list-style-type: none"> <li>• Basic understanding of restoring products without original documentation</li> <li>• Ability to identify, prevent and correct waste and zero-defect/zero-waste manufacturing</li> <li>• Ability to optimise the use of resources in production cycles; and environmental management.</li> <li>• Ability to implement and operate process technologies and industrial production systems in which waste or by-products become new inputs.</li> <li>• Understanding the 3 principles of the circular economy: Elimination of waste and pollution, Circulation of products and materials to their highest value, Regeneration of nature</li> </ul> |

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| <p>Records remanufacturing processes and ensures adherence to environmental and quality regulations (ISO 14001, EU Waste Framework Directive, etc.).</p> | <ul style="list-style-type: none"> <li>• Fundamentals of solid waste streams and their sources and focus on the 4Rs: Reject, Reduce, Reuse, Recycle.</li> <li>• Ability to understand the mechanical systems and components for effective disassembly and reassembly.</li> </ul> |
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Table B-8: Finance & accounting analyst job profile archetype

| Responsibilities  | Skills & CE skills  |
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| <p>Managing financial operations, cost analysis, and economic forecasting to ensure profitability and sustainability.</p> <p>Monitors production costs, raw material expenses, and operational budgets to enhance financial efficiency.</p> <p>Identifies financial risks, ensures regulatory compliance, and enforces internal financial controls.</p> <p>Aligns financial planning with environmental, social, and governance (ESG) goals, including carbon footprint accounting and green investment strategies.</p> | <p><u>Transversal Skills</u></p> <ul style="list-style-type: none"> <li>• Critical thinking</li> <li>• Communication</li> <li>• Strategic thinking</li> <li>• Ethical judgment</li> <li>• Flexibility and adaptability</li> <li>• Teamwork</li> <li>• Attention to detail</li> <li>• Project management</li> <li>• Change management</li> <li>• Embeddedness</li> <li>• Lifelong learning</li> </ul> <p><u>Technical skills</u></p> <ul style="list-style-type: none"> <li>• Ability to monitor, select and take advantage of tax incentives and access to credit, funding for R&amp;D&amp;I projects on circular economy/sustainability.</li> <li>• Knowledge of international geopolitics and understanding of implications for business</li> <li>• Ability to monitor regional, national and international policies, legislation and regulations related to the different areas of the circular economy. Understanding of the implications on business activities and ability to influence their evolution.</li> </ul> |

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|  | <ul style="list-style-type: none"> <li>• Ability to make reliable forecasts of return flows and their composition, qualitative properties etc.</li> <li>• Ability to demand Planning and Fulfilment Capability</li> <li>• Ability to assess costs and benefits and manage risks of possible investments and projects.</li> <li>• Ability to plan and implement the transition to new circular business models (cross-sectoral / servitisation-based, etc.)</li> <li>• Ability to create financial modeling for energy efficiency projects, lifecycle costing, ESG metrics.</li> <li>• Ability to keeping up to date with laws, policies, and incentives that promote greener industrial practices.</li> </ul> |
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Table B-9: IT Engineer job profiler archetype

| Responsivities   | Skills & CE skills   |
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| <p>Managing industrial IT infrastructure, supporting automation systems, and optimizing digital workflows to improve efficiency, productivity, and sustainability.</p> <p>Oversees the setup and maintenance of IT systems, networks, and cloud computing in manufacturing environments.</p> <p>Utilizes AI, machine learning, and big data tools to enhance operational efficiency and predictive maintenance.</p> <p>Supports cloud-based industrial applications and edge computing for real-time processing.</p> | <p><u>Transversal skills</u></p> <ul style="list-style-type: none"> <li>• Critical thinking</li> <li>• Communication</li> <li>• Multidisciplinary teamwork</li> <li>• Attention to detail</li> <li>• Project management</li> <li>• Lifelong learning</li> <li>• Stress and emotion management</li> <li>• openness for information sharing</li> <li>• Active listening</li> <li>• Change management</li> <li>• Knowledge management</li> </ul> <p><u>Technical skills</u></p> <ul style="list-style-type: none"> <li>• Ability to densify, priorities and exploit the opportunities offered by digital and Industry 4.0 technologies</li> </ul> |

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| <p>Implements green IT solutions, energy-efficient computing, and digital strategies to support sustainable manufacturing.</p> | <p>(e.g. additive manufacturing, collaborative robots, etc.)</p> <ul style="list-style-type: none"> <li>• Ability to select and use solutions for digitizing product information, such as digital passports, labels and watermarks for traceability and mapping of resources and hazardous substances (e.g. digital product passport)</li> <li>• Ability to select, implement and use digital platforms for data sharing and integration between multiple actors (Data Spaces)</li> <li>• Ability to select and apply solutions based on Distributed Ledger Technologies (e.g. CircularChain, Circularise)</li> <li>• Ability to apply modelling and simulation techniques (Digital Twins)</li> <li>• Data management, engineering, analysis and visualization skills</li> <li>• Ability to select, implement and use artificial intelligence-based applications to support multi-criteria decision-making processes (e.g. design choices, best solution for end-of-life product, etc.)</li> <li>• Ability to apply supporting hardware lifecycle optimization and e-waste management strategies</li> </ul> |
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Table B-10: Impact assessment consultant job profile archetype

| Responsibilities   | Skills & CE skills   |
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| <p>Leads the research and design of new products and processes, focusing on innovation, efficiency, and sustainability.</p> <p>Identifies emerging technologies and integrates them into manufacturing</p> | <p><u>Transversal skills</u></p> <ul style="list-style-type: none"> <li>• Critical thinking</li> <li>• Communication</li> <li>• Ethical judgment</li> <li>• Project management</li> <li>• Attention to detail</li> </ul> |

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| <p>operations to drive product improvement and operational excellence.</p> <p>Conducts comprehensive assessments to evaluate the environmental (e.g., carbon footprint, resource use) and social impacts (e.g., labor conditions, community effects) of manufacturing processes.</p> <p>Prepares sustainability reports that align with international standards (e.g., GRI, ISO 14001, EU Taxonomy) and regulatory requirements, ensuring full compliance.</p> <p>Analyzes the entire life cycle of products, from raw material extraction to disposal, identifying opportunities to reduce resource consumption and waste generation.</p> <p>Evaluates and recommends improvements to supply chains, focusing on sustainability criteria, ethical sourcing, and reducing environmental impact.</p> | <ul style="list-style-type: none"> <li>• Flexibility and adaptability</li> <li>• Active listening</li> <li>• Multidisciplinary teamwork</li> <li>• Strategic thinking</li> <li>• Innovation</li> <li>• Workforce-up skilling</li> <li>• Environmental storytelling</li> </ul> <p><u>Technical skills</u></p> <ul style="list-style-type: none"> <li>• Ability to monitor regional, national and international policies, legislation and regulations related to the different areas of the circular economy. Understanding of the implications on business activities and ability to influence their evolution.</li> <li>• Knowledge of Standards and Certifications and ability to apply them. Ability to contribute to their creation / evolution.</li> <li>• Knowledge of international geopolitics and understanding of implications for business</li> <li>• Ability to monitor and take advantage of tax incentives and access to credit, funding for R&amp;D&amp;I projects on circular economy/sustainability.</li> <li>• Ability to assess secondary metal market trends</li> <li>• Ability to keeping up to date with laws, policies, and incentives that promote greener industrial practices.</li> <li>• Ability to understand basic economic concepts like supply, demand, costs, benefits, economic sustainability, production, scarcity and efficiency</li> </ul> |
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Table B-11: R&amp;D/product designer job profile archetype

| Responsibilities   | Skills & CE skills  |
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| <p>Designs products with a strong emphasis on ergonomics, ensuring that they are user-friendly, safe, and effective for the target market.</p> <p>Collaborates with R&amp;D and engineering teams to create solutions that address both the functional needs and physical capabilities of users.</p> <p>Ensures that product designs and manufacturing processes align with sustainability goals, including resource efficiency, recycling, and reducing environmental impact.</p> <p>Ensures that R&amp;D efforts comply with industry standards, quality regulations, and environmental law.</p> <p>Focuses on selecting sustainable materials and manufacturing processes that align with ergonomic principles and reduce environmental impact.</p> | <p><u>Transversal skills</u></p> <ul style="list-style-type: none"> <li>• Critical thinking</li> <li>• Creative thinking</li> <li>• Attention to detail</li> <li>• Multidisciplinary teamwork</li> <li>• Flexibility and adaptability</li> <li>• Strategic thinking</li> <li>• Lifelong learning</li> <li>• Active listening</li> <li>• Ethical judgment</li> <li>• Change management</li> <li>• Project management</li> <li>• Knowledge management and coaching</li> </ul> <p><u>Technical skills</u></p> <ul style="list-style-type: none"> <li>• Ability to understand the interconnection between economy, environment and society</li> <li>• Fundamentals of solid waste streams and their sources and focus on the 4Rs: Reject, Reduce, Reuse, Recycle</li> <li>• Understanding the 3 principles of the circular economy: Elimination of waste and pollution, Circulation of products and materials to their highest value, Regeneration of nature</li> <li>• Ability to apply multiple lifecycles thinking involving modularity, durability and safety considerations, as well as maintainability, reparability, upgradeability, reusability and recyclability of products and materials.</li> <li>• Ability to understand the influence of circular product design</li> </ul> |

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|  | <p>on the success of the circular supply chain</p> <ul style="list-style-type: none"><li>• Ability to apply Design approaches that support sustainability and circular economy - such as Design for Reliability, Design for Multiple Life Cycles (Disassembly, Remanufacturing, Recycling), Design for Supply Chain, Design for Sustainability</li><li>• Ability to develop innovative solutions to increase the use of recyclable and compostable materials, to increase the use of secondary raw materials with a view to replacing virgin materials with recycled ones, production residues and by-products, and to eliminate, replace or reduce the presence of hazardous substances in products or improve their traceability in order to facilitate recycling.</li><li>• Ability to develop recyclable, compostable materials</li><li>• Ability to implement co-design practices (participatory design/collaborative design) for the circular economy, involving the main actors in the circular product value chain</li><li>• Ability to identify real consumer needs, develop information on consumer behavior towards alternative products and services to conventional ones.</li><li>• Ability to engage users in all aspects of the circular economy, e.g. by enabling them to share and care for products (shared or owned) and encouraging them to return them at the end of a cycle use</li><li>• Ability to develop easily accessible services to extend product life, e.g. product upgrades,</li></ul> |
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|  | <p>predictive maintenance and repair, scalable on attractive economic models for suppliers and consumers</p> <ul style="list-style-type: none"><li>• Ability to measure product-service circularity and assess the environmental, economic and social impact of circular design interventions</li></ul> |
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