

How can the circular economy support the advancement of the Sustainable Development Goals (SDGs)? A comprehensive analysis

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ABSTRACT

As the Circular Economy (CE) moves up in the agenda of research, policy, and businesses, understanding its impact on the Sustainable Development Goals (SDGs) becomes more important. This research analyzed the potential impact that 27 circularity strategies have on each of the 17 SDGs and their associated 169 targets. The results suggest that CE strategies can contribute to all SDGs, but most effectively to SDGs 8, 12, and 13, and least to SDGs 4, 5, 10, and 16. However, for these relationships to exist, CE strategies must follow one or more of the seven pathways that have been identified: 1) Reduced, traceable extraction; 2) Regenerative, biobased production; 3) Human inclusive industries; 4) Shareable longevity; 5) Consumers at the center, not consumerism; 6) Clean and effective end of life, and 7) Reduced and clean energy and transport. Among them, pathways 2, 4, and 6 proved to be the most influential, accounting for 66 % of the potential contributions to the SDGs. Conversely, the results of this analysis revealed that, while the CE mostly focuses on products and materials, the SDGs emphasize people and places (the environment). The results of this research, in particular the identified pathways, can help practitioners and policymakers to evaluate the contribution of current CE approaches to the SDGs, and guide them in the design of better strategies for leveraging the potential of a CE as a transition tool to advance the SDGs. Overall, this research sets the basis for a deeper understanding of the opportunities and limitations of the Circular Economy as a framework to advance the SDGs.

1. Introduction

In September 2000, the leaders of 149 countries gathered to sign a collective agreement to work toward the accomplishment of the “Millennium Development Goals (MDGs).” This historical moment was not only the largest ever-gathering of world leaders, but it proved to be a primer on what shared sustainable development could look like through the use of a common language and a monitoring mechanism (Sustainable Development Goals Fund, 2015). In 2015, these goals were widened and transformed into the Sustainable Development Goals (SDGs). Unlike the MDGs, the SDGs consider a broader set of goals across the economic, social, and environmental dimensions (de Jong and Vijge, 2021) reflected in 17 goals and 169 targets (SDG-Tracker, 2018).

The SDGs present an opportunity to “permanently transform the nature of development and make environmental and social sustainability a defining characteristic of economic activity” (Stevens and Kanie, 2016). However, researchers and private stakeholders have raised criticisms of the

insufficient mechanisms to monitor and implement the goals inside businesses and institutions (García-Sánchez et al., 2020; Moldavska and Welo, 2019; Sullivan et al., 2018). These opposing views exhibit a dichotomy: While the importance of the SDGs and their urgency is well established, the specific strategies that institutions can use to improve their performance toward these goals are less defined (Mora-Contreras et al., 2023). At the center of this dilemma, the Circular Economy (CE) has evolved as a framework to bridge the idealism of the SDGs with the practicality of business strategies (Geissdoerfer et al., 2017). The CE replaces the linear “take-make-use-lose” economic model with strategies to retain value through cascading and regenerative practices (García-Saravia Ortiz-de-Montellano and van der Meer, 2022). The goal of these practices is to slow down the consumption and production loops and promote environmental quality, economic prosperity, and social equity (Ellen MacArthur Foundation, 2013; Kirchherr et al., 2017).

The research on the relationship between the SDGs and the CE has grown significantly ever since (Merli et al., 2018). Some scholars have

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signaled that there are still gaps in understanding how the CE can promote economic growth while protecting the environment and society (Geng et al., 2012; Ghisellini et al., 2016; Pomponi and Moncaster, 2017; Schögl et al., 2020; Zhijun and Nailing, 2007). Similarly, Murray et al. (2017) have concluded that the CE does not include the social dimension, which is crucial for sustainability, and Millar et al. (2019) point out that the relationship between SDGs and CE has not yet been factually established. Dantas et al. (2021) established a relationship between the CE and Industry 4.0 to support SDGs 7, 8, 9, 11, 12, and 13, while Rodríguez-Anton et al. (2019, 2022) analyzed the SDGs and nine European CE targets and found connections to the SDGs 6, 8, 9, 11, 12, 13, 14, and 15, but neither could provide an explanation for these relationships. Following this research line, the study by Schroeder et al. (2019) established connections between CE practices and SDGs 6, 7, 8, 12, and 15 and concluded that more in-depth research is required to build on this knowledge. At the global level, The Sustainable Development Goals Report 2022 by the UN has charted the progress toward the realization of the SDGs, but so far, mention of the role of CE is present only toward goal 12 (United Nations, 2022). At the regional level, the Joint Research Center of the European Commission has developed a map to relate any European policy document to different SDGs by using text mining and natural language processing (Steve et al., 2023), both with the goal of shortening the gap between policy and practice. At the national level, entities such as the Holland Circular Hotspot (2020) have also developed a detailed guideline linking the CE with goals 2, 6, 7, 8, 12, 15, and 17. However, to our current knowledge, previous studies have not conducted a comprehensive mapping of the relationships between CE strategies and SDGs.

It is within this nascent body of literature that this research takes place and furthers the existing knowledge by systematically and in detail analyzing not only the potential connections between CE and the SDGs, but also the pathways and reasons for these relationships. Understanding the backbone of these connections is essential for developing mechanisms and strategies to ensure progress on the SDGs through the use of CE principles. This means that we must understand, not only how a particular CE strategy can be linked to the different SDGs but also under which criteria these relationships become true.

To exemplify, Sharma et al. (2021) stated that increased waste recycling rates can positively contribute to Goal 9: *Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation*. This raises two questions: how will this practice support the achievement of this goal? and: which minimum conditions need to be in place for this statement to remain true? In other words: what are the pathways by which this or any other CE strategy can support the accomplishment of each of the different SDGs? This further level of understanding moves our knowledge from a yes/no answer to a yes-if, no-unless proposition.

In this unexplored territory, our research questions emerge. The goal of this research is to discover actionable strategies and specific criteria for businesses and stakeholders to ensure that their efforts are pointing toward the accomplishment of sustainable development. In this context, this study addresses the following research questions: (RQ1) Which circularity strategies can contribute to the advancement of the seventeen different SDGs? And (RQ2) What are the mechanisms that allow these practices to have the claimed contribution to the SDGs? To answer these questions, the methodological design is presented in Section 2. Section 3.1 presents the results of RQ1, while Section 3.2 discusses the results pertaining to RQ2. Finally, Section 3.3 addresses the gaps and risks observed during the analysis. Section 4 presents conclusions and an outlook for future research.

2. Methods

To answer the two research questions, the research was conducted in two stages: argumentation and pathway formation. The argumentation process examined whether a particular circular strategy was linked to

any of the SDGs, and the pathway formation stage analyzed the mechanisms by which this connection existed. The overall aim was to identify, validate, and interpret CE strategies and their correlation to one or more of the SDG goals and targets. This approach is represented in Fig. 1, and explained below.

2.1. Argumentation

The goal of this process was to establish a comprehensive dataset of connections between individual CE strategies and the SDGs and Targets. This part consisted of three steps: Building the dataset (dataset definition), finding the connections (correlation analysis), and arguing the logic of these connections (theoretical validation).

2.1.1. Dataset definition

The SDGs, as defined by the UN, are classified into 17 different goals and 169 targets (United Nations, 2015). We considered both goals and targets, as the targets do not always represent the full complexity of a goal (Spaiser et al., 2017). For the circularity strategies, the inventory was established based on a value retention framework for circular strategies that the authors established and published before (García-Saravia Ortiz-de-Montellano and van der Meer, 2022). This framework considers seven processes by which value in a product or process on the system can be retained, named the value retention stages (VRS). Each stage has specific strategies, which are actions that can be taken to enable each VRS. The defined dataset included both value retention stages and their 27 associated strategies, as listed in Table 1. For the remainder of this article, the specific targets of the SDGs are abbreviated SDG-t, and the Circularity strategies as CE-s.

2.1.2. Correlation analysis

After the definition of the two frameworks, each CE-s was analyzed against each SDG-t to find out the correlations. This was established based on evaluating the relationship between each pair of CE-s and SDG-t, and specifically the potential influence of a particular CE-s on an SDG-t. As an example, the CE-s of Reparability and Maintenance, within the value retention stage of Use, Reuse and Resell, is considered (See Table 1). To evaluate its relationship with Goal 1 - no poverty, six questions, corresponding to the targets of this goal as well as the goal as a whole, were asked:

1. Can product reparability/maintenance aid in eradicating extreme poverty? (SDG-t 1.1)
2. Can product reparability/maintenance aid in reducing people living in poverty? (SDG-t 1.2)
3. Can product reparability/maintenance support the implementation of appropriate social protection systems, including floors, for the poor and vulnerable? (SDG-t 1.3)
4. Can product reparability/maintenance support the poor and vulnerable to have equal rights to economic resources, as well as access to basic services? (SDG-t 1.4)
5. Can product reparability/maintenance help build resilience for the poor and vulnerable to climate-related extreme events and other economic, social and environmental shocks and disasters? (SDG-t 1.5)
6. Can product reparability/maintenance contribute to the reduction of poverty in general? (SDG 1 collectively)

Answers to these questions for each pair of CE-s and SDG-t were examined by evaluating the literature. Once one or more articles indicating a relationship for each pair were found, an argument was built synthesizing the nature of this relationship in the process here called Theoretical validation.

2.1.3. Theoretical validation

Noting the presence of categorical variables on both sides of the

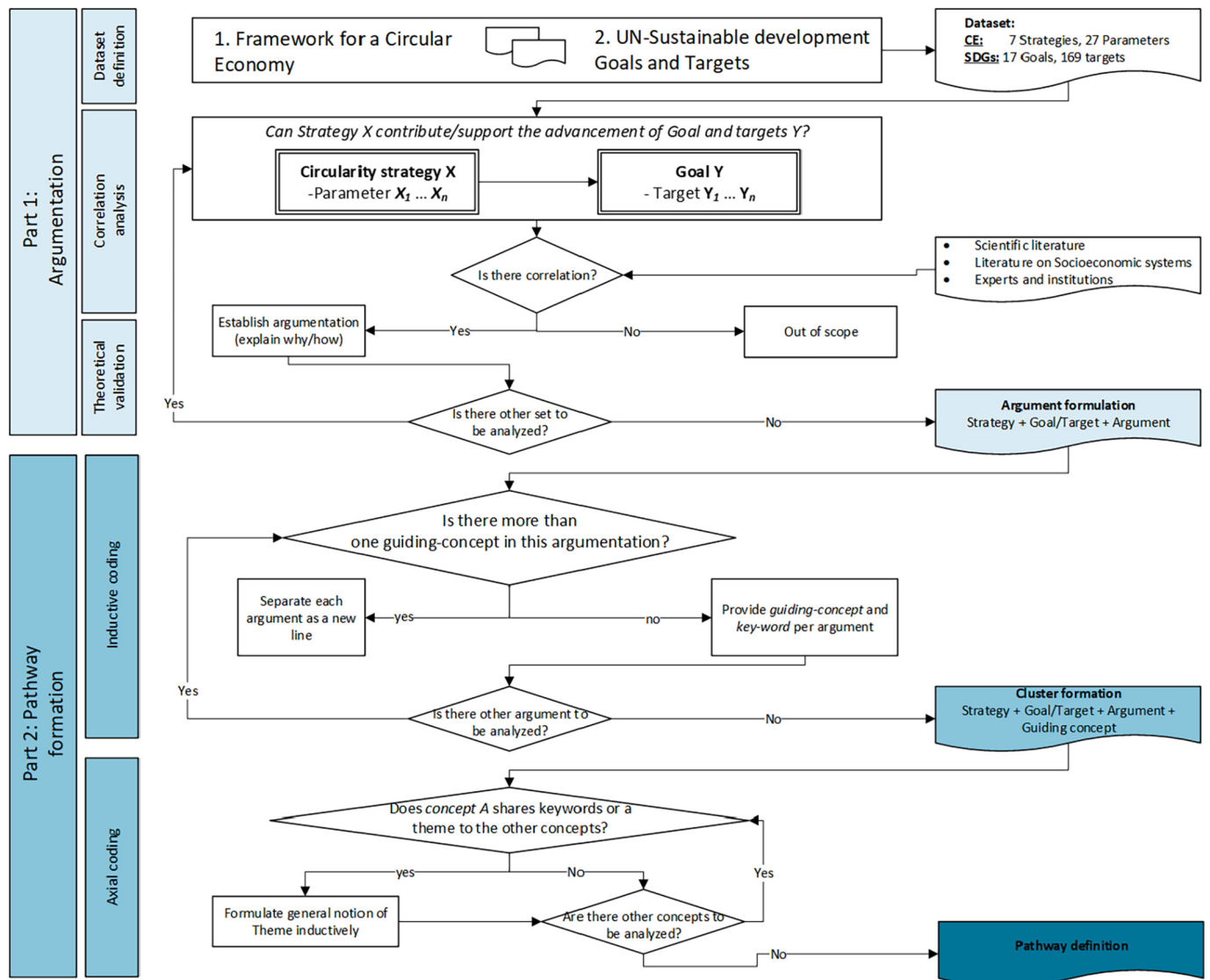


Fig. 1. Flow diagram of methodological approach.

analysis and the potential complexity of the relationship, qualitative meta-synthesis was used for theoretical validation. This analysis is recommended for synthesizing the findings of collected studies in order to develop an integrated understanding of a particular phenomenon or topic (Zimmer, 2006). It should be noted that meta-synthesis is not an exhaustive review of literature on a given topic (systematic review methods), nor is it the quantitative analysis of data from other studies (data meta-analysis). Meta-synthesis entails a comparison, translation, and analysis of findings to generate new interpretations and distilling meanings (Jensen and Allen, 1996).

Following the correlation analysis, the argument for each match between a pair of CE-s, SDG-t and supporting literature, was built by describing *why/how*, or *if/when* this connection exists. This step provided a conditional context to a particular CE-s. For example, repair activities can support Goal 2: No poverty *if* local and community-based repair activities and trade of repaired objects are in place, as was described by Schröder et al. (2019). The process of constructing an argument for each pair of CE-s and SDG-t based on the supporting literature was repeated for all pairs.

The detailed and lengthy nature of this work required streamlining the process among researchers to safeguard the validity of the results. Researcher A systematically performed the initial correlation analysis and theoretical validation, while Researcher B re-analyzed each

argument and the corresponding literature for clarity, consistency, and correct interpretation. Lastly, researcher C revised the finalized dataset. This process was iterative until all CE-s and SDG-t were evaluated, validated, and re-analyzed, and it was used for both argumentation and pathway formation steps.

2.2. Pathway formation

Out of the argumentation part of this research, a total of 142 pairs of CE-s and SDG-t were found. Due to the extensive size of this initial dataset, it was necessary to undertake additional analysis to classify the specific insights associated with each match. The objective was to identify broader patterns and clusters of arguments without imposing any preconceived concepts or keywords. This systematic procedure is referred to as pathway formation.

2.2.1. Inductive coding

The goal of this first step was to code each match to find common concepts or logic across arguments. The selected method was inductive coding to allow themes to emerge without having a previously structured set of criteria. For this, the guiding question was, “*What are the guiding concepts or keywords at the basis of this argument?*” Each argument was assigned its relevant keyword(s). No criteria were used to limit the

Table 1

Inventory of CE value retention stages and strategies. Adapted from [García-Saravia Ortiz-de-Montellano and van der Meer \(2022\)](#).

Value Retention Stages (VRS)		Strategies	
1	Reduce	1.1	Reduce primary extraction and export of raw materials
		1.2	Reduce quantity of production and consumption of goods
		1.3	Reduce dependency on scarce and non-renewable materials
		1.4	Reduce supply chain complexity
		1.5	Reduce product and material complexity and toxicity
		1.6	Enable material traceability
2	Regenerate	2.1	Prevent / reverse bioaccumulation of chemicals in the environment
		2.2	Restore ecosystems where primary materials are taken
		2.3	Use regenerative agricultural and farming practices
3	Use, Reuse and Re-sell	3.1	Flexible ownership of products
		3.2	Product longevity and reusability
		3.3	Second-hand markets and fair market values for re-selling
		3.4	Reparability and maintenance
		3.5	Product sharing capacities
		3.6	Use extension of materials from biological cycles
		3.7	Promotion of Circular behavior
4	Repair, Refurbish and Remanufacture	4.1	Business models for cascading of products
		4.2	Modularity, standardization, and accessibility of components
		4.3	Upgradability of products
5	Recycle	5.1	Increased recycling in closed and open loops
		5.2	Use of recycled material over raw materials
		5.3	Reduce quantity and impact of waste
6	Recover	6.1	Recover energy and minerals from waste
		6.2	Recover organic matter from organic waste
7	Recirculate	7.1	Shared and extended product responsibility
		7.2	Collaborative systems for recirculation
		7.3	Improved logistics and reverse logistics systems

length or scope of a keyword, therefore a keyword might be several words long. In the above-mentioned example “repair activities can support Goal 2: No poverty if local and community-based repair activities and trade of repaired objects are in place”, relevant keywords are local economy and trade, and community-based systems. As an initial step of the pathway formation, the aim was to break each argument into smaller-sized concepts that allowed further processing.

2.2.2. Axial coding

After coding the arguments into keywords, these were related together in order to reveal common areas of understanding or *pathways*. The goal was to examine the relationships among different keywords to uncover their connections, interdependencies, and dimensions, and by doing so, to develop a more comprehensive understanding of how the categories are interconnected. To achieve so, the keywords were arranged under different possible categories until the following criteria were achieved: (1) Each category (pathway) is clearly differentiated from other pathways (2) All keywords obtained from the inductive coding are included within a pathway. Once a pathway was formed and its keywords were clustered, they were renamed, if needed, for communicative clarity.

Out of the inductive and axial coding processes, twenty-five keywords were identified and clustered into seven different pathways (presented in [Table 2](#)). Therefore, each pathway contains the keywords as its core elements, while remaining connected to the initial CE-s and

Table 2

Seven pathways and their core elements.

Pathway		Core elements	
1	Reduced, traceable extraction	1.1	Reduced extraction in primary activities
		1.2	Cleaner extraction practices
		1.3	Material and product traceability
2	Regenerative, biobased production	2.1	Regenerative production of biological resources
		2.2	Diverse food production systems and supply chains
		2.3	Resource recovery
3	Human inclusive industries	3.1	Inclusivity and fair payment
		3.2	Local innovation, new business models, and entrepreneurship
		3.3	Community responsibility
		3.4	Training and education on CE
4	Shareable longevity	4.1	Designed extended use and reparability of products and components
		4.2	Businesses and policies promote product and component reuse
		4.3	Increased access to resources for minorities and vulnerable groups
5	Consumers at the center, not consumerism	5.1	Education on circularity across the value chain
		5.2	Consumer empowerment
		5.3	Business models and product design favor consumer well-being
		5.4	Communication strategies promote responsible consumption, longer use, and cascading
6	Clean, effective End of Life	6.1	Design out toxicity and un-recoverable materials
		6.2	Separate waste into mono-material streams
		6.3	Develop infrastructure to recover value from biological waste
		6.4	Develop infrastructure to recover value from technical waste
7	Reduced and clean energy and transport	7.1	Aim at local, low, and clean energy transport systems
		7.2	Develop circular urban mobility and transport
		7.3	Cascading industries use low and clean energy
		7.4	Integrated communication and logistics systems across the value chain

SDG-t matches. The argumentation and pathway formation steps allowed for a dataset that provides insight at different levels of detail: At CE-s to SDG-t level; at VRS to SDG; and at a higher level, where the connections between different CE-s reveal the pathways by which several SDGs might be furthered. These findings are discussed in the results section.

3. Results and Discussion

This research determined the relationship between specific CE strategies and the SDGs by analyzing their interconnections (RQ1 – [Section 3.1](#)) and potential pathways of delivery (RQ2 – [Section 3.2](#)) while paying attention to risks, shortcomings, and areas where CE and the SDGs are misaligned ([Section 3.3](#)).

3.1. The Interconnections between the CE strategies and SDGs

In the argumentation step, 142 matches were found. Each of them consisted of one CE-s, one SDG-t, and one referenced argument. Each CE-s was then aggregated into its respective VRS, and each SDG-t was also aggregated to its respective SDG. [Fig. 2](#) illustrates a matrix plot of the relationship between CE stages and SDGs. The magnitude of each circle represents the aggregated number of matches between a CE-s and SDG-t from a given VRS that contributes to a specific SDG. In this sense, a larger size describes a VRS with more CE-s influencing a specific SDG, but should not be interpreted as an absolute measure of the impact that

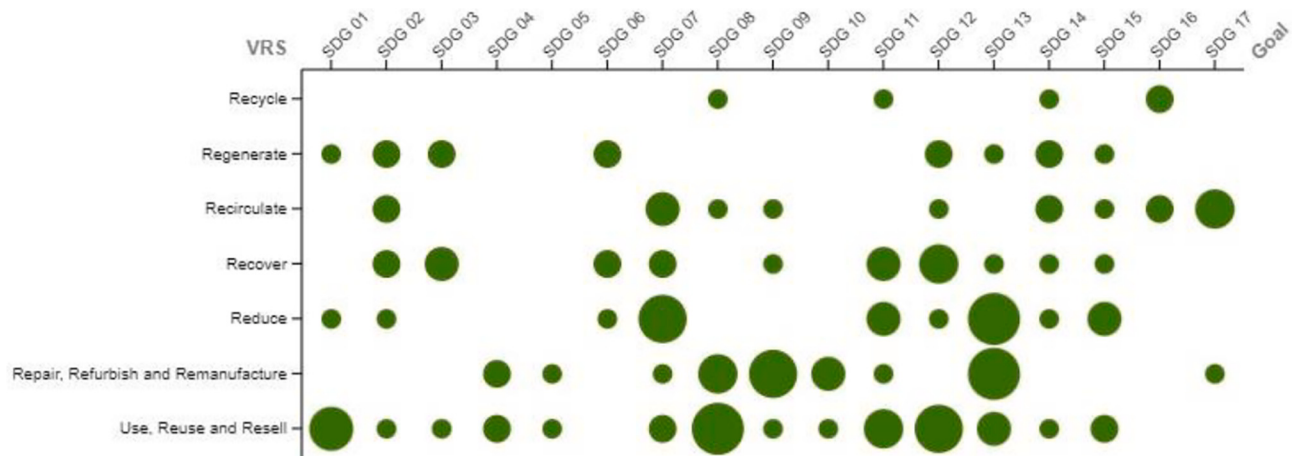


Fig. 2. The interconnections between the CE strategies (VRS) and SDGs (CE-s sorted from least to most overall impact to the SDGs).

any given VRS can have on an SDG. The results suggest that the most frequently addressed SDG by CE-s is climate action (Goal 13). This can be a result of the current emphasis in research and policy on the environmental dimension of sustainability, including CE, and is in line with the recent research identifying climate action as the most urgent SDG by experts and sustainability professionals (GlobeScan, 2021).

The results of this study identified the goals of responsible consumption and production (Goal 12), affordable and clean energy (Goal 7), and decent work and economic growth (Goal 8) as the next most frequently addressed SDGs by the CE strategies, respectively. The presence of SDGs 7, 8 and 12 as prominent beneficiaries of the CE is also reflected in the work of Dantas et al. (2021), and Schroeder et al. (2019). However, Rodriguez-Anton et al. (2019, 2022) did not find any connection between the nine European CE strategies and SDG 7. The resulting linkage between the CE strategies and the SDGs 7 and 12 argues in favor of the role that CE-s can play in the transition from the current consumptive and fossil-based linear economy to a circular one, including renewable energy (Olabi, 2019). Nonetheless, the possibility of overconsumption in a CE due to the rebound effect needs to be noted when linking the CE strategies with this SDG (Castro et al., 2022). The presence of SDG 8 as one of the most frequently addressed SDGs reflects the importance of cascading strategies across sectors, geographies, and scales as a source of productive activities, employment, and business-community engagement, which is aligned with the findings of Chaturvedi et al. (2019) on the role of CE-s in the global south.

On the other hand, gender equality (Goal 5) was the least addressed by CE-s, followed by quality education (Goal 4), reduced inequalities (Goal 10), and peace, justice, and strong institutions (Goal 16). Similarly, none of the previous research covered in the literature review found a connection to SDGs 4, 5, 10 or 16 (Dantas et al., 2021; Holland Circular Hotspot, 2020; Rodriguez-Anton et al., 2019; Rodriguez-Anton et al., 2022; Schroeder et al., 2019). This gap between CE-s and Goals 4, 5, 10, and 16 has also been found by Corvellec et al. (2022) and Murray et al. (2017) and points to important social issues that are still missing in the circularity frameworks. A relevant observation of the results of this study is that all of the less addressed SDGs are directly associated with people.

The results of this study regarding the most and least affected SDGs by CE-s are mostly aligned with previous studies. However, partnerships for the goals (Goal 17) - identified as the most important SDG by the UN (United Nations, 2019) - and zero hunger (Goal 2) - identified as the most important SDG by Globescan (2021) - are not among the most impacted SDGs by CE-s. This points toward a gap between the goals of world leaders and decision-makers on ending poverty and hunger and enhancing the health and well-being of people (Broom, 2019) and the impacts that CE-s might have if implemented. The results suggest the

need to consider not only the technical and biological cycles of the CE but to pay more attention to its actors.

Looking at the different CE-s, it can be seen that the “use, reuse, and re-sell” strategy is the most effective strategy toward the general achievement of the SDGs, affecting 14 out of 17 and with significant magnitudes for decent work and economic growth (Goal 8), responsible consumption and production (Goal 12), and no poverty (Goal 1). This can be explained by the fact that this strategy targets a reduction in the consumption and production of primary materials and favors product use through flexible ownership, sharing, repair, and re-selling. Such strategies increase the lifetime of products and shift the economic effort from primary production and manufacturing, typically capital-intensive, to maintenance and repair, typically labor-intensive (Stahel and Clift, 2016). This linkage is crucial for the CE, as nearly no other strategy has an impact on SDG 1 - no poverty.

The “reduce” and “repair, refurbish and remanufacture” strategies also have a notable potential impact on the SDGs. Both strategies proved to be promising in advancing climate action (Goal 13). Furthermore, the “reduce” strategy presented a considerable impact on affordable and clean energy (Goal 7), which can be explained by reducing the overall required energy and resources, including non-renewables. Furthermore, decreasing the complexity of a product’s design and providing cascading opportunities, especially in infrastructure, can also support the achievement of industry, innovation, and infrastructure (Goal 9).

Our results demonstrate that the most promising strategies for the advancement of SDGs through CE-s are the ones related to product value retention, keeping products in use for longer. Comparatively, “recycling” ranked as the least effective strategy in achieving the SDGs. This is especially notable as recycling and circularity are commonly and wrongly used interchangeably (Fellner and Lederer, 2020; Lim et al., 2020). Our findings are in line with the work of Knäble et al. (2022), who conclude that recycling has low to no impact on sustainable development, when compared against other strategies.

3.2. The Pathways from CE-s to SDGs

The following section describes the results obtained from the inductive and axial coding of the results from Section 3.1. After establishing the interconnections between the CE-s and SDGs, the analysis revealed that seven main pathways had been identified connecting CE-s to one or more SDGs. The seven pathways identified are: (1) Reduced, traceable extraction; (2) Regenerative, biobased production; (3) Human inclusive industries; (4) Shareable longevity; (5) Consumers at the center, not consumerism; (6) Clean and effective end of life and (7) Reduced and clean energy and transport. These seven identified pathways allow for a systems perspective on the various CE-s and life cycle

stages. This establishes a basis for more fully integrating social, environmental, and economic considerations into CE-s by creating a link between specific strategies and particular SDGs. Furthermore, these pathways serve as a primer for the future development of indicators to evaluate businesses' contribution to the advancement of the SDGs.

Fig. 3 shows the link between the CE-s, pathways, and SDGs. As with Fig. 2, the thickness of the line represents the aggregated number of arguments matching any given pathway and goal. In this sense, a thicker line represents a higher number of CE-s within a VRS linked to a specific pathway. Similarly, a thicker line in the pathways, represents a higher number of CE-s associated to a specific SDG-t that are connected through the pathway. Details on each pathway are summarized in Table 2: Seven pathways and their core elements. This analysis shows that each of the CE-s (left column) touches upon at least three different pathways. The results suggest that even though CE-s can support the SDGs, as discussed in Section 3.1, several mechanisms (pathways) should be in place for this relationship to exist. The results of earlier studies, such as Rodríguez-Anton et al. (2019), have already indicated the existence of a relationship between CE-s and SDGs. However, this analysis reveals that the connection between a given CE strategy and an SDG is not straightforward but nuanced and complex, pointing to the importance of including social, geographical, environmental, behavioral, and economic indicators, and not just material and energetic considerations. Furthermore, there is a wide spread between the Pathways (center column of Fig. 3) and the SDGs (right column), which suggests that there are several mechanisms to support the SDGs, and efforts in one pathway can have an effect on several goals at the time.

Of the seven identified pathways, the one that shows the most impact on the SDGs is *Shareable longevity* (23 % of connections), which clusters mechanisms to extend a product's use and reuse with an emphasis on providing vulnerable groups access to products and services. Toward the CE-s (left column of Fig. 3), *Shareable longevity* is connected to reduced extraction of raw materials through extended use, reuse and re-sell of

products, and cascading strategies. The results demonstrate that the most strongly influenced goals are: reduction in poverty (Goal 1), affordable and clean energy (Goal 7), decent work and economic growth (Goal 8), industry innovation (Goal 9), responsible consumption and production (Goal 12), and climate action (Goal 13). This is in line with the urgency established by (Stahel, 2016) on making reusable products the norm to achieve sustainable development and complements the findings from Schröder et al., who conclude that sharing, reusing, and upcycling activities have supported developing economies for decades in their quest to fight poverty and achieve economic growth (2019).

The second pathway with the highest impact is *clean, effective end-of-life* (EoL) (18 % of connections). This pathway includes phasing out toxic and unrecoverable materials and the development of cascading industries for biological and technical cycles, including the separation of waste into clean material streams. This pathway can support the goals of climate action (Goal 13), good health and well-being (Goal 3), sustainable cities (Goal 11), affordable and clean energy (Goal 7), and water quality and health (Goals 6 and 14). The importance of phasing out toxic, un-separable and un-recoverable materials has been previously highlighted by Leslie et al. (2016) for the plastics industry, and the importance of cascading biological materials is in line with the results of the study on cascading strategies for wood by Mair and Stern (2017). The widespread impact that cascading industries –and the right material and waste management design– could have in the advancement of the SDGs is notable. However, this also highlights the urgency to 'foster the dialogue between product designers and EoL managers' (Bezama, 2016) to develop and integrate these industries as a circular manufacturing ecosystem. An important finding of this pathway is the emphasis on *local* cascading systems at the EoL point as a means to promote local development and prevent waste losses and leaching into the environment. This finding is in line with the results of the study by Joshi et al. (2019) and supports the notion that waste and waste management are key elements not only in environmental protection but also in social inclusion

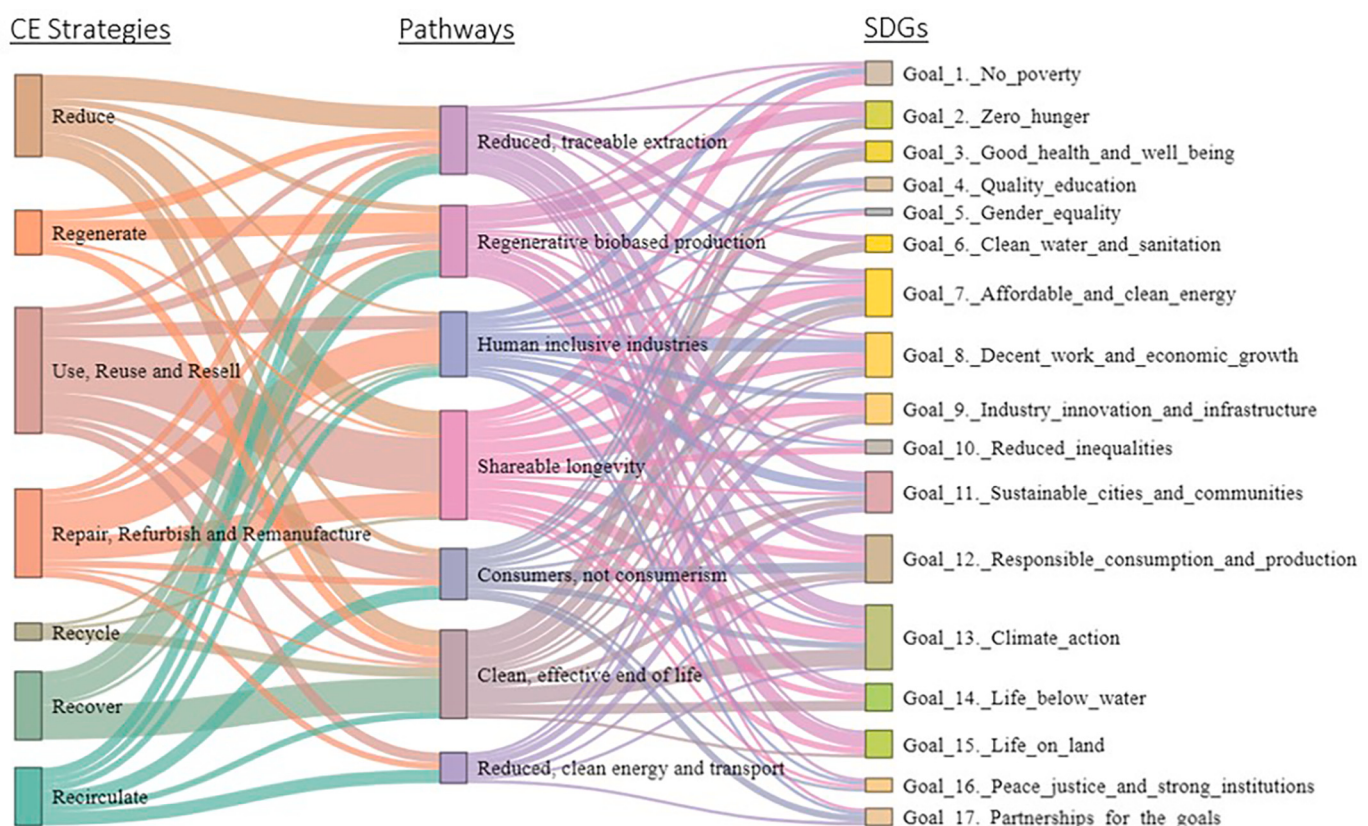


Fig. 3. Contribution of CE Practices to the SDGs through seven specific pathways. Left: CE-s, Center: Pathways, Right: SDGs.

and economic development (Noble, 2019).

The *Regenerative and biobased production* pathway (15 %) emphasizes the importance of regenerative biobased production systems and crop diversification for social and climatic resilience. This pathway influences mostly the goals of zero hunger (Goal 1), good health and well-being (Goal 3), climate action (Goal 13), and life on land and under-water (Goals 14 and 15). The results support the research by Rhodes et al. and Howard et al. on the importance of regenerative agriculture for systems' resilience (Howard et al., 2018; Rhodes, 2017).

The *Reduced and traceable extraction* (14 %) emphasizes the importance of reducing the total requirement of raw, non-renewable materials, substantially increasing the sustainability of unavoidable raw extraction, and supporting the traceability of resources for their recovery at the EoL. This will mostly impact ensuring clean water (Goal 6), affordable and clean energy (Goal 7), sustainable cities (Goal 11), responsible consumption and production (Goal 12), and climate action (Goal 13).

The *Human inclusive industries* (13 %) pathway emphasizes that any industry or CE-s must be inclusive, fair, and community responsive as well as promote local innovation, training, and education for the CE. Through this, CE has the potential to support the goals of no poverty (Goal 1), quality education (Goal 4), gender equality (Goal 5), decent work and economic growth (Goal 8), industry innovation (Goal 9), sustainable cities and communities (Goal 11), peace, justice, and strong institutions (Goal 16) and reduced inequalities (Goal 10). The importance of considering social aspects in CE has been highlighted by Walker et al. (2021) and the impact of social inclusivity in long-term sustainable development has also been discussed by Babu (2020) whose research concluded that social inclusivity in business has an essential role in job creation, poverty reduction, maintenance of culture, environmental protection, and community building.

The pathway *Consumers at the center, not consumerism* (11 %), addresses the relationship of businesses with consumers, consumer awareness, empowerment, and education, and the role that companies have in promoting consumers' well-being, mental health, responsible consumption, and circular behaviors. Supporting consumers and strategizing against consumerism can have an influence on primarily advancing the goals of responsible consumption and production (Goal 12), climate action (Goal 13), affordable and clean energy (Goal 7), and partnerships for the goals (Goal 17). We found only one connection between this pathway and Goal 3: Good health and well-being, which signals an existing gap in the understanding of 'well-being' in SDGs and the lack of CE-s that specifically target users and their relationship with products and services (Camacho-Otero et al., 2018).

Lastly, the pathway *Reduced and clean energy and transport* (6 % of all matches) addresses the impact that mobility, logistics, transport, and energy use can have on the SDGs. The main impact of this pathway is on sustainable cities and communities (Goal 11), industry innovation and infrastructure (Goal 9), climate action (Goal 13), affordable and clean energy (goal 7), decent work and economic growth (Goal 8), and partnerships for the goals (Goal 17). These results show that clean energy and transport have a lower impact on the SDGs in comparison with other pathways. However, it is noteworthy to consider its essential role in enabling most of the CE-s, making it a point of concern for the CE, as clean transport and energy are crucial to ensure a sustainable transition (Korhonen et al., 2018; Li et al., 2010).

3.3. Missing the mark: gaps between CE-s and the SDGs

This section discusses the main gaps of the CE as a framework for the advancement of the SDGs and the limitations found in the SDGs that – according to the authors and the academic literature – might require redefinition and actualization. The identification of these gaps provides boundaries to the extent by which the CE can be promoted as a framework for sustainable development and the areas in which is still necessary to create effective strategies that are socially equitable,

environmentally sustainable, and economically viable. Furthermore, the limitations in both the CE and SDGs are a reminder of the dynamic and complex nature of sustainable development and emphasize the importance of continuous feedback and actualization of frameworks and policies.

3.3.1. Risks of using current CE-s for the advancement of the SDGs

This sub-section presents the areas in which gaps between CE-s and SDG were found. These gaps reflect current CE definitions and research. Limitations on the SDGs are addressed in Section 3.3.2. The identified gaps are not absolute to the CE as a whole but rather point toward areas where more research, better policy, and clearer strategies are needed.

3.3.1.1. Counterproductive social and environmental effects of export of used materials and products. Unmanaged and unregulated export of large volumes of technological waste, textiles, used plastics, and waste might increase poverty, reduce a country's productivity, and create health problems and environmental pollution (Baden and Barber, 2005) (Risk to Goals 1 and 3). This is also the case with the production and export of circular products to countries with no circularity infrastructure, particularly collection, sorting, and recycling systems, clean energy, and waste-water treatment plants (Preston et al., 2019) (Goals 3, 6, and 7). Research on international trade agreements and mechanisms specific for repaired, reused, and cascaded products are still needed, especially for products that are produced, used, repaired, and re-sold across different regions and countries (Barrie and Schröder, 2022) (Goals 9 and 17).

3.3.1.2. Misrepresentation of the importance of the full spectrum of biological cycles. Even though there is a wide overlap between circularity and sustainability in academic and public literature, the role of CE in safeguarding ecosystems is not clear (Morseletto, 2020), and largely sees the environment as a source of capital, not as a system to be restored and protected. As a consequence, CE literature underrepresents the importance of ecosystem resilience, diversity, preservation, diversification, and restoration (Kennedy and Linnenluecke, 2022), or ways to integrate the value created by these ecosystems to the notion of 'value retention' that is core to CE (Goals 13, 14 and 15). The cascading of biological cycles as represented by CE literature (Ellen MacArthur Foundation, 2019), does not consider the role of infrastructure for food loss and waste across economically diverse global supply chains (Magalhães et al., 2021), crop diversity and animal rearing (and its by-products) in achieving food and ecosystem resilience, climate change, reduction in fertilizer and pesticide use and ecosystem regeneration, and neither the challenge that crop diversity can present on the development of single-stream waste management practices, and the safe return of chemically treated biological waste to the biosphere (Karuppiyah et al., 2021). (Goals 2, 11, 14, and 15).

3.3.1.3. Certain industries have little academic foundation for implementing CE. There is little academic coverage on strategies, impacts, metrics, and priorities for CE in the healthcare sector (Goal 3); housing, including its social impacts (Goal 11); aquaculture, fisheries, and the regenerative management of water bodies (Goal 14), and the development and forecasting of infrastructure and technology for high-volume cascading, and the consequences this can have on the environment and society (Goal 9).

3.3.1.4. Education in CE is limited to awareness. CE is growing in the education sector through courses, online communication, and the development of new methodologies. However, there is no coverage of education to increase technical and transferrable skills essential to circular systems such as design, repair, refurbishment, and remanufacture (Burger et al., 2019) (Goals 4, 8, and 9).

3.3.1.5. Risk of overshoot and focus on economic growth. Through

cascading and industrial development at EoL, CE presents a risk in terms of water use and management and its competition against the availability of drinking water. As with any industry, EoL industries might increase the risk of further ecosystem pollution unless accounted for and treated appropriately (Sauvé et al., 2021) (Goal 6). Similarly, increased energy use for value retention industries and overemphasis on the use of renewable energies instead of a reduction in overall energy consumption (Ruzzenenti et al., 2019) might impact Goal 7 (Goal 7). Finally, CE, as represented by large bodies of academic literature and public coverage, still follows the ‘economic growth’ framework and aims at increasing economic growth instead of preserving value and reducing consumption (Bauwens, 2021; Busu, 2019; George et al., 2015) (Goal 8).

3.3.1.6. Limited understanding of the social role of the CE. There is little academic and public coverage on the ways in which circular business models can foster inclusion and empowerment and the role of women as enablers of CE and of CE as an enabler of gender equality (Bebasari, 2019; Pla-Julián and Guevara, 2019) (Goals 5 and 10). Generally, academic literature on CE does not address social issues and the role of circular innovation in preventing violence, injustice, slavery, and abuse across value chains (McLaren et al., 2020; Pitkänen et al., 2020) (Goal 16).

3.3.2. Limitations on current SDGs from a CE perspective

This sub-section describes the areas in which -according to the authors and scientific literature- the SDGs lack important goals and targets that represent an updated vision of current challenges and social and environmental priorities from the perspective of CE.

3.3.2.1. Scarce coverage of urban societies. Urban and sub-urban poverty, health and well-being, and associated non-communicable illnesses, such as obesity, depression, and other mental health conditions, are not represented in the SDGs (Agvei-Mensah et al., 2015; Lund et al., 2018) (Goal 1,3). Sustainable urbanization and urban planning are essential to the accomplishment of multiple SDGs and climate-mitigation goals (Cohen et al., 2021) however, their broad definitions do not include EoL targets and make it difficult to evaluate the specific contribution of CE-s in the urban environment (Goal 11).

3.3.2.2. Economic and financial focus overpower social and environmental focus. Traditional economic growth is still used as a key target and ambition for sustainable development (Goal 8); poverty and the role of institutions and partnerships are measured mostly from financial indicators at country levels and do not address the role of communities, businesses, universities, and other institutions in enabling the SDGs and promoting peace and justice, as has been repeatedly addressed by other researchers and policymakers (Goals 1, 16 and 17) (Bauwens, 2021; Belmonte-Ureña et al., 2021; Raworth, 2017). There is a strong push for industrial development but no mention of second-life and cascading industries (Goal 9). Goal 17 aims at significantly increasing the exports of developing countries, with no consideration of the risks this might pose to sustainability and sustainable development (Goal 17).

3.3.2.3. No distinction between natural and anthropogenic climatic events. Resilience to climatic events doesn't consider the difference between natural ‘climatic disasters’ (e.g., hurricanes, earthquakes, cyclic flooding) and anthropogenic climatic events (e.g., air pollution, deforestation, soil erosion). Because of this, there are no indicators of the reduction or prevention of anthropogenic contributors to climate change (Goals 1, 13, 14, and 15).

3.3.2.4. Narrow definitions on broad fields such as agriculture, education, and gender. Agricultural indicators do not consider the role that crops other than food (such as crops for energy, fibers, and materials) and food and agricultural waste play in food security, and sustainable

development (Goals 2, 7, 9 and 12). Moreover, the goals and targets in education do not include access to continuous, informal, applied, or digital education (Goal 4). Similarly, the definitions of gender do not include the rising population with different gender identities (Goal 5).

3.3.2.5. No indicators to prevent overconsumption. Goals and targets do not address reducing overconsumption of water (Goal 6), reduction in total energy use (Goal 7) and favor economic growth and GDP as indicators of sustainable development instead of preservation of existing infrastructure, and social and natural capitals (Goals 8, 9 and 12). This emphasis might contradict the goal of achieving societal and environmental resilience (Goals 1, 2, and 13). Furthermore, the current targets and indicators measure the production and consumption of resources and not their use. The concept of *resource use* favors recirculation and regeneration, whereas production and consumption establish a binary, unidirectional flow. There are no targets linking products, consumers, and businesses and their role in reducing overconsumption and promoting sustainable development (Goals 9, 11, and 12).

The overall results of this analysis strengthen the importance of the CE as a tool to achieve the SDGs in line with what Dantas et al. (2021), Rodriguez-Anton et al. (2019, 2022) and the Holland Circular Hotspot (2020) have previously established. However, the authors of this paper also acknowledge that the results outlined in this paper are associated with limitations. The first and most important one is the use of the number of strategies as an indicator of the size of impact between a VRS and an SDG. Further research should develop methods to reliably quantify such impact. A second limitation considers the Interconnectedness among pathways. The line that separates each of the seven identified pathways cannot be sharply differentiated, and, as with any complex system, there are multiple codependences and relationships among pathways. The effects of these relationships as enablers or inhibitors of change remain unexplored. Finally, the third limitation refers to the timeline of impact. The effects that circular strategies might have in terms of resource availability and environmental impact will be more visible at longer timelines (e.g., 20, 50, 100 years), while the goals and targets of the SDGs have a shorter timeline (<10 years). The effects of this mismatch have not been explored. Despite these limitations, the findings presented here provide a reliable primer for the future development of the CE as a framework that allows businesses to contribute to the SDGs.

4. Conclusions

The results of this research show that using the Circular Economy as a framework to advance the SDGs is possible and desirable. Particularly, CE can effectively support SDGs 8 – decent work and economic growth, 12 – responsible consumption and production, and 13 – climate action. On the other hand, with the current strategies, CE has the least impact on goals 4- quality education, 5 – gender equality, 10 – reduced inequalities, and 16 – peace, justice, and strong institutions.

This study identified distinct pathways by clustering the interconnections between CEs and SDGs. These pathways, consisting of 7 clusters and 25 core elements, provide a systemic perspective for understanding the role of CE strategies as enablers of the SDGs. The seven pathways are 1) Reduced, traceable extraction; 2) Regenerative, bio-based production; 3) Human inclusive industries; 4) Shareable longevity; 5) Consumers at the center, not consumerism; 6) Clean and effective end of life and 7) Reduced and clean energy and transport. Pathways 4, 6, and 2 are the most influential, accounting for 66 % of the total matches between CE-s and SDG-t.

On the other hand, CE can be a risk for the SDGs, especially if the export of waste and used products to developing economies remains unmanaged and unregulated. Moreover, efforts toward sustainability emphasize economic growth and do not include safeguarding ecosystems’ resilience and diversity; education is limited to awareness and not

the acquisition of technical EoL skills; and strategies do not consider the social role that CE has in fostering empowerment and community engagement. Furthermore, considering the importance of the CE as an enabler of the SDGs, we argue that goals and indicators should be included in the SDGs to measure material retention through cascading and end-of-life industries, prevention of overconsumption, total energy reduction, and different forms of national well-being beyond economic measures.

One of the key differences that emerged from this analysis is the strong emphasis of CE on products and materials, which contrasts with the emphasis of the SDGs on people and places (the environment), leaving a gap between products, the socioeconomic circumstances of the people that produce and use them, and the environment from which, and to where such products are extracted and disposed of. This is a lesson to learn from both sides and establishes two important gaps. The SDGs must consider the social, economic, and environmental roles that products and materials have in society, and the CE must deepen its understanding of the *actors of the circular economy* and their socioeconomic and demographic circumstances.

The results of this research serve as guiding principles to evaluate the relevance of new CE strategies for the advancement of the SDGs and provide a reliable bridge between CE practice and policy. Following the example shown in the introduction, through this analysis, we can conclude that the increase in waste recycling will *not* substantially contribute to SDG 9 - Inclusive and Sustainable industrialization *unless* waste management industries are: 1) located at the point of product use, including developing countries, 2) Human inclusive to both, their employees and their communities, and 3) designed for low energy transport and operation. Furthermore, we can also conclude that a better way to support Goal 9 is through the development of repair, refurbishment, and remanufacturing industries that promote longer use of products, support community building, and are low in energy and high in job creation. As with this example, the impact of any circularity strategy can be effectively linked to the different SDGs it impacts, providing a deeper, more insightful entry point for analysis.

We contend that the seven pathways linking specific CE strategies and the SDGs serve as a foundation for evaluating action plans to ensure they possess the essential elements for contributing to the SDGs. Moreover, practitioners, academics, business managers, policymakers, and decision-makers can leverage these pathways to design new strategies that align with the CE principles and contribute to the SDGs. Specifically, stakeholders can assess the contributions of existing or new CE strategies to the SDGs by analyzing the correspondence of their strategy against the 25 core elements of the pathways. In this sense, local and regional policymakers can evaluate the presence of these 25 core elements when setting new policies to assess or enhance their contributions to the SDGs. Likewise, companies can examine, for example, how the core elements of “Human inclusive industries” can guide them toward advancing the SDGs, and therefore leveraging their road to achieving the SDGs.

The use and application of these results at different system levels and by different stakeholders hold particular importance for the advancement of the SDGs, given the notable data gaps existing in terms of geographic representation, timeliness, and the level of disaggregation, as outlined in the latest gap report by the UN (United Nations, 2022). The analysis of the synergies between various stakeholders (individuals, companies, organizations, policymakers), strategies (CE), and goals (SDGs) in different geographical locations can be intricate and require handling big data, and state-of-the-art technologies like digital transformation and Industry 4.0, which are relevant research gaps emerging from this field. Overall, we argue that the results of this work serve as a primer for the future development of indicators to evaluate the contribution of businesses, value chains, and regions to the advancement of the SDGs and set the basis for a deeper understanding of the opportunities – and limitations – of the CE as suitable a framework for sustainable development.

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