DEA Insights into Circular Economy Implementation: Literature Review and Guidelines for supporting H4C development

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Circular economy (CE) principles advocate for the reduction of waste and the continual use of resources, creating a closed-loop system that minimises the environmental impact while promoting economic growth and sustainability. Small and Medium Enterprises (SMEs) play a crucial role in this system due to their agility, innovation capabilities, and significant contribution to employment and economic development. This research explores the role of SMEs in increasing the effective development of Hubs for Circularity (H4C) using a non-parametric approach, Data Envelopment Analysis (DEA). This approach offers a robust framework by enabling the evaluation of multiple inputs (e.g., resource consumption, investment in technology) and outputs (e.g., waste reduction, economic output) to identify efficient and inefficient practices in organisations and regions. The use of this analysis allows for identifying not only the efficient practices of SMEs but also areas where regions can improve their circular practices. The insights gained from DEA analysis aim to guide SMEs in adopting and refining circular practices that enhance the development of H4C and maintain an entrepreneurship focus. The outcomes of this research are expected to provide guidelines on indicators, regional development, and policymaking, designed to help SMEs and their stakeholders improve circularity and support the development of H4C through their application.

Additional Key Words and Phrases: Circular economy (CE), Sustainability, Small medium enterprises (SME), Hubs for circularity (H4C), Data Envelopment Analysis (DEA), Eco Industrial parks (EIP), Industrial Symbiosis (IS)

1 INTRODUCTION

Circular economy is a critical topic of the 21st century and it can be described as the transition from a linear economy, which follows a „take-make-dispose" model [21] to a circular model, which would preserve the utility properties as well as the value of the resources [2]. A linear economy accelerates the consumption of the resources and their end-of-life cycle of the resources, whereas a CE would replace the main vulnerability of the linear cycle, the resource scarcity [2, 19], by implementing a closed-loop model, which promotes the use of the input resources and materials for multiple phases. This does not only reduce the waste of the planet, but it also provides various economic and social benefits such as: new opportunities of inclusive growth and employment, well-being of the stakeholders involved as well as economic and social stability [2, 19, 21]. Sustainability can be seen as the main driver of CE adoption and there is a strong confluence between them. When companies want to evaluate their CE performance level, they need to analyse in depth their sustainable practices as well as their business models [30]. An accurate evaluation of the circularity performance needs to take into account the three dimensions of sustainability: environmental, economic and social [30] as well as the circular business models of the mentioned company. One particular system approach that has gained a lot of attention in the past years in the industrial sector is the Industrial Symbiosis (IS) approach. This strategy follows the core principles of circularity and it can be described as a process which takes the surplus resources from one industrial process and transfers it into another industrial process under the form of the new input [10, 16], which makes both industries benefit from one another. This kind of circular model can be well incorporated across various companies located in geographic proximity, which strive for adopting CE implementation [16, 20]. This leads us to the concept of Hubs for Circularity (H4C), an initiative promoted by the European Commission, which stands for bringing all the enterprises and the involved stakeholders together to implement IS practices which result in waste minimization, overcoming social barriers through better information sharing and spreading awareness [15, 24].

Small Medium Enterprises (SME) play a vital role in the sustainable development of a region and they have at least equal impact as big enterprises in achieving the sustainable performance through sustainable practices and the implementation of IS models [27]. Even with the large number of SMEs around the globe, there is currently not much data available about how SMEs adopted sustainable practices [32]. Additionally, SMEs have no clear path in how they should forward in the development of H4C. A potential solution to this lack of information would be to use DEA to analyse the impact of SMEs in H4C. DEA is a non-parametric approach, which measures the efficiency of Decision Making Units (DMU) of business, organisations or regions and it can take multiple inputs and outputs [7]. In this case, it can constitute a robust framework which can assess the role of SMEs in the development of an efficient H4C.

The main research question can be formulated as:
What role do SMEs play in the development of effective H4C and how can DEA contribute to exploring this role?

This research question can be divided into two sub-questions:
1. What kind of indicators should be used in DEA to capture a multi-dimensional view of the SMEs contributions to H4C, including economic, environmental and social perspectives?
2. How can DEA insights from efficient regions guide SMEs and inform policies to improve circular practices and performance in inefficient regions, enhancing H4C implementation?

2 METHODS OF RESEARCH

The primary method for conducting this research involves performing a literature review, which explores the two sub-research questions previously mentioned to answer the main research question. Search engines such as Google Scholar and ScienceDirect are used to find relevant papers.

For RQ1, the literature identifies key CE indicators to enhance the DEA technique's quality and accuracy. The focus is on multi-dimensional indicators to increase the analysis's value. For RQ2, the literature explores how DEA insights can inspire SMEs across regions, highlighting efficient practices from high-performing areas as models to achieve balanced CE implementation. The review also examines policymaking using DEA insights and the ongoing H4C development and recommended strategies for Europe.

The main output of this research is a set of guidelines for indicators aimed at helping SMEs and stakeholders increase circularity and develop H4C. In developing the guidelines, insights from the literature review are used to answer the research questions. Thus, the analysis of these papers identifies recurring themes on the impact of CE in SMEs at both micro and meso levels. Most literature involves a DEA approach in the CE sector, enhancing the quality of the guidelines.

The guidelines are divided into three areas: indicators, regional development, and policymaking. The intersection of these areas enhances SMEs circularity and impacts the development of H4C. These guidelines serve as a starting point for further analysis of the CE impact on SMEs and the optimisation of processes to increase their circularity. Implementing these guidelines will enable stakeholders to gain a clearer understanding of how to initiate and prioritise improvements in their CE performance.

At the academic level, the guidelines can be validated by experienced professionals in the CE industry and subsequently applied in organisations and regions. Based on the results, researchers can further refine the guidelines by conducting more in-depth analyses using DEA techniques to monitor CE efficiency, assess improvements, and generate new insights to be considered.

In this context, section 3 delves into the existing literature, providing context on CE implementation in SMEs and introducing the DEA method and its potential. Section 4 examines literature relevant to RQ1, focusing on available CE indicators for SMEs, challenges in selecting the right indicators, and the potential of composite indicators. Section 5 addresses literature for RQ2, exploring regional development disparities, the importance of industrial parks, the policymaking process, and policies related to H4C development in Europe. Section 6 presents research results, including guidelines based on insights from the literature review and their justification. Lastly, section 7 includes the conclusion, with subsections on future research and limitations.

3 LITERATURE REVIEW

To understand the role of CE implementation in SMEs for the development of H4C, this section provides an overview of the CE in SMEs, and the challenges and enablers associated with CE adoption. Moreover, it briefly discusses the role of government incentives, the impediments SMEs face in transitioning from a linear economy to a CE, and the key factors for successful CE implementation. The DEA analysis and its application in assessing the performance and circularity of SMEs are also discussed.

3.1 Circular Economy in Small Medium Enterprises

Accounting for 90% of the world's businesses, SMEs significantly contribute to industrial pollution, responsible for 70% of it, and consuming more than 13% of the global energy demand [9]. CE is seen as the right solution for improving SMEs' sustainability. The main principle behind CE is that resources are kept in the economy even after a product reaches its end-of-life period, generating further value [6]. However, the transition to a CE requires crucial changes and innovation in technology, social, finance, and policy sectors [6, 13, 35, 39]. Proper implementation of CE practices should consider various perspectives and indicators related to economic, environmental, social, and governance factors [13, 35].

3.1.1 Incentives. Government incentives are crucial for CE implementation in SMEs [8, 35]. So far, several measures have been introduced by the EU to promote the adoption of CE in SMEs, and measurements have been conducted across Europe to determine patterns of CE activity engagement [17]. For example, the European Commission developed a CE framework using smart regulation, market instruments, research, innovation, and incentives, focusing on SMEs and collaborating with international partners [6]. Additionally, the EU has made data available through the Flash Eurobarometer 441, documenting CE practices among European SMEs. [39] analyses microdata from this dataset and concludes that the implementation of CE in EU SMEs is heavily dependent on the country of operation.

[39] highlights the heterogeneity in economic development, national programs, funding mechanisms, and institutional frameworks across Europe. The paper strongly suggests the need for better support for SMEs through targeted programs in investments, infrastructure, technology, and skills, as also mentioned by the European Commission [6, 39]. By providing the right policies and training incentives, governments can reduce pollution created by SMEs [8]. [35] mentions that governments should encourage SMEs to start with efficiency improvements and, after experiencing benefits, assist them in advancing to CE technologies through supportive policies and incentives.

3.1.2 Impediments. Some studies confirm that SMEs are not yet fully prepared to engage in CE, highlighting several impediments that make the transition from a Linear Economy (LE) to a CE difficult [35]. Identified barriers include financial challenges, awareness issues, lack of resources, weak commitment from organizational management, lack of financial support, and lack of governance support [9, 35]. Moreover, the lack of indicators to measure enterprise circularity challenges holistic evaluation as most indicators overlook CE implementation across social, economic, and governance sectors, and disregard managerial differences driven by economic and social status.[13].

3.1.3 Enablers. [22] develops a multilevel conceptual framework highlighting the challenges and enablers of SMEs in the Indian market. To overcome the barriers to CE transition, the study proposes the adoption of government policies and managerial policies, as well as the continuous development of circular business models due to their uncertainties and future market demands in the SMEs [22]. [35] highlights the transition from LE to CE of SMEs and their related impediments and prospects. Key prospects for SMEs include waste minimisation, economic benefits, resource efficiency, and improved corporate image. "Management will" is identified as a crucial driver for CE implementation in SMEs, emphasising both environmental and profit benefits. The study underscores the government's role in promoting CE practices among SMEs, advocating for encouragement and motivation over strict implementation of circular practices [35].

3.2 DEA in SMEs

The adoption of CE practices in SMEs needs to be continuously monitored and evaluated to ensure the efficiency of the implemented practices within the company [12, 29]. However, measuring the effectiveness of these measures requires a systematic approach [34]. Various indicators are available for assessing CE effectiveness [25]. Research in the field identified effective methods for measuring CE performance assessment [34]. The most common traditional method used to measure circularity is the Life Cycle Assessment (LCA) method, which evaluates environmental impacts throughout a product's life cycle, including raw material extraction, production, use, and disposal [34]. Generally, LCA assesses eco-efficiency and sustainability of products in various sectors, focusing on materials, energy, and pollution during the: BOL (Beginning of Life), MOL (Middle of Life), and EOL (End of Life) stages, with an emphasis on the environmental and economic aspects [34].

Another popular method used is Data Envelopment Analysis (DEA), a non-parametric approach that evaluates the efficiency of decision-making units (DMUs) using input-output analysis [34]. DEA is generally used in measuring CE performance in energy efficiency analysis, municipal solid waste recycling, and sustainable supply chain management, often in combination with Material Flow Analysis (MFA) and Input-Output (I-O) models [34]. DEA also considers multiple lifecycle stages and variables, focusing on environmental aspects, while encompassing economic and social dimensions. The main difference between LCA and DEA is that LCA provides a holistic view of environmental, whereas DEA focuses on the efficiency of specific processes and units, incorporating environmental, economic and social dimensions [34].

Traditional tools like LCA, entropy weighted method (EWM), and fuzzy clustering methods [5] assign weights to different CE indicators to provide a CE score. However, these methods can be subjective and inconsistent, leading to significant errors [5]. DEA, being a non-parametric tool that constructs an I-O model, eliminates the need to assign precise weights to each criterion, thereby reducing bias in the analysis [1].

First introduced by Charnes [4], DEA is initially described as a nonparametric method which can handle multiple inputs and outputs, allowing it to evaluate complex entities for their efficiency level of their Decision Making Units (DMU) [4]. DEA has increased significantly in popularity throughout the years due to its high potential. [11] analyses 40 years of DEA research (1978-2016) and it confirms its extensive use in the sustainability sector. DEA has been used to evaluate SMEs efficiency in implementing smart, green, resilient, and lean manufacturing practices, highlighting its ability to calculate efficiency scores by comparing their input-output ratios against top performers within the dataset [1]. Another study uses DEA to measure the waste management efficiency of 26 EU countries [13], comparing a basic DEA model with a weight-restricted one and it notices the DEA's limitations in predicting maximum performance and its sensitivity to outliers.

The DEA technique is suitable for measuring CE effectiveness due to its flexibility in choosing multiple inputs and outputs [11]. It reduces bias in assigning importance to specific CE processes and incorporates a multidimensional view, including environmental, economic, and social dimensions. DEA can help organizations at micro and meso levels [33], as well as regions of specific countries [37] to evaluate their circularity by using models that include inputs and outputs from all three dimensions [13, 33]

4 CE PERFORMANCE INDICATORS FOR SME

A critical aspect of effective analysis for SMEs is selecting the right indicators for DEA [18, 28, 31]. The challenge lies in choosing appropriate CE indicators due to a lack of standardization, complicating the analysis process for SMEs [3, 18]. The variety of indicators is crucial for gaining accurate insights into SMEs' efficiency in implementing CE practices, covering environmental, economic, and social aspects [18]. This section reviews existing CE indicators and explores the challenges of selecting the right indicators for SMEs. It also looks into the development of composite indicators for SMEs to incorporate various CE perspectives.

4.1 Available indicators

The widespread adoption of CE in the business market has led to extensive research on circular practices and the circular metrics or indicators that can help evaluate the performance of businesses [12, 18, 25, 30]. Moreover, the European Environment Agency (EEA) emphasised the importance of tracking the progress made by businesses after transitioning to a CE [1]. [33] mentioned that indicators for measuring CE performance should be chosen by participants based on their needs, thus including different aspects. Different levels, such as micro-level, meso-level, and macro-level, also need to be considered, in which the first two are the most relevant for SMEs. [12] argues that micro level indicators encompass products, companies and consumers, while meso-level indicators focus on eco-industrial networks benefiting regional development. At the micro-level, companies need specific indicators based on their unique characteristics and the 3Rs principle of waste (reduce, reuse, recover), whereas at the meso-level, indicators should focus on industrial symbiosis and the performance of plants and industrial parks [33]. [18] highlights that most indicators in scientific papers refer to macro-level companies, with meso and micro-level indicators being less explored.

[18] conducts a systematic literature review (SLR) to highlight existing CE indicators at the micro-level and their alignment with the three dimensions of sustainability. The study identifies 30 indicators—single, quantitative, and composite—were identified from academic papers. The review find the diversity of CE indicators at the micro-level complicates the selection for companies, which primarily focus on recycling. However, reuse strategies, which are more effective for CE implementation, receive less attention.

The 30 indicators are categorised into the three dimensions of sustainability: economic, environmental, and social (Figure 1). 17 indicators focus on the economic dimension, particularly on the cost and price of products, materials, and processes. 12 indicators address the environmental dimension, mainly focusing on the CO_2 impact of processes, water footprint, and ecosystem quality. 4 indicators cover the social dimension, considering employee involvement, awareness and satisfaction, working environment, and job creation.

[1] https://www.eea.europa.eu/en/topics/in-depth/circular-economy

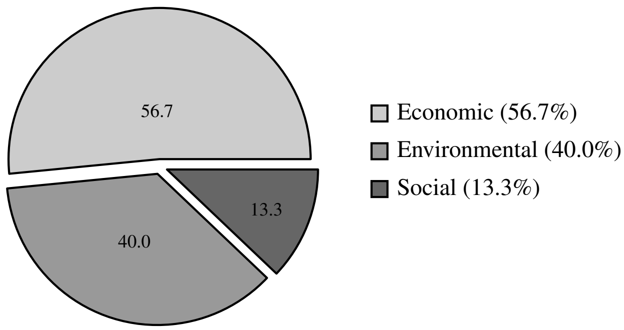

Fig. 1. Distribution of indicators in the three dimensions of sustainability at the micro-level adapted from [18]

4.2 Challenges in selecting the right indicators

Choosing the suitable indicators for each company can be challenging for the stakeholders [26]. The lack of available data is one of the root causes of these problems [33]. A study in the Netherlands [29] pointed out the EEA's suggestions on evaluating the progress of CE at a national level, suggesting that the template questions provided by the EEA are insufficient as they mostly cover circularity matters, overlooking the CE processes and its economic and environmental effects. The study highlights different company views on CE benefits, with some considering certain aspects as "collateral benefits." To achieve broad acceptance of CE indicators, these different viewpoints must be acknowledged and reconciled through a consensus process. The lack of consensus on measuring CE transition and its effects complicates the development of appropriate indicators.

Another impediment to defining quantifiable indicators is the lack of data from companies. [33] highlights that the complexity of obtaining relevant data for CE arises from the increased search time and financial costs for companies. Additionally, data privacy is listed as another root cause of this lack of data. Another study done in Spain, [3] among SMEs highlights the lack of uniformity in the data available for measuring CE efficiency. The study identifies 23 CE measures applied in Spanish SMEs and classifies them into six categories. It highlights the lack of uniformity of companies when reporting their practices, making it difficult to compare across different companies. The study affirms the need for more standardised reporting of CE practices to better understand and evaluate the impact of these practices [3].

The study by [18] also emphasises the lack of standardisation in measuring the level of circularity. It explains that the main cause of this lack of standardisation is the different understandings of what CE entails and its most relevant aspects when measuring its effectiveness. This highlights the dependence of CE indicator analysis on each company's understanding of CE at the micro-level. Lastly, the study suggests that further research should explore the development of industry-specific indicators, which can increase CE implementation in industries and provide standardised ways to measure CE adoption [18].

4.3 Composite indicators

[18] highlights some of the most common indicators used at the micro-level and states that practical indicators consist mostly of single and quantitative indicators. The study highlights the trade-off between simplicity and comprehensive coverage, meaning that single indicators might lack depth but offer practical usability, especially for companies focusing on micro-level CE indicators. In contrast, multidimensional indicators aim to include more CE concepts but have a higher complexity level regarding practical usability. Therefore, the need for a holistic approach in choosing the right indicators is strongly emphasised in [18].

Another study, building on the background knowledge from [18], delves deeper into the concept of composite indicators and develops a strategic measurement framework to monitor the circular performance of organisations at the micro-level [12]. The framework uses the Analytic Hierarchy Process (AHP) to define and weight criteria for CE-related indicators (C-indicators) and employs the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to rank and select them. This process calculates the composite C-indicators for the 10 R-strategies (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover). The study presents values for 10 composite C-indicators for all R-strategies and an overview of the Circularity Performance Index (CPI), which sums these indicators. The weights for the C-indicators are determined through consensus-building meetings. The study recommends further research into circularity analysis and benchmarking, suggesting DEA as a suitable method for benchmarking modelling [12].

5 INSIGHTS ON REGIONAL, INDUSTRIAL AND POLICY ASPECTS OF CE

This section explores the implementation of CE across regions and evaluates the insights obtained through DEA regarding the regional circularity development and its disparities. It highlights the importance of IS networks, as reflected through EIPs, in enhancing circularity and regional development. Finally, it addresses the process of policymaking for regional development and the policies related to H4C development in Europe.

5.1 Regional Disparities

The DEA method can be applied by various countries for its unbiased approach to effectively analyse a country's performance and reveal its regional differences [1].Regional disparities are particularly noticeable when analyzing insights from DEA in the field of sustainability. Numerous factors influence the performance of organizations in sustainability. The analysis allows provinces to identify the root causes of why certain regions outperform others within a country[38].

A study in China analyses 30 provinces' environmental efficiency using a DEA approach and highlighs disparities between the Eastern, Western, and Central regions [38]. The eastern region demonstrates superior environmental efficiency attributed to stronger economic influence, advanced technology, and strict government environmental policies. The study highlights that policies significantly impact regional development and can positively affect environmental performance. Policies such as China's "Go West" initiative have facilitated significant investments in technology, along with favorable tax and land policies, enabling western cities like Guizhou and Ningxia to improve environmental performance comparable to the east [38]. Conversely, inconvenient locations can hinder investment and lower regional performance.

5.2 Industrial Parks

Industrial parks are key drivers of sustainable development, influencing regional economies, resource consumption, and environmental pollution [36, 40]. Consequently, CE development in industrial parks is crucial for enhancing regional sustainable development [36]. The adoption of circular practices in Eco Industrial Parks (EIP) needs continuous monitoring and evaluation. Industrial symbiosis, where various industries collaborate to optimise resource use and minimise waste, is common in industrial parks [10, 16]. Therefore, the resource dimension is critical when evaluating CE efficiency in industrial parks [36]. Resource consumption measures the raw material and energy used, highlighting how efficiently resources are utilised in an industry.

Effective industrial symbiosis relies on maintaining efficient resource consumption. A significant positive correlation (0.747) has been observed between resource use and environmental performance in [36]. The study also confirms the importance of multidimensional values of CE in EIPs, such as economic, environmental, resource, and social values. However, it acknowledges that social equity is difficult to quantify in the industrial sector, which primarily focuses on production. Nonetheless, social value can be represented by resource and environmental dimensions.

After conducting a DEARA (Data Envelopment Regression Analysis) assessment on 20 EIPs in China, findings suggest that parks with high GDP and leading industries in high-tech or manufacturing are the main drivers of the strong correlation between resource consumption and environmental performance [36].

China has been accelerating its transition towards a CE, with various initiatives targeting EIPs [10]. The industrial symbiosis network continues to develop and is being evaluated and monitored to achieve the goal of using waste as a resource. In Europe, several initiatives towards a CE have been implemented, as mentioned in section 3.1.1. The IS activity in Europe covers different coordination mechanisms and scopes depending on the country's initiatives and network typology. [10] explores IS networks in Europe, categorizing them into three types: self-organised networks, facilitated networks, and planned networks (see Table 1).

Self-Organised Networks develop organically through direct interactions among industrial actors, driven by economic gains and cost-saving opportunities, often reusing waste heat, steam, and energy. Facilitated Networks involve third-party intermediaries coordinating IS activities, supported by programs and policies, identifying IS opportunities, and promoting transactions. Planned Networks result from a central plan or vision, typically for a specific industrial area, incorporating shared infrastructures and services, driven by strategic planning and government initiatives to promote sustainable industrial development.

Type of Network	**Countries**	**Examples of Parks**
Self-Organised Networks	Northern Europe, including Denmark, Sweden, Finland, Norway	Kalundborg (Denmark), Harjavalta (Finland), Landskrona (Sweden), Kemi-Tornio (Finland)
Facilitated Networks	UK, Finland, Denmark, Belgium, Italy, France, Hungary, Romania, Poland, Slovenia	NISP- National Industrial Symbiosis (UK), facilitated structures in Finland, Denmark, Belgium, Italy, France, Hungary, Romania, Poland, Slovenia
Planned Networks	Netherlands, Spain, Italy	Eco-Park Terneuzen (Netherlands), Parc d'Alba (Spain), Torrent Estadella (Spain)

Table 1. Summary of Industrial Symbiosis Networks in Europe adapted from [10]

5.3 Regional development in EU

While there is limited research on CE performance in EIP in Europe, some studies have analysed waste generation at a regional level in the EU from environmental and economic perspectives using the DEA technique. As mentioned earlier in section 4.1, companies and regions tend to focus on recycling as a primary method of implementing CE practices. Recycling is considered the outer circle of CE, making it the least sustainable option compared to other methods such as reduction and reuse. The general consensus on measuring recycling is varied, with diverse methods including multiple inputs and corresponding indicators [18]. Consequently, recycling has become a predominant concept and measurement method in waste management.

5.3.1 Waste management in EU. Numerous studies have analysed the Waste Management (WM) field in European regions and municipalities using the DEA method [14, 23]. The EU Commission has designed specific indicators for the WM field, highlighting its importance [23]. For example, Marques [23] evaluates the performance of municipal WM in 24 EU countries from 2011 to 2019. The main input indicators includes material consumption, political concerns, and economic status, highlighted by GDP per capita. The output indicators are recycling rates, circular material use rate, and waste-to-energy. The insights obtained from DEA reveal important trade-offs and correlations, particularly for policy development. Significant variability are noted between the performance of Northern and Southern European countries, with northern countries generally performing better. Additionally, a positive correlation is found between higher education levels in a country and WM efficiency, while certain production functions (gross fixed capital formation, unemployment, share of renewable energy) negatively impact the adoption of CE. The study also highlights the trade-off between economic growth, indicated by GDP, and environmental sustainability, noting that high GDP countries often face challenges in maintaining environmental sustainability. Cross-border collaborations were suggested as beneficial for underperforming regions [23].

A similar study on waste generation in the EU evaluates 172 regions from 17 EU countries using DEA with four different models, each with slight variations in input and output indicators [14]. Unlike the previous study [23], this one marks GDP as an output indicator for all four models. The results show significant differences in efficiency scores across the models due to varying waste treatment approaches. With GDP as an output indicator, the study finds that regions with higher GDP per capita generally perform better, suggesting a positive correlation between economic output and WM efficiency. However, the study concludes that efficient WM depends not only on national policies but also significantly on regional practices. Therefore, region-specific policies and practices are essential for improving WM and enhancing CE performance [14].

5.4 Policymaking

Policies can significantly influence the successful transition to CE in companies at both the micro and meso levels [39]. However, the lack of tailored policies for SMEs also poses an impediment in having a good CE performance [35]. The insights from DEA applied at organisations from a micro and meso-level can have a substantial impact in creating policies, that are tailored for each companies based on the DEA insights. Unfortunately, not sufficient evidence is found on policies that are created based on a DEA analysis, which makes it difficult to present the already available policies.

5.4.1 Evidence from China based on DEA insights. As previously mentioned, there is limited academic evidence of CE policies derived from DEA analysis, with most sources focusing solely on energy and/or environmental (EE) efficiency [36]. Although these fields share common aspects, EE is a subset of CE efficiency because CE includes all the principles of the "3R" (reduce, reuse, recycle), thereby encompassing the energy-economy-environment (EEE) subsystems [37]. In China, the lack of CE policies and their implementation has led to a decline in the country's environmental efficiency. According to [37], the development imbalance between the Eastern, Central, and Western regions of China presents challenges in coordinating the relationship between energy, economy, and environment for policymakers. Eastern regions generally perform better than the western and central regions, creating an imbalance in CE performance across the country [36]. The study asserts that the Chinese government should enforce policies rather than just establish them, and better coordinate various policies. This highlights the need for prompt action to achieve effective results. An important role in this process is played by local governments, which are often overlooked but serve as crucial intermediaries in formulating and implementing policies in their regions [37]. Local governments should strive to balance economic development with environmental regulation.

5.4.2 Towards implementing H4C in Europe. Meso-level organisations play an important role in accelerating the transition to a CE [10]. Industrial Symbiosis serves as a foundation for creating mutual collaboration between organisations to valorise resources and services across all sectors and value chains, thereby highlighting the importance of CE for businesses and stakeholders [20]. The concept of Hubs for Circularity is particularly significant as it accelerates the transformation of companies into circular organisations, which ultimately share energy, materials, services, infrastructure, and information to achieve climate and resource neutrality [24]. In Europe, the implementation of hubs is highly encouraged and has been promoted by the Processes4Planet partnership [2] [24] analyses the distribution of circular regions in Europe by applying different clustering methods. The framework proposed by the study acknowledges the 4R strategy (reduce, reuse, recycle, recover) as effective for the European process industries in creating urban industrial-symbiosis networks. The prioritisation of reduce strategies is highlighted as the key enabler of circularity across all sectors, from industries to SMEs. These strategies can be applied differently to create hubs depending on the region of Europe. Western Europe is more predominant in creating H4Cs due to its industrial density, whereas Eastern Europe is more scattered in the industrial sector. Table 2 highlights the types of H4Cs to be developed in Europe and the policies that could accelerate their emergence.

Part of Europe	**Policies and Opportunities**
Northern Europe	Opportunities for hubs related to wind energy.
Southern Europe	Potential for the use of solar energy.
Western Europe	Innovation based on spatial proximity, developing pilot projects, leveraging many R&D centres, and global energy innovation trends.
Eastern Europe	Development policies to transfer technology and innovation, developing hybrid hubs, expanding networks to include diverse SMEs.

Table 2. Policies and Opportunities for H4C in Different Parts of Europe adapted from [24]

6 RESULTS

To conclude the answers to the research questions, a set of guidelines has been developed based on the content explained, incorporating suggestions related to indicators (Table 3), regional development (Table 4), and policymaking (Table 5) for SMEs and regions of countries to enhance their CE performance. The context of making the policies is based on the DEA technique, and most of the policies are tailored to fit this context. The development of the guidelines has been done by concluding all the papers considered in answering the research questions. Moreover, a justification for the choice of the guidelines is provided.

6.1 Indicator Guidelines

6.1.1 Justification for the Inidicator Guidelines. Guideline 1 mentions the need for incorporating all three strategies (reduce, reuse, recycle), which has been noted as critical in including a broad perspective of CE [18, 34]. So far, most SMEs have focused on recycling strategies to enhance their CE performance, even though recycling is the least effective method for achieving CE efficiency. The other strategies are not developed and thus lead to inaccurate evaluations. [24] argues that reduce strategies would be the most efficient method to reach circularity performance and can be implemented in SMEs,

[2]https://www.aspire2050.eu/p4planet/about-p4planet

No.	Indicator Guidelines
1	The indicators chosen for measuring CE performance at the micro-level should incorporate all the 3R strategies of circularity, with a strong focus on reuse strategies.
2	Indicators for both micro and meso levels should aim to be equally divided between the three dimensions of sustainability.
3	A general consensus on how CE is perceived and how it should be measured by organisations should be made clear.
4	The development of more standardised reporting CE practices through enhancing industry-specific indicators that lead to uniformity in reporting.
5	A holistic approach is needed when choosing indicators for measuring circularity performance by having a balanced number of single and multi-dimensional indicators.
6	Companies can make use of composite indicators, which are comprised of multiple R-strategies, to measure their Circular Performance Index (CPI). Based on that, companies can define new value propositions and make strategic choices to enhance their CE performance.

Table 3. Indicator Guidelines for CE Performance at the Micro and Meso Level Based on a DEA Approach

including at the micro and meso levels. [18] identifies that most indicators refer to recycling but argues that reuse indicators would be the most efficient to achieve CE performance at a micro-level, yet they currently do not receive enough attention. Thus, having a balanced set of indicators that include all the 3R strategies is key to achieving CE effectiveness.

Guideline 2 emphasises the need to have indicators that incorporate all three dimensions of sustainability: economic, environmental, and social. This would help increase the efficiency of measuring CE effectiveness by considering all angles. [18] analyses the balance of the three dimensions of the indicators at the micro-level and concludes that the most focus is on economic indicators, followed by environmental, with social indicators receiving the least attention from companies. This division might be due to different interpretations of CE values by companies, which prioritise certain values, such as economic, more than others. [29] points out that companies view CE benefits in their own way and consider some aspects as "collateral benefits," which might be the case for the social and environmental aspects. [13] builds on this theory, stating that companies overlook the differences in managerial approaches driven by social factors, which strongly influence good CE implementation. [36] argues the importance of a multidimensional view in EIP to form a successful IS but also highlights the difficulty of quantifying social values in an industrial sector with a strong focus on production.

Guideline 3 talks about reaching a consensus on what CE entails and the critical measurements for it. During the indicator research, the diverse selection of CE indicators chosen by companies was noted, leading to the measurement of different aspects of CE [18], [29]. The different viewpoints of CE should therefore be combined to reach a general consensus, which would also lead to the development of the right indicators for measuring CE performance [29].

Guideline 4 mentions the need for standardisation when measuring CE performance. This lack of uniformity has been one of the root problems in measuring circularity so far and can lead to inaccurate results of performing a CE analysis in SMEs. [3, 18] highlight that SMEs have difficulties in comparing their circular practices, leading to a bottleneck in comparing practices across different companies. The standardisation of reporting data is the solution that could increase the quality of the analysis.

Guideline 5 focuses on the choice of indicators when performing a CE analysis. There exists a trade-off between single and multidimensional indicators. Single indicators lack depth in CE coverage but offer practical usability, especially at the micro-level, whereas multidimensional indicators incorporate more CE concepts but have increased complexity in practice [18]. In this case, a holistic approach when analysing CE performance is needed to include a multidimensional focus by having composite indicators that incorporate all three dimensions of sustainability: economic, environmental, and social.

Guideline 6 discusses the implementation of composite indicators when conducting a CE analysis in SMEs. Composite indicators have the potential to take all the 10 R-strategies of CE into account (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover) and combine them into multiple composite indicators [12]. The composite indicators can then be put into a Circular Performance Index, helping SMEs evaluate their circularity performance and make decisions to enhance their circular practices. Defining new value propositions for companies to implement CE would lead to adjustments of CE strategies and related R-strategies, fostering circularity with an entrepreneurial touch. In this case, the presence of composite indicators would streamline the process of making the right decisions when adapting CE strategies.

6.2 Regional Development Guidelines

No.	Regional Development Guidelines
1	The government could provide more investment in less developed regions to enhance the adoption of advanced technologies, thereby improving circularity performance.
2	To create an IS integration, companies in EIP could focus more on the resource dimension of the CE.
3	EU regions could consider applying other dimensions of circularity, such as reuse, reduction, and resource consumption, to enhance circularity across all types of industries.
4	The EU could provide more environmental awareness education to the population, which can increase the adoption of CE practices.

Table 4. Regional Development Indicators Based on a DEA Approach

6.2.1 Justification for the Regional development Guidelines.

Guideline 1 highlights the need for investment in technology, which can help less developed regions improve their CE performance. Technology has been proven to streamline processes [36, 38]; thus, by adopting advanced technologies, production processes can become more efficient and circular. Therefore, governments should analyse and support less developed regions with circular policies and technology investments to improve their performance standards.

Guideline 2 acknowledges the importance of Eco-Industrial Parks (EIPs) in developing a CE. Industrial symbiosis can be seen as the main driver of the transition to circularity [20, 24]. In an EIP, most processes focus on production, making resources the foundation for creating IS networks [36]. This is why the resource dimension should receive special attention when implementing and monitoring circular practices, as it involves critically analysing how efficiently resources are utilised in an industry [36]. Moreover, a strong correlation between environmental performance and resource consumption has been found by [36], highlighting the need for detailed attention to the distribution and usage of resources.

Guideline 3 reflects on the need to diversify the circular initiatives applied in the EU. Currently, in the EU, most studies on CE regional performance focus on waste management. One underlying reason is that companies and countries in the EU generally focus on applying recycling strategies to achieve circularity, even though recycling has been proven to be the least effective in achieving a CE [18]. In this case, EU countries and related companies should prioritise other dimensions like reuse, reduction, or resource consumption, which are more effective in achieving circularity. Implementing holistic circular processes can increase CE efficiency and encourage companies to explore diverse CE processes, increasing innovation on a regional level.

Guideline 4 emphasises the role of education in promoting circular practices. This guideline focuses exclusively on the social dimension, which can significantly impact effective CE implementation in EU countries and regions. Informing people about the impact of CE globally would increase their awareness of its necessity in their regions and encourage them to adopt CE practices. [23] clearly states that educating people leads to an improved Human Development Index (HDI) for EU countries and ultimately leads to better circularity adoption, after analysing the disparities in CE performance between northern and southern EU countries. This guideline also encourages regions to prioritise the value of the social factor when monitoring their CE effectiveness.

6.3 Policymaking Guidelines

No.	Policymaking Guidelines
1	Governments could adopt a stricter attitude towards implementing policies for the CE.
2	Local governments could take more responsibility for the effective implementation of CE policies.
3	Targeted policies could be developed to enhance the CE performance of regions and their corresponding SMEs.
4	Based on H4C opportunities across Europe, tailored policies could be developed to increase the formation of Hubs for Circularity.

Table 5. Policymaking Guidelines Based on a DEA Approach

6.3.1 Justification for the Policymaking Guidelines. Guideline 1 emphasises the role of government in adopting policies, which has been proven to be one of the key players in supporting the adoption of CE in SMEs [8, 35]. However, so far the government has only encouraged the adoption of policies and not actually required their implementation by companies. This results in an imbalance of regional development, as seen in China [36]. Thus, the unprompted attitude of the government can pose an impediment to adopting CE across a country and creating circularity in all regions. The need for targeted investments in CE technologies would help all regions perform better in terms of circularity [36–39]. Therefore, a stricter approach by the government could be beneficial in speeding the adoption of CE across all regions of a country and enhancing the efficiency of circular processes [36].

Guideline 2 points out the role of local governments in implementing CE policies across regions. Their role is to act as intermediaries between the central government and the regions, meaning that they are responsible for the effective implementation of CE policies by taking practical action [37]. Nevertheless, it is important to have good coordination between the central government and the local one in managing the policies and ensuring they can be established and ultimately applied in regions effectively.

Guideline 3 discusses the idea of targeted policies that could influence the effectiveness of SMEs and their regions. The influence of the national context of CE, sector-specific factors, and the size of the companies have been shown to be critical when it comes to the level that CE is implemented in companies [39]. To address these influences, tailoring CE policies by sector could strategically integrate circularity into existing SME processes, improving efficiency without the need for extensive operational changes. The EU has already been working on creating a framework to opt for an integrated approach across all policy areas and levels [39]. Besides that, region-specific policies can also enhance CE performance [14]. Tailoring the policies depending on the region's CE situation can be effective and it could be done with the help of local governments.

Guideline 4 highlights the opportunities of creating H4C in Europe. In order to form hubs, an overview of the opportunities across Europe should be analysed. [24] states that Northern Europe should focus more on hubs related to wind energy, whereas Southern Europe should focus on hubs using solar energy. Thus, the differences in the parts of Europe regarding the industrial potential of creating H4C are significant and should be taken into account by creating tailored policies for all parts of Europe. This would help them develop and enhance their processes according to their opportunities. Western Europe is more prone to having H4C due to its industrial density, so more policies could be made about developing pilot projects and more investment into R&D should be applied, whereas Eastern Europe is more scattered, thus development policies to transfer technology and innovation could be applied, for example [24].

7 CONCLUSION

This paper explores how DEA insights can effectively improve CE adoption in SMEs, contributing to the formation of H4C. DEA has shown the potential to be a suitable method for analysing the circularity of SMEs at both micro and meso levels, providing valuable insights for enhancing CE effectiveness. The study offers guidelines on indicators, regional development, and policymaking to boost CE implementation in SMEs and their regions, facilitating H4C development. These guidelines are based on the research addressing RQ1 and RQ2.

cThe guidelines target various sectors critical to H4C development and involve diverse stakeholders. Their value lies in providing stakeholders with a clear starting point to prioritise circularity in SMEs and regions. The indicator guidelines are essential for monitoring circularity at micro and meso levels, helping companies and managers select suitable indicators, track circularity, and define new strategies to enhance CE performance. Researchers can also use these guidelines to evaluate company efficiency and develop optimised indicators.

The regional development guidelines focus on meso-level and IS network creation. They target industrial parks and regions, involving direct stakeholders such as EIP members, government, local authorities and indirect stakeholders like the EU. The main points of these guidelines suggest that it would be beneficial for stakeholders to increase investment in CE adoption through targeted investments and broaden CE applications to include other dimensions. Additionally, the EU is advised to promote and enhance CE education to the general public, in order to improve CE implementation. By following these guidelines, the stakeholders can actively promote CE in regions and across society. This can boost the CE implementation and ultimately the development of H4C.

The policymaking guidelines highlight the importance of targeted policies in enhancing CE performance. Involved stakeholders include governments and local authorities, who act as intermediaries between central governments and regions. Tailoring policies to regional CE situations can lead to faster, more effective implementation and better results without extensive operational changes. Local governments implementing these tailored policies can significantly advance CE development and H4C implementation.

7.1 Future research

A primary focus for future research should be on validating these guidelines through implementation by relevant stakeholders and assessing their impact on SMEs and regional circularity. Documenting the effects of these policies will help evaluate their effectiveness. Additionally, further research is needed on other CE-related R-strategies, such as reuse and reduce, as these areas are underexplored. Applying DEA to analyse the efficiency of these strategies could yield valuable insights.

Achieving a consensus on CE definitions among stakeholders is essential for standardising data measurement using DEA. Ultimately, these DEA insights can inform effective decision-making, enhancing CE practices and supporting the development of H4C.

7.2 Limitations

While conducting the literature review to answer the sub-research questions, several limitations have been encountered. Firstly, the lack of papers that include DEA analysis at a micro and meso level poses a challenge in finding information about DEA insights for CE development. Second, most DEA studies are conducted in China, resulting in a lack of evidence regarding DEA insights in the EU. Moreover, the papers employing DEA approach in the EU primarily focus on waste generation and management, thus emphasising recycling strategies while neglecting other essential strategies of the CE. Furthermore, few papers and limited evidence of H4C have been found since it is a relatively new concept with limited exploration in the academic literature.

8 ACKNOWLEDGEMENTS

The author of this paper would like to thank Marcos Machado and Patricia Rogetzer for their invaluable support and insights, which have been immensely appreciated.

9 APPENDIX

During the preparation of this work the author used ChatGPT in order to revise spelling and grammar check and format visual elements. After using this tool, the author reviewed and edited the contents as needed and takes full responsibility for the content of the work.

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