Measuring Circularity: The Gordian Knot of the 21st Century

Arjen Wierikx
HU University of Applied Sciences

Néomie Raassens
Eindhoven University of Technology

Alex Alblas
Eindhoven University of Technology

Pascal Ravesteijn
HU University of Applied Sciences

ABSTRACT

Organizations are currently facing substantial challenges regarding becoming circular by 2050 – also referred to as Circular Economy (CE). Subsequently, increasing complexity on all organizational levels creates uncertainty about respective organizational and technological capabilities and adequate strategies to develop these capabilities. Organizations are struggling to pick up the CE ambitions and answer the "what's in it for me" question. On the other hand, scholars are developing models and frameworks to enable organizations to measure CE performance. Over 125 assessment methods are available for micro-level assessment – measuring up to 365 different metrics. Moreover, extant literature presents barriers and opportunities for CE-transformation focusing on industry, sector, and region, among others. Furthermore, although a more holistic perspective is required to mature for circularity, this is currently lacking. In this paper, we present a multi-methodology view on the use of different approaches for measuring circularity. Our main goal is to extend the existing body of knowledge with an eye on applicability and research directions to untie the Gordian knot of measuring circularity.

Keywords: circular economy, sustainable development, assessment, holistic view, transformation

INTRODUCTION

Circular Economy (CE) is broadly discussed and on the agenda of policymakers, scholars, consumers, and a growing number of C-level managers. There is an increasing awareness of the need to pay conscious attention to circularity, and subsequently, a growing number of examples, frameworks, models, tools, and assessments are becoming available (Kristensen & Mosgaard, 2020; Lindgreen et al., 2020; Parchomenko et al., 2019; Vinante et al., 2020). Although it is perceived as such, circular thinking is not something new of the 21st century. Already in 1966, Boulding presented his Spaceship Earth concept, suggesting that we should carefully think about our material and gas flows (Boulding, 1966).

Aware of the need and the growing pressures, governments worldwide are launching ambitions to be fully circular by 2050. In this context, the European Commission recently adopted the European Green Deal (COM 640, 2019) as a reference framework to achieve the climate neutrality target by 2050, with the New CE Action Plan (COM 98, 2020) as one of its main pillars (Valls-Val et al., 2022). Hence, many companies, knowledge institutions, and governments are looking to improve circularity in various areas.

Against this background, it is evident that there is an increasing focus on how digital technology (DT) can boost the circular transition (Awan et al., 2021). DTs like the Internet of Things (IoT), Big Data Analysis (BDA), 3D Printing, and Artificial Intelligence (AI) are viewed as key enablers to increasing circular performance (Awan et al., 2021; Bressanelli et al., 2018; Kristoffersen et al., 2020; Liu et al., 2022).

Regardless of the formulated ambitions and the available potential of DT, the question arises how circularity can be made measurable. What is the point in time an individual company or consumer can stand up, raise their hand, and state: 'I've reached the level of full circularity, as challenged by our leader'. To support progress towards CE and deploy available DTs to the fullest, the ability to measure and monitor circularity through monitoring frameworks, evaluation tools, and indicators is essential (Kristensen & Mosgaard, 2020; M. Saidani et al., 2018).

The measurement of circularity is at the center of many research questions (Saidani et al., 2018; Potting et al., 2017; Bocken et al., 2017; Linder et al., 2017). Academic models and grey literature are available to gain insights into CE-measures. Consensus on these models is not reached, and misconceptions about CE become visible during deployment (Kumar et al., 2019; Tan et al., 2022; Uhrenholt et al., 2022). Also, while the models and the ambitions are there and leading companies present change programs, explorative interviews have indicated that, especially amongst SMEs, there is still significant ignorance (Kumar et al., 2019). Today, the required capabilities for achieving sustainability—particularly the necessary competencies in day-to-day operations—have not yet been consolidated and agreed upon. Part of the problem may be that some organizations show their commitment to being sustainable merely by changing their rhetoric and pursuing green-washing (Cleven et al., 2012; Laufer, 2003; Stiller & Daub, 2007).

Hence this paper aims to explore The Gordian Knot of measuring circularity. For this purpose, three research questions are proposed: RSQ1: What is the current state of the art concerning available assessments of measuring circularity? RSQ2: How is measuring circularity implemented in practice? RSQ3: What arguments give reasoning to the level of adoption of assessment approaches in practice?

To answer these questions, the remainder of the paper is structured as follows. In the second section, attention is paid to the theoretical background related to the diverse concepts of CE performance, the current state of the art, viewpoints and tools, frameworks, and some of the main misconceptions and challenges. In section 3, the research methodology is discussed. The findings are presented in section 4, and the paper culminates in section 5 with concluding remarks, recommendations, and proposed directions for future studies.

THEORETICAL BACKGROUND

The concept of the Circular Economy

Research on CE first emerged through scientific conversations on waste and resource management in the late 1960s (Boulding, 1966). CE served as an umbrella concept for a heterogeneous set of ideas on managing pollution and extending material resource life (Blomsma & Brennan, 2017). Over the years that followed, the problem-centric narrative on waste handling and prevention shifted toward an opportunity-centric narrative that emphasized the retention of economic value and the systemic looping and cascading of materials (McDonough & Braungart, 2002; Pearce et al., 1990; Zeiss et al., 2021). Since the early 2000s, the opportunity-centric narrative has gradually gained more attention in the business management context, advancing the conversation from mainly technical analysis to also sociotechnical discourse (Bocken et al., 2017; Bressanelli et al., 2018; Prendeville & Bocken, 2016) by taking a more inclusive view that integrates stakeholders, products, components, and material flows across all product lifecycle (PLC) stages of pre-use, in-use, and post-use (Zeiss et al., 2021). CE is an economic model with the goal of minimizing resource input as well as waste and emission leakage by narrowing, slowing, and closing material loops (Geissdoerfer et al., 2017; Kirchherr et al., 2017).

Although 114 definitions of CE exist, many scholars claim the definition by the Ellen MacArthur Foundation (EMF) as the most prominent (EMF, 2012; Geissdoerfer et al., 2017; Kirchherr et al., 2017; Schut et al., 2018): *"The circular economy is an economic and industrial system that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles."* (EMF, 2012). This definition indicates that material flows fulfill an important role in the body of thought concerning circular economy (Schut et al., 2018). The terms restorative and regenerative are used to describe a metaphorical aspect of circularity. Restorative conjures up a circuit of endless use, reuse, and repair. Regenerative speaks to a sort of cycle of life that maintains and upgrades conditions of ecosystem functionality (Morseletto, 2020). Building on the work of Boulding, Pearce & Turner, Stahel and McDonoguh & Braungart, the R-Frameworks were introduced as a conceptualization of CE-strategies (Boulding, 1966; McDonough & Braungart, 2002; Pearce et al., 1990; Potting et al., 2017; Stahel, 1994; Zeiss, 2019). The most well-known framework is the 10-R framework (Potting et al., 2017). The initial intent of the framework was and is to measure innovation in the product chain.

With the introduction of circular thinking, the traditional take – make – waste economy is shifting (Suzanne et al., 2020). More and more, the linear model is replaced by open business models in extended product life cycles (Kortmann & Piller, 2016; Suzanne et al., 2020). Business models and supply chain concepts are revisited (Lewandowski, 2016; Vegter et al., 2020). Existing elements are terminated or changed, and new elements are added (Lewandowski, 2016). In addition, new types of companies are founded (like a waste broker). In the deployment of R-strategies in open business models, different scenarios can be recognized depending on technology innovation and centralization of government (Bauwens et al., 2020).

Lindgreen et al. (2020) present CE as an umbrella concept: *"A broad concept or idea used loosely to encompass and account for a set of diverse phenomena"* (Blomsma & Brennan, 2017; Hirsch

& Levin, 1999; Lindgreen et al., 2020). They identify three fundamental principles: (1) CE focuses on value retention of resources, aiming at a decoupling of raw material extraction and growth, (2) the framework of CE options is hierarchical, and guides preferred priorities in resource management options, and (3) CE is aimed at generating multidimensional impact with the overall end goal to facilitate reaching Sustainable Development (SD). The latter is of particular interest as it connects CE with SD.

Circular Economy and Sustainable Development

The concept of sustainability can be traced back to a book written by Hans Carl von Carlowitz in 1713 (Carlowitz, 1713). However, the idea itself goes back much further. Since time immemorial, communities have worried about the ability of their environment to sustain them in the long run. Many ancient cultures had traditions that limited the use of natural resources. The more contemporary use of the term sustainability begins in 1972 with the United Nations Conference on the Human Environment held in Stockholm which had the topic of SD (Hou et al., 2017). In 1983, the United Nations World Commission on Environment and Development (WECD), also known as the Brundtland Commission, was formed. In 1987, the commission published Our Common Future, a formal release of the concept of SD. According to Our Common Future – otherwise known as the "Brundtland Report" – SD is defined as a development that *"meets the needs of the present without compromising the ability of future generations to meet their own needs"* (Brundtland, Khalid, et al., 1987). Based on this definition the term triple bottom line was coined, which refers to the three fundamental pillars of corporate sustainability (Cleven et al., 2012; Savitz, 2013): The economic bottom line; The social bottom line; The environmental bottom line.

SD is a comprehensive dynamic concept involving economy, society, culture, technology, and natural environment. It clearly points out that developing the economy and protecting the environment and resources relate to each other and act as the cause and effect of each other. It called for rethinking the traditional development modes and designing SD modes for the future. Beginning in the 1990s, new terms appeared, such as reverse logistics, green logistics, and green supply chain. Obviously, these terms reflect the impact of SD (Hou et al., 2017).

Often, circularity and sustainability are used as synonyms. However, they are not. Being circular does not mean being sustainable. Also, being sustainable does not mean being circular. The two concepts go hand in hand, but that does not have to be the case in all situations. CE is sometimes interpreted as a vehicle to facilitate moving towards SD (Lindgreen et al., 2020). Geissdoerfer et al. (2018) zoom in on the relationship between the two concepts. Millar et al. (2019) challenges the proposition that implementing CE is facilitating a move towards SD. Sauvé et al. (2016) critically evaluate some epistemological problems of both concepts. In reviewing available CE-definitions (Awan et al., 2020; Kirchherr et al., 2017), it is found that only a few studies link CE to all three dimensions of SD (society, economy, and environment) (Lindgreen et al., 2020). Overall, the relation between the two multifaceted concepts is undecided and strongly depends on the interpretation of CE. However, recent literature focusing on CE indicators often considers SD to be the desired end goal of circular strategies (Corona et al., 2019), and states that, for CE to successfully support SD, all three dimensions of sustainability must be included (Kristensen & Mosgaard, 2020; Lindgreen et al., 2020).

The most modern translation of sustainability can be found in the SD Goals (SDG, 17 goals and 169 underlying goals), which the United Nations established in 2015. The following are especially important for the implementation of the CE (Niero & Rivera, 2018; Schroeder et al., 2019): SDG 6: clean water and sanitation; SDG 7: Affordable and clean energy; SDG 8: Decent work and economic growth; SDG 12: Responsible consumption and production, and SDG 15: Life on land. Now we have established the CE definition, we move on to the question how it is used in practice.

RESEARCH METHODOLOGY

The objective of this study is to give insight into the Gordian knot of measuring circularity and how the approaches are conceived in practice. To achieve this objective, a systematic literature review and a small number of explorative interviews are conducted. This multi-methodological research procedure, including two distinct phases, allows for reporting descriptive as well as thematic results. Analyzing and interpreting data through the combination of these two approaches gives the ability to triangulate the data to gain a multidimensional perspective (Foster, 1997) and, with that, increase the validity of the research.

The interviews and literature review were executed simultaneously, allowing for an iterative approach. Semi-structured interviews were conducted with practitioners (C-level managers in manufacturing and trade) (6), policymakers (2), and researchers (2) in order to determine underlying challenges and triangulate the results of the literature review. A systematic literature review approach was executed (Denyer & Tranfield, 2009; Gough et al., 2012), following the approach of Denyer & Tranfield (2009), which is used more often in the CE-domain (Batista et al., 2018; Bressanelli et al., 2019; Masi et al., 2017; Vegter et al., 2020). The approach consists of four steps (see Figure 1): 1. Screening, 2. Sampling, 3. Analyzing and Interpreting, and 4. Synthesis of the Findings. In the subsequent sections, these steps are described in more detail. The results are presented in the Findings section.

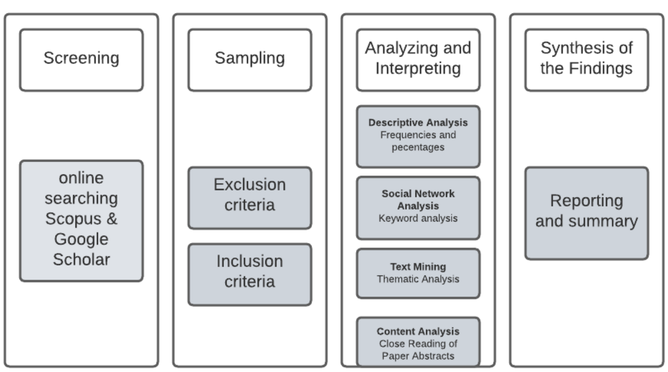

Figure 1: Systematic literature research design (Koseoglu & Bozkurt, 2018)

<u>1. Screening</u>

This study integrates two research domains: CE and performance. Based on these two domains, several search strings can be formulated to locate the widest possible set of related articles. Table

2 shows the search strings used. In order to identify the broadest possible set of related articles, the searches will primarily be executed in the Scopus database.[1] The search results are exported to Readcube Papers for further analysis.[2]

2. Sampling

To enable study selection and evaluation a set of inclusion and exclusion criteria of articles has been compiled. The inclusion and exclusion criteria are described in Table 1.

Table 1: In- and exclusion criteria for this literature review

Inclusion criteria	**Exclusion criteria**
- Articles written in English	- Articles written in other languages
- Peer-reviewed articles and conference papers	- Articles with emphasis Material Flow Analysis (MFA) and/or Life Cycle Analysis (LCA) only
- Articles related to the current state of art of measuring circularity and the adoption and implementation of circularity measurement in practice.	- Article only on sustainability - Etc.

Conference papers are included at this stage to review the latest development in the various domains.

3. Analyzing and Interpreting

The articles will be studied to find information related to measuring circularity, CE-performance, CE-metrics, and CE-assessment approaches. Following the steps Screening and Sampling, generates a start set of papers. This set is used to enter a backward and forward snowballing process following Wohlin (2014). The online tool Connected Papers is used to identify related relevant papers using artificial intelligence for both forward and backward snowballing[3]. Seminal start set articles are selected using the following criteria: # of citations, # of references, year of publication, journal, and similarity to origin (0-100).

4. Synthesis of the findings

The following section presents the results of the literature review triangulated with the input from the explorative interviews.

FINDINGS

There is a wide divergence in terms of assessment level, focus, developer of the method, and relationship with methods outside CE (Sacco et al., 2021). Also, it is important to notice that other terms are found to describe assessment tools, such as “measures”, “metrics”, ‘index”, or

[1] https://www.scopus.com/
[2] https://app.readcube.com/
[3] https://www.connectedpapers.com/

“indices”(M. Saidani et al., 2018). On measurement of CE at the micro level, the term ‘indicators’ has previously been used widely (Keeble et al., 2003; M. Saidani et al., 2018). However, some authors signal that a general understanding or definition of this term appears to be lacking (Kristensen & Mosgaard, 2020). Academic literature also interchangeably uses other terms for approaches to compress quantitative or qualitative information into manageable units. Examples include variable, parameter, measure, metric, measurement, dashboard, index, and framework (M. Saidani et al., 2018; Veleva & Ellenbecker, 2001). Most of them extend their scope beyond the traditional indicator as being a singular point of concentrated information. To capture the wide range of applied terms, Lindgreen et al. (2020) use the term ‘assessment approaches’.

For this study, in creating the reference set, all potential alternatives to performance are used. Table 2 presents the search strings and results for the Scopus database search (updated August 25, 2022).

Table 2: Scopus search results

Search string	# Of articles
TITLE ("circular econom*" AND performan*)	123
TITLE ("circular econom*" AND assessment*)	207
TITLE ("circular econom*" AND metric*)	13
TITLE ("circular econom*" AND maturit*)	9
TITLE ("circular econom*" AND measur*)	71
TITLE ("circular econom*" AND indices)	31
TITLE ("circular econom*" AND index)	31
TITLE ("circular econom*" AND indicato*)	87
TITLE ("circular econom*" AND framew*)	235
TITLE ("circular econom*" AND variabl*)	4
TITLE ("circular econom*" AND paramete*)	6
TITLE ("circular econom*" AND dashboa*)	1

All articles were exported into the Readcube Paper App. Duplicates were removed automatically. As can be seen, the strings are limited to TITLE only. Using a TITLE, ABSTRACT, and KEYWORD string delivers a multiple of articles of which the majority is not relevant for this study (e.g., focus on MFA and/or LCA).

In total 665 article were found applying the 12 search strings in Scopus and deleting duplicates.

The set of 665 articles is analyzed based on citations, references, year of publication, and journal. A small number of seminal articles related to the research questions is identified. For- and backward snowballing using Connected Papers is applied to identify additional articles. Table 3 presents the results of this iteration. As can be seen, saturation is reached after analyzing 6 seminal articles.

Table 3: Connected papers additions

Reference	Connected papers	Combined
(Sacco et al., 2021)	41	683
(M. Saidani et al., 2018)	41	704
(Kristensen & Mosgaard, 2020)	41	713
(Franco et al., 2021)	41	727

(Oliveira et al., 2021)	41	731
(Lindgreen et al., 2020)	41	731

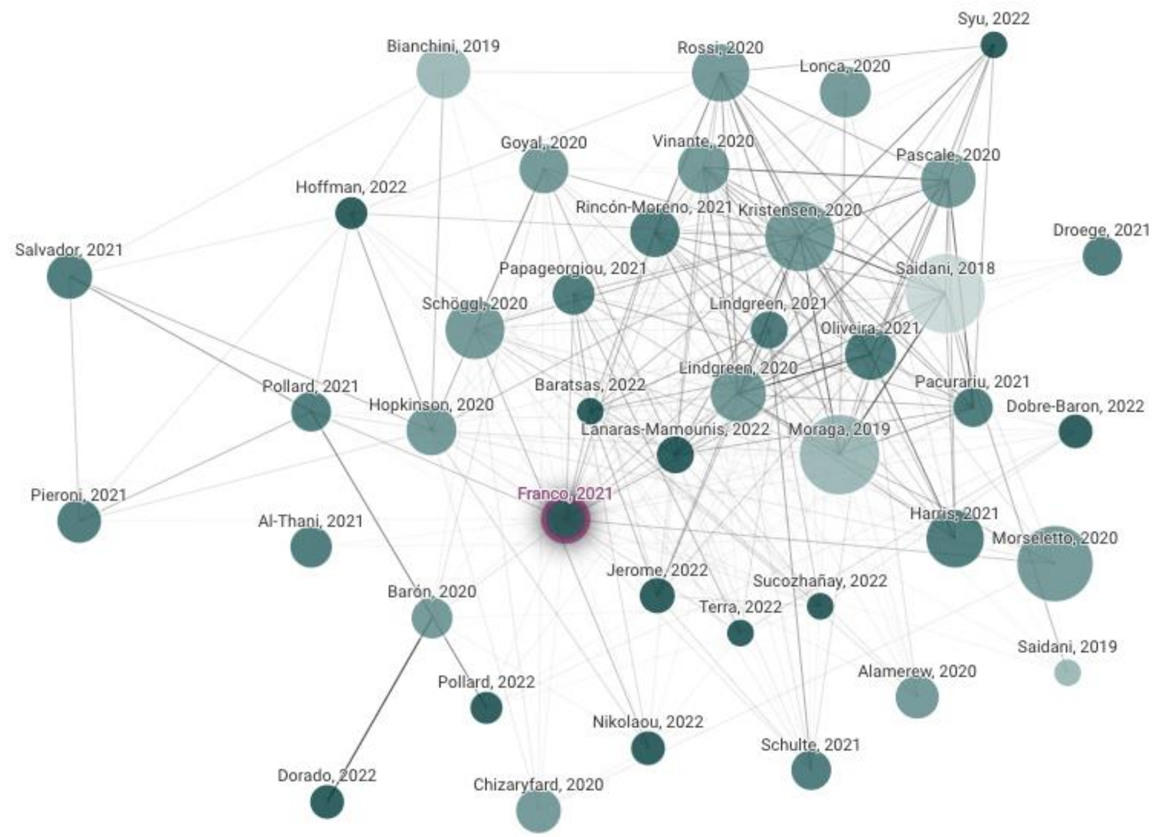

Figure 2: Connected Papers example - origin paper: Franco et al. (2021)

Legend: Papers are arranged according to their similarity.

The set of 731 articles is used for further evaluation[4]. While titles and abstracts are reviewed for the entire set, reviewing the complete body of literature is not within the scope of this study. Hence, not all papers found using the search terms were actively utilized for this study (Uhrenholt et al., 2022).

Measuring CE is necessary

Companies are using circular metrics to communicate with their customers (Oliveira et al., 2021). Moreover CE-assessment tools contribute to the advancement of the concept by facilitating information exchange, monitoring progress, inform decision-making, and improve circular business investment decisions (Lindgreen et al., 2020; M. Saidani et al., 2018). The absence of broadly accepted metrics can be described as a barrier to transitioning to a CE (Lindgreen et al., 2020). Tecchio et al. (2017) for example, note that “the absence of adequate metrics and standards

[4] https://lists.papersapp.com/7jpBslykvK6e

has been a key barrier to the inclusion of resource efficiency requirements" (p. 1533). Niero & Kalbar (2019) find that companies in the fast-moving consumer goods sector make limited use of performance indicators or quantitative CE assessments in their implementation of CE-related policies. Lindgreen et al. (2020) state that only a small fraction of investigated organizations presents a dedicated set of key performance indicators (KPIs) to their approach to CE. Among others, Dey et al. (2022) and Nasir et al. (2017) touch upon the importance of CE measurement tools by stating that to *"[…] enable and accelerate CE-transition driven by industry, integrative decision support tools to identify and tap potentials of CE-transition scenarios on company and inter-company level are necessary"* (p. 48). Summarizing, the field of CE-assessment has a low level of maturity, and the level of implementation of CE-assessment approaches by organizations appears to be limited. This forms a barrier to transitioning to a more circular—and sustainable—society (Lindgreen et al., 2020). Moreover, besides the above-mentioned developments, there is a strong scarcity of research in the field of CE from a multi-disciplinary perspective that facilitate real-life applications (Dey et al., 2022; Nasir et al., 2017).

CE-assessment level

The definition of CE invites us to consider the concept on different levels (Javaid et al., 2019). For example, the Circularity Gap Report initiative (CGRi) (*CGRi*, n.d.) calculates, generally accepted, levels of circularity on a macro level. Of the reference set of 731 articles, 14 articles explicitly address the macro level. CE-performance can generally be measured on three distinctive levels (micro - products, organizations, meso - industrial symbiosis networks, and macro-city, country, and beyond) (Y. Geng et al., 2012; Javaid et al., 2019; Lindgreen et al., 2020). The meso level is addressed by 13 articles. The micro level (addressed explicitly in 24 articles) can be defined as the complex structures of rules that constitute systems such as organizations (Dopfer et al., 2004, p. 267). This organization perspective of the micro level will still include many different levels of scale, such as manufacturing plants (Yong Geng & Doberstein, 2008), products (Kristensen & Mosgaard, 2020) or suppliers, producers, consumers, and designers (Bruel et al., 2019; Michael Saidani et al., 2019). To create a complete overview of available assessment approaches, (Lindgreen et al., 2020) argue that the micro level is considered to contain CE elements relevant to the decision-making context within organizations. This wide-ranging interpretation still includes products, business models, companies, and supply chains. Excluded from this scope are approaches focusing on eco-industrial parks (meso level) and cities, nations, and beyond (macro level).

While the various roles of actors moving towards a CE have not been formalized in literature, companies are expected to drive this transition (Lindgreen et al., 2020; Urbinati et al., 2017). Organizations are the entities that transform resources such as raw materials (natural capital) into goods and services (man-made capital) (Lindgreen et al., 2020). As the micro level has a broad scope, many metrics referred to as micro-level indicators do not cover the complexity of a CE and may lead to different interpretations of what this specific CE level is targeting during circularity assessments (Lindgreen et al., 2020; Oliveira et al., 2021). Therefore, (M. Saidani et al., 2017) introduce a new, product-centered term to the CE context, the nano level (discussed in 3 articles), which describes "the circularity of products, components, and materials, included in three wider systemic levels, all along the value chain and throughout their entire lifecycle" (Oliveira et al., 2021). In parallel, the systemic CE view provided by (Huamao & Fengqi, 2007; Niero & Rivera,

2018) shows that CE levels influence and interact with one another, i.e., the upper levels are based on the lower levels, which, in turn, orient their development (Oliveira et al., 2021).

Meta studies

Especially interesting is the number of articles with emphasis on 'review'. Over 12% of the articles (90 out of 731) focus on reviewing CE in relation to a performance-related construct. Strangely enough, given all the available tools, methods, and frameworks, none of the four interviewed C-level managers confirmed to be familiar with any of them. In that regard, the recent study by (Valls-Val et al., 2022), presenting an overview of approaches / tools that can measure the level of circularity of organizations (Figure 3) is of particular interest.

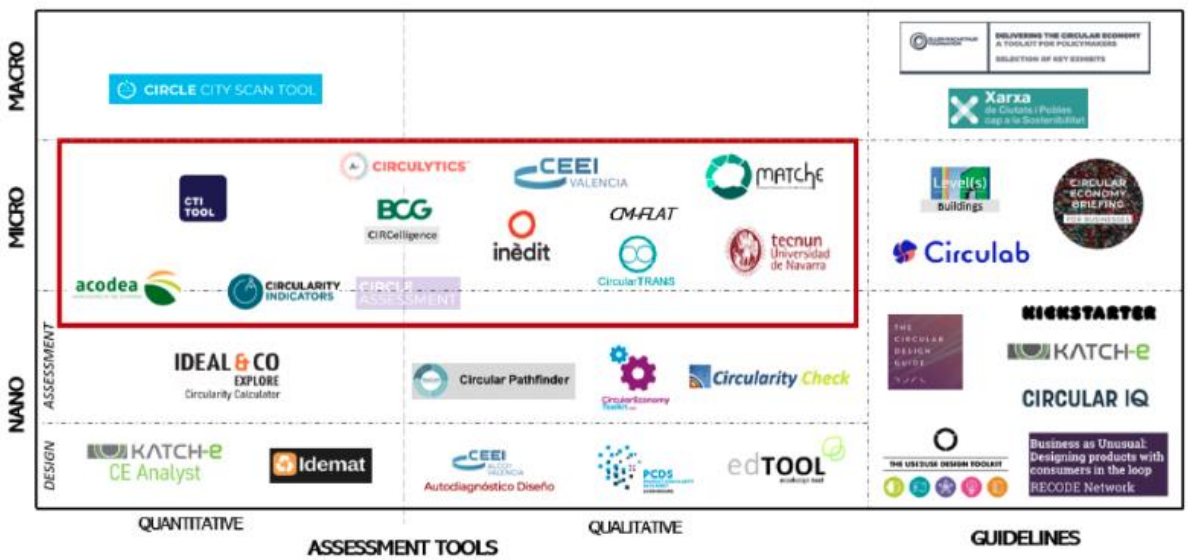

Figure 3: Existing tools for the assessment of the circular economy (Valls-Val et al., 2022)

This (to the knowledge of the author, most recent) study, follows a series of other meta-studies collecting and analyzing different approaches. Table 4 presents an overview of seminal articles on meta-studies presenting CE-assessment approaches.

Table 4: CE-assessment meta studies

Reference	Approaches	Characteristic
(Valls-Val et al., 2022)	12	Tools capable of measuring the level of circularity of organisations.
(Vinante et al., 2020)		Focus on 365 different organization level metrics, classified in 23 categories.
(Kravchenko et al., 2020)		Review and ex-ante classification of sustainability performance indicators for proactive CE-strategies assessment
(Kristensen & Mosgaard, 2020)	30	Focus on micro level, zooming in on 'CE categories' and connection to SD (SD) dimensions. Less attention for implementation perspective. Also includes grey literature.
(Lindgreen et al., 2020)	74	Newly constructed review framework, applying four review perspectives: A general, descriptive (methodological), normative (inclusion of SD/CE

		dimensions), and prescriptive (implementation-focused) perspective.
(Corona et al., 2019)	72	Zooms in on 'validity', 'reliability', and 'utility' of metrics, and connection to existing method-ologies (Life Cycle Assessment (LCA)/Material Flow Analysis (MFA), no focus on micro level.
(Moraga et al., 2019)	20	Introduces classification framework for CE indicators, both on macro- as well as micro level. Addresses different CE strategies captured by indicators.
(Parchomenko et al., 2019)	63	Applies Multiple Correspondence Analysis (MCA) to assess metrics. No distinction between different levels of assessment.
(Michael Saidani et al., 2019)	55	Proposes intricate taxonomy of indicators, applying 10 differentiation categories.
(Sassanelli et al., 2019)	45	Collects and reviews CE-performance assessment methods. Primary focus on methodological foundation. No specification of level of assessment.
(Elia et al., 2017)		Review, analyses, and comparison on how environmental assessment methodologies based on quantitative indicators are effective in measuring CE-strategies' level of application in companies, products and services.

Academic, Governmental and (Semi-commercial)

Resulting from analyzing the meta studies and reading abstracts of the 731-article reference set, a list of 82 micro level approaches on measuring circularity is created. Important to note is that this list is limited to academic approaches only. Consequently, when adding (semi-)commercially available tools, as mentioned e.g., by (Valls-Val et al., 2022), the number of available approaches grows to over 100. Conversely, not all these approaches are validated sufficiently, and some are lacking transparency. Furthermore, in addition to academic and semi-commercially developed approaches, a growing number of standards is created (ISO/CD 59004-59010-59020-TR 59031) (BS8001.2017) and will be implemented in the coming years (Niero & Rivera, 2018; Pauliuk, 2018; Sacco et al., 2021). In summary, if a company is interested in measuring circularity, there are about 125 different approaches to choose from that can be implemented.

Sector focus

Table 5 presents an overview of the sector focus within the reference set of CE-performance related articles. From this, we see significant emphasis on manufacturing and construction, some focus on chemical industry and hardly any attention for retail, wholesale, and fashion. In any case this is remarkable as e.g., the fashion industry is often presented as a sector with significant potential in contributing to improving circular performance (Ciccullo et al., 2019; Exalto-Sijbrands & Ravesteijn, 2021). Respondent 3, CEO of a wholesale organization, reflects: *"In discussions with my customers, I use my intrinsic motivation to become circular, to convince them to do the same. Does that count for my circular performance as well?"*

Table 5: Sector focus in CE-performance studies

Sector	# articles
Manufacturing	54

Building / construction	48
Chemical	22
Trade / wholesale	10
Fashion	4
Retail	1

Product focus

Traditionally, measuring circularity concentrates on a focus on material inflow and outflow. MFA and LCA are used as a reference. Of the reference set, 21 articles emphasize LCA and 4 have specific attention for MFA. On both topics, circular performance is measured by analyzing the product and the product life cycle in detail (e.g. (Eberhardt et al., 2020; Stijn et al., 2021). Though most approaches do have a broader scope, dealing with critical materials is one reason to include the material flow (Bullis & Mielke, 2019). This is confirmed in the interview with one of the policy makers (respondent 4) who stated that: "*measuring circular performance can only be done if detailed analysis up to the level of critical materials is within scope*."

CONCLUSIONS

After conducting a systematic literature review on CE and performance and triangulating the results with the outcomes of 8 explorative interviews, the following conclusions are formulated.

The Gordian knot that will keep us busy for some time

Although consensus on the necessity to measure circularity has been reached, the question "how" has not yet been answered unambiguously. Many possible approaches have been developed. New ones are added frequently. Respondent 6 states: *"we are reporting on circular revenue. However, discussions on the detailed metrics, will continue for some time"*

All studies presented in Table 4 reached the following two common conclusions: 1) The lack of consensus when evaluating CE strategies due to a large number of metrics/indicators/methods that exist, and 2) The need for standardized procedures to achieve an evaluation. The significant differences in the tools analyzed show the disparity in conceptions of what needs to be considered when assessing CE and the different understandings of the CE concept. The many different viewpoints and lack of consensus illustrate the complexity and multifaceted structure of the CE phenomenon. Solving this challenge decisively is like untying the Gordian knot, denoting a bold solution to a complicated problem. Even though new perspectives are introduced regularly, a common understanding and untying of the Gordian knot in due time is not to be expected.

Misconceptions and ignorance

Different from the analysis of the literature, in practice, SD and CE are perceived as synonyms. Motivated by the lack of clarity surrounding the CE-domain, the outcome of the interviews shows that the focus is on SD. Furthermore, interview outcomes and literature show ignorance of mainly SME companies. This is worrisome as SMEs account for over 90% of all business and over 50% of all pollution (Dey et al., 2022). For this reason, interview respondents report a variety of arguments for not putting CE on the agenda prominently: *"There is no customer demand"* (respondent 3); *"My CE ambitions are pushed back by governmental regulations / certifications"* (respondent 1); *"As CEO, I'm not convinced this is going to help our planet*" (respondent 1); *"I do like to be more ambitious but being profitable is the main driver*"(respondent 6); *"Scarcity of resources to make the plan happen*" (respondent 2). The chief outcome is that a significant gap between theory and practice is manifested. The companies presented in the articles are frontrunners and could serve as examples in the future.

And counting…

The review resulted in a long list of tools, models, assessments, frameworks, and methods. Without pretending to be exhaustive, the author database currently contains around 125 different approaches, developed from three different sources: academics/scholars, (semi)profit, and governmental organizations. Moreover, reading through research recommendations and interviewing researchers is not where it stops. Additional approaches (and with that, meta-studies) will become available.

Narrative on the micro level

Even though the definition of micro level seems clear, analysis of articles and interview results show differences. Between different assessment disciplines, various interpretations of the meaning of micro-level exist. An additional nano level is introduced to enable a clearer distinction. It is argued whether this extra level brings additional clarity. Moreover, when focusing on performance, a micro level is not just a single company; it also includes the phenomenon of supply chains. Subsequently, there is also the system or holistic perspective.

One size does not fit all

Most studies focus on manufacturing organizations. Some have no organizational focus. A limited number of studies highlight a specific type of company context. Studies on, e.g., the trade sector or logistics service providers, are limited. Zooming in the manufacturing organization, the one-size-fits-all does not apply, a contingency perspective is required. Analysis of the interviews of respondents from the manufacturing industries has shown that achieving circular ambitions differs in tier 1, tier 2, and OEM types of companies (Respondent 1: *"As a tier-2 supplier we must produce what is being told. There is no room for circular co-design or what-so-ever. How can we become circular"*. Future research will have to convert these differences into the respective models. Subsequently, accomplishing circular maturity also depends on the nature of a company. The literature analyses show a distinction between legacy and primarily CE-driven companies.

Limitations of this study

By shedding light on the wide variety of articles discussing the measurability of CE, we argue that this study contributes to the foundation of untying the Gordian knot and its appropriate use in practice. While the extant literature review includes many articles, the number of explorative interviews available in this study for triangulation is limited. Nevertheless, these interviews have provided significant added value. Hence, for future research, expansion of the interviews is planned. Subsequently, detailed qualitative analysis of the interviews using coding techniques is recommended and planned as well. Ultimately, it is expected that more detailed results will appear on the (un)willingness to measure circularity.

Recommendations for further research

In essence, for an individual company to stand up and declare their respective level of circularity is still far away. The extant literature provides a significant number of models, frameworks, and methodologies. However, amongst scholars, consensus on universal deployment is not reached. Available commercial and semi-commercial tooling is not very widespread. It is recommended to continue studying in more detail the major concerns for SME companies not to start measuring circular performance. The outcome of this work generates insight into sense-of-urgency / awareness regarding adopting measuring circularity. Remember that, for some, sense of urgency will only come once measuring circularity is mandatory as part of e.g., ISO certification. Moreover, concerning limited availability of knowledgeable people within most SME companies, future approaches require a significantly lower threshold for usage and deployment. In any case, profit must be recognized and accepted as the main driver. Quoting a simple statement from respondent [2]: 'with being circular, you cannot buy bread at the bakery. Finally, the number of peer-reviewed articles on measuring circularity from a holistic or system perspective is still limited. Nevertheless, analysis has indicated that taking a broader perspective is promising. Of course, becoming circular is focusing on material in- and outflow. Equally important, however, is having an eye for all other processes and leakages. Therefore, the domain of process maturity concerning circularity seems promising and deserves attention. At the same time, the broader perspective additionally offers opportunities to connect with the lean philosophy. To the best of our knowledge, research, where the lean philosophy is used to increase circular performance and untie the Gordian knot, is still limited.

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