IIIEE Theses 2023:07

Circularity indicators in practice

Exploring companies' application and linkages to sustainability

Emilia Paredes Bassi

Supervisor

Emma Johnson

Thesis for the fulfilment of the
Master of Science in Environmental Management and Policy
Lund, Sweden, May 2023

Published in 2015 by IIIEE, Lund University, P.O. Box 196, S-221 00 LUND, Sweden,
Tel: +46 – 46 222 02 00, Fax: +46 – 46 222 02 10, e-mail: iiiee@iiiee.lu.se.

ISSN 1401-9191

Acknowledgements

Thank you to Emma, my supervisor, for her invaluable support and excellent advice throughout the thesis process and the steps leading to it. Thank you also to my professor Philip Peck, for discussing early ideas with me. Thank you to my peer feedback group and our guiding professor Jessika Richter.

Thank you to the Chilean organisation promoting the use of circularity indicators, and everyone who participated in the questionnaire and interviews; for generously taking the time to provide valuable insights and share their inspiring perspectives with me.

Thank you to Ignacio Cobo for sharing his ideas and listening to mine, and to him, Rodrigo Mujica, and Marina Hermosilla, for helping me in the process of finding my empirical cases.

Thank you to Maxi for his companionship and care through this entire experience, and to all my family and friends for being there.

Abstract

The Circular Economy (CE) has gained global recognition as a way to enable sustainability improvements in production and consumption systems. Numerous circularity indicators (c-indicators) have been developed by academia and practitioners to be used at the company level as analytical tools to measure progress towards a more circular economy. Nevertheless, there is a lack of empirical evidence on their practical adoption. At the same time, it is unclear how c-indicators interrelate to sustainability assessment and sustainability goals. Through inquiry of practitioners' experiences, this study explores companies' perspectives regarding the use of c-indicators. In particular, the study identifies purposes that c-indicators can help fulfil, factors that have influenced the application of c-indicators, and linkages between c-indicators and sustainability assessments. The study gathered data from practitioners within company settings and external expert organisations through a questionnaire and semi-structured interviews. The main findings of the study are threefold. First, they indicate that c-indicators have offered valuable support mainly to monitor and improve circularity performance and facilitate learning processes within companies. Second, the factors that most influence companies' application of c-indicators relate to data availability and management; new knowledge, skills, and resources; and the ability to generate internal and external alignment around the concept of CE and the relevance of assessing circularity. Lastly, given the novelty of c-indicators, circularity assessment, and the integration of circular strategies, various perspectives coexist regarding how the concepts of circularity and sustainability interrelate and how these linkages are reflected in assessment practices. Based on these findings, practitioners and academia are recommended to: i) When making decisions based on c-indicators' results, it should be clear to companies what falls within the scope of applied c-indicators, and what circular strategies or circular criteria are beyond their scope and should also be considered to ensure selected actions best contribute to improved performance; ii) work towards overcoming data challenges and lack of coordination within companies and across value chain actors; iii) further advance the streamlining of data collection and calculation processes that feed into both circularity and sustainability assessment; and iv) clarify the linkages and differences between circularity goals and sustainability goals, to facilitate the interpretation of assessments and the operationalisation of circularity and sustainability.

Keywords: circular economy, circularity indicators, circularity assessment, sustainability assessment, industry

Executive Summary

Background, research aims and approach

In the search for solutions that can advance sustainability efforts, Circular Economy (CE) has gained global attention. To aid the implementation of CE at a micro-level, academia and practitioners have highlighted the need to assess companies' progress in implementing circular strategies. Circularity indicators (c-indicators) have been recognised as analytical tools to measure such progress, and they may become increasingly relevant as regulatory pressures for verified progress and data sharing increase in the realm of CE.

Numerous c-indicators alternatives have been developed by academia and practitioners to be used at the company level, but there is a lack of empirical evidence on their practical adoption. Particularly, there are few documented users' perspectives regarding purposes that c-indicators help to fulfil and factors that may influence their suitability and successful adoption. These insights are relevant to tailor c-indicators towards users' needs, as well as to provide the right support to companies which are adopting them for decision-making. At the same time, it is still unclear, both conceptually and in practice, how c-indicators interrelate to sustainability assessment and sustainability goals. That is to say, how these c-indicators fit within the broader landscape of sustainability assessments and goals, and how companies link and differentiate circularity progress and sustainability impact from circularity initiatives. Thus, there is a need to investigate companies' actual experiences with c-indicators to contribute to advancing the operationalization of the CE at the company level.

Considering the aforementioned insights, this thesis aims to explore how companies use c-indicators developed by practitioners and the linkages they perceive between c-indicators and sustainability assessments. The research questions (RQs) addressed in this thesis are the following:

- **RQ1:** What purposes do circularity indicators provide for companies?
- **RQ2:** What factors influence the application of circularity indicators in companies?
- **RQ3:** What are the linkages between circularity indicators and sustainability assessment in companies?

The research design follows a qualitative exploratory approach, combining deductive and inductive strategies. The study gathers data from practitioners within company settings and external expert organisations through a questionnaire and semi-structured interviews. Insights were obtained from 9 companies through the use of the questionnaire, followed by interviews with 5 companies and 6 expert organisations. The data analysis involved a deductive-inductive coding procedure, identifying the first key elements from the literature review which were complemented with emergent topics.

Main findings

RQ1: What purposes do circularity indicators provide for companies?

The use of c-indicators by companies has been found to be beneficial for monitoring performance, establishing appropriate targets, and guiding actions towards a circular economy. The use of c-indicators also facilitates learning processes and cultural changes. To a lesser extent, c-indicators are also recognised for their support of external communication and identification of opportunities for collaboration. The ability of c-indicator frameworks to provide a broad and systemic picture of CE is a feature that stands out in all the benefits associated with their use.

RQ2: What factors influence the application of circularity indicators in companies?
In terms of factors influencing c-indicators' use, companies face challenges associated with data collection and management, which leads to cumbersome processes and the need to rely on assumptions in certain cases. At the same time adopting c-indicators frameworks can provide guidance to identify relevant data needs, and the implementation of technology is recognised as an opportunity to address increasing needs to assess and report simultaneously about various topics.

Having appropriate knowledge, skills, and resources was also mentioned as a necessary factor, which includes a clear understanding of CE and its scope, and acquiring the knowledge required to interpret metrics' results and suggest actions. In this sense, ensuring training transversally within a company is highlighted. As with data issues, while successfully using c-indicators requires new skills and resources, adopting these types of frameworks also facilitates learning and common understandings within and across companies.

From a broader perspective, data-related challenges and demands for new knowledge, skills, and resources are related to the systemic nature of CE. **The application of c-indicators requires new types of internal and external alignment among business units and actors**. Internal practices highlighted to ensure alignment needed for circularity assessment include establishing interdisciplinary teams; integration of experts and targets transversally across business units; and providing guidance so business units can easily connect metrics and targets with tangible tasks. In turn, to incentivise external alignment with value chain actors, setting clear criteria and targets for procurement is needed, as well as facilitating providers' provision of new data, for example through Environmental Product Declarations.

Lastly, the **current lack of standards in the realm of c-indicators is highlighted as an obstacle to better implementation** of c-indicators and their decision-making support. Practitioners from expert organisations highlighted the issue, noting that common definitions and standards are much needed for companies' application of c-indicators, as otherwise issues regarding framework selection, comparability, coordination, and good practice sharing become difficult. ISO standards on Circular Economy currently under development may provide some support in this matter.

RQ3: What are the linkages between circularity indicators and sustainability assessment in companies?
This question was approached from the perspective of situating c-indicators in the broader context of companies' assessment practices, identifying if circularity assessment and sustainability assessment are differentiated, exploring linkages in data use, and inquiring about the assessment of sustainability impacts from circular strategies.

Companies have in place various assessment and reporting approaches beyond c-indicators, such as GRI reporting standards, GHG protocol, SDGs, as well as other systems developed internally. Companies do not seem to agree on the goals that these approaches serve, in terms of whether they mainly provide information about sustainability, circularity, or both. Interestingly, more companies using the CTI framework perceived it as being useful for measuring both circularity and sustainability. In contrast, based on the definitions presented in this thesis and the indications in its user guide, CTI is focused on measuring intrinsic circularity only.

While some overlaps were found in the scope between other assessment approaches and c-indicators, the latter provides a novel perspective of assessment based on a

systemic view, offering insights that can point to new areas to be managed and improved within companies. Furthermore, **there are interactions in data use between c-indicators and other assessments, particularly with carbon footprint accounting**, which for companies recently adopting c-indicators appears to facilitate their calculation. This seems logical as carbon emissions quantification was established earlier. **In a company case with circularity and sustainability assessment procedures established earlier, findings indicate that circularity assessment and sustainability assessment are seen as complementary aspects of an integrative evaluation framework.**

CE is seen as a tool to achieve more sustainable outcomes, while also being included within sustainability as an environmental aspect. In this sense, **circularity initiatives are often managed as one component of environmental sustainability strategies.** In practice, companies' perspectives suggest **c-indicators and associated targets are intended to support circularity improvements as a desirable final environmental outcome.** Nevertheless, basing decisions on c-indicators' performance may lead to circularity improvements that are not necessarily considering whether the chosen course of action improves economic, environmental, and social performance

When explicitly asked, companies acknowledge that there is a difference between verifying circularity performance and final sustainability impacts. This conversation was focused on the environmental dimension, even though the interaction with economic and social aspects is also recognised. In practice, companies tend to correlate resource-related indicators, such as the ones included in their c-indicator frameworks, to positive environmental performance. Thus, an important point highlighted in this thesis is that caution should be exercised when drawing environmental implications from c-indicators' performance. One company with a more mature approach illustrates a way in which to address this. When assessing and managing circularity performance; other "complementary assessments" are also conducted in the scope of the project or operations analysed, to keep track of more final impacts in emissions and water.

Conclusions and recommendations

The findings of the thesis have enabled the elaboration of several reflections which may be informative to those developing c-indicators, as well as those using them, evaluating their adoption, or supporting others in their use. Some highlighted reflections are presented below.

1. C-indicator frameworks can shape how companies talk about and work with CE

Companies have reported that c-indicators support learning by providing a common and structured language and scope for CE. Thus, it is important that companies manage enough information to avoid overlooking relevant CE aspects not directly addressed by the specific c-indicator frameworks they may be using. These aspects could relate to circular strategies not covered by the framework, or the recognition that not all circular strategies are equally valuable in terms of sustainable impact, which may not be visible in the frameworks.

2. Actions are needed to overcome data challenges and ensure external and internal alignment

Influencing factors highlighted in this study signal areas where companies and those supporting them can focus to ensure successful c-indicator application. Private sector networks can enable discussions regarding data exchange between companies and highlight good practices in data management to accelerate digitally enabled decision-

making. Technology solutions providers can consider examples of data management challenges imposed by CE's systemic nature in the use of c-indicators. Companies can develop training initiatives and integrate experts where needed, promote interdisciplinary teams, and develop internal guidance tools to connect c-indicators and targets to business units' realities.

3. There are opportunities to streamline data collection and management for circularity and sustainability impacts

Identification of potential and existing interactions in information flows between c-indicators and sustainability impact assessment can support practitioners in generating more streamlined data structures. Through time, if circularity assessment becomes an established practice, comprehensive data gathering may serve as input to calculate not only specific c-indicators but also inform carbon accounting, LCAs, and other sustainability impact quantification.

4. There are opportunities to further clarify the linkages and differences between circularity goals and sustainability goals

Most companies in the study tend to rely on informed assumptions to link circularity performance to positive effects on carbon footprint. Nevertheless, a lack of more systematic verification may result in overlooking trade-offs and being unable to quantify the actual impact of an initiative. In time, companies can develop concrete procedures associated with circular strategies to account for impacts and trade-offs. While it is important to acknowledge potential sustainability trade-offs associated with circular strategies, recognising their importance should not lead to obstacles or inaction towards promoting circular strategies that can help realise more sustainable practices.

Table of Contents

List of Figures

List of Tables

Abbreviations

CE	-	Circular Economy
CSRD	-	Corporate Sustainability Reporting Directive
CTI	-	Circular Transition Indicators
C-indicators	-	Circularity Indicators
DPPs	-	Digital Product Passports
EBITDA	-	Earnings before interest, taxes, depreciation, and amortisation
EMF	-	Ellen McArthur Foundation
EPR	-	Extended Producer Responsibility
ESPR	-	Eco-design for Sustainable Products Regulation
EU	-	European Union
GHG	-	Green House Gas
GRI	-	Global Reporting Initiative
KPI	-	Key Performance Indicator
LCA	-	Life Cycle Assessment
LCC	-	Life Cycle Costing
MFA	-	Material Flow Analysis
S-LCA	-	Social Life Cycle Assessment
SASB	-	Sustainability Accounting Standards Board
SBTi	-	Science Based Target initiative
SDGs	-	Sustainable Development Goals
SMEs	-	Small and Medium Enterprises
WBCSD	-	World Business Council for Sustainable Development

1 Introduction

Existing production and consumption systems have impacts leading to interconnected environmental and social issues (Reid et al., 2010). Calls for action to transform systems towards more sustainable approaches have been voiced for decades from several standpoints of society (IISD, 2012). In the search for solutions to face these challenges and advance sustainability, the concept of Circular Economy (CE) has emerged, which has received increasing attention from policymakers, researchers, and companies. CE can be understood as a system in which production, distribution and consumption processes incorporate strategies such as reducing, reusing, recycling, and recovering materials in replacement of the 'end-of-life concept', operating at the micro (products, companies), meso (industrial parks) and macro levels (city to global scale) (Kirchherr et al., 2017).

CE has been recognised and leveraged by policy decision-makers. While different levels of maturity can be observed, there is a global trend in countries across all continents advancing CE-related policy agendas (Weick & Ray, 2022). The EU has positioned itself as a frontrunner in this topic, releasing a Circular Economy Action Plan for the first time in 2015, which was updated in 2020 (*Circular Economy Action Plan*, n.d.). Furthermore, the European Green Deal- a package of policies to support the transition towards carbon neutrality by 2050 (*A European Green Deal*, 2021)- recognises the Circular Economy Action Plan as an agenda that aims at accelerating the changes required towards achieving its goals (European Commission, 2020).

CE has been advocated to enable the creation of economic value while reducing the pressure of activities on the environment and society, providing a direction to follow in efforts towards sustainability (Ellen MacArthur Foundation, n.d.). It is worth noting that despite CE being often presented as a practical solution to achieve sustainability, the relationship between the concepts has been found to lead to both synergies and trade-offs (Geissdoerfer et al., 2017).

To aid the implementation of CE at a micro level, academia and practitioners have highlighted the need to assess companies' progress in implementing circular strategies (Valls-Val et al., 2022). Internal assessments can help companies gain insights about their circularity performance (Franco et al., 2021; Khitous et al., 2020; Saidani et al., 2019), as well as supporting the verification of environmental, social, and economic impacts from circular strategies (Corona et al., 2019; Das et al., 2022; Harris et al., 2021), and the exchange and communication of information (DNV, 2021; Serna-Guerrero et al., 2022). Furthermore, companies' assessment choices can play a role in shaping CE as a concept, by emphasizing certain properties and influencing the language associated to it (Parchomenko et al., 2019).

There are various ways to understand assessment approaches to CE at the micro level (Cagno et al., 2023; Negri et al., 2021; Roos Lindgreen et al., 2020; Valls-Val et al., 2022). In a company's transition towards implementing circularity, distinct assessment tools may be needed, which vary in functions, objectives, and relevant stages of application; spanning from qualitative checklists to complex life cycle assessments (LCAs) (Chen et al., 2020). Despite heterogeneity when discussing circularity assessment, it is possible to identify a widespread interest on the development and analysis of what can be conceptualized as circularity indicators (Corona et al., 2019; De Pascale et al., 2021; Parchomenko et al., 2019). The term circularity indicator can be abbreviated as c-indicator, following terminology suggested by Saidani et al. (2019).

Based on de Oliveira et al. (2021), c-indicators can be defined as analytical tools to measure the degree of association of a system with advancing CE. C-indicators have received increasing attention from both academia and practitioners (Roos Lindgreen et al., 2020; Saidani et al., 2019), and a great number of indicators to support circularity at the company level have been developed (Cagno et al., 2023; Chrispim et al., 2023).

C-indicators may become increasingly relevant as regulatory pressures for verified progress and data sharing increase in the realm of CE. For instance, in early 2023, the EU Corporate Sustainability Reporting Directive (CSRD) entered into force (*Corporate Sustainability Reporting*, n.d.). This directive explicitly included 'resource use and circular economy' as one of the factors in which information should be reported (*Directive (EU) 2022/2464*, n.d.). Furthermore, the European Commission's current proposal of the 'Eco-design for Sustainable Products Regulation (ESPR)' considers the introduction of Digital Product Passports (DPPs), which are seen as a key tool to enable circularity by providing clear and common requirements, traceability, information for decision making, target setting and verification of compliance (BCG & WBCSD, 2023). The importance of assessing circularity is also reflected in global standardisation efforts through the current development of the standard ISO323 in Circular Economy. This standardisation looks to define key terminology and common frameworks to implement, measure and assess circularity in companies, as well as to facilitate product data exchange (*ISO/TC 323 - Circular Economy*, n.d.).

In this context, advancing knowledge about the application of c-indicators at the company level becomes relevant to gain insights into critical aspects that need to be addressed to ensure that data and assessments can effectively support a transition towards a CE that contributes to more sustainable outcomes. These insights can serve as input for the aforementioned regulatory and standardisation efforts, as well as for academia and practitioners who are already advancing these developments.

1.1 Problem definition

Despite a prolific emergence of c-indicators, research on use cases is still scarce and requires more development (Chrispim et al., 2023; Kristensen & Mosgaard, 2020; Negri et al., 2021; Roos Lindgreen et al., 2020, 2022; Saidani et al., 2019). The use cases that have been documented in the literature have mostly focused on testing indicators and tools which have not yet been practically adopted by companies (Cagno et al., 2023; Kravchenko et al., 2020a; Nika et al., 2021). Thus, these are rather validation exercises with company data or preliminary insights on potential use. Due to the lack of empirical evidence, not much is known about the expected and actual benefits linked to c-indicators' application from users' perspectives, as well as insights from actual experience regarding factors that may influence c-indicators' suitability and successful adoption (Roos Lindgreen et al., 2020).

Additionally, previous studies have highlighted the need to further advance knowledge and procedures to link circularity and sustainability assessments (Harris et al., 2021; Kristensen & Mosgaard, 2020; Negri et al., 2021; Opferkuch et al., 2022; Saidani et al., 2022; Stewart & Niero, 2018; Walker et al., 2022). This relates to a broader topic of discussion around CE and its links with sustainability (Cagno et al., 2023; Geissdoerfer et al., 2017). There is limited information on how companies engaged in circular transitions and using assessment tools such as c-indicators link these approaches with their sustainability goals and assessments (Opferkuch et al., 2022; Roos Lindgreen et al., 2022).

Furthermore, c-indicators have been developed with no clear standards and guidelines (Roos Lindgreen et al., 2021). This results in a highly fragmented set of options, which is argued to

hinder c-indicators' adoption and their ability to support transformations (Kristensen & Mosgaard, 2020; Roos Lindgreen et al., 2021). In this scenario, early evidence has shown that c-indicators developed by practitioners- either externally by organisations or internally by companies- have been more highly adopted than those developed by academia (WBCSD, 2018). This situation points to the importance of carrying out more research particularly about c-indicators developed by practitioners, given their higher adoption, which arguably suggests they are more likely to be impactful for companies and could also contribute to reducing fragmentation issues. In fact, two non-academic organisations who have developed c-indicators for companies, namely the Ellen McArthur Foundation (EMF) and the World Business Council for Sustainable Development (WBCSD), are participating in the standardisation efforts for measuring and assessing circularity through ISO (*ISO/TC 323 - Circular Economy*, n.d.)

The rapid development in the field of CE and c-indicators calls for frequent updates to gain accurate insights of companies' transitions and application of tools (Saidani et al., 2019), which adds to the relevancy of carrying out further research in this area. Additionally, a narrow scope in terms of geographies, sectors and company size has also been highlighted by previous research studying c-indicators and links with sustainability at the micro level (Opferkuch et al., 2022; Walker et al., 2022), which gives relevancy to studies that add insights from diverse settings.

Summarising, the relevance of assessing circularity has been widely voiced by academia and practitioners. The effort to advance circularity assessment has materialized to a great extent in the emergence of c-indicators that can be adopted by companies. Nevertheless, there is little knowledge about companies' application experience of c-indicators, thus benefits and challenges from users' perspectives remain scarcely documented. Additionally, it is still unclear, both conceptually and in practice, how c-indicators interrelate with sustainability assessment and goals. That is to say, how these c-indicators fit within the broader landscape of sustainability assessments and goals, and how companies link and differentiate circularity progress and sustainability impact from circularity initiatives. In this context, investigating companies' actual experiences with c-indicators developed by practitioners- which are already more adopted than those developed by academia- may provide an opportunity to advance knowledge regarding the two aforementioned issues, and in turn, contribute to advancing the operationalization of CE at the company level.

1.2 Aim and Research Questions

The previous section highlights the need to learn more about companies' perspectives and experiences regarding the use of c-indicators. Through inquiry of practitioners' experiences with c-indicators, this thesis will contribute through two research aims. First, it aims to explore insights gained from the actual adoption of c-indicators at company level, regarding purposes fulfilled and factors influencing their application. Second, it aims to explore what are perceived and practical linkages between c-indicators and sustainability assessment in companies. The research questions addressed in this thesis are the following:

RQ1: What purposes do circularity indicators provide for companies?

RQ2: What factors influence the application of circularity indicators in companies?

RQ3: What are the linkages between circularity indicators and sustainability assessment in companies?

The study can help inform companies that currently use or are planning to use c-indicators, and those developing or seeking to contribute to the field of circularity assessment and sustainability assessment, about: i) factors that should be considered for c-indicators to contribute to their expected purposes and the ability of companies to make use of them, and ii) good practices and challenges that could be considered and addressed for the integration of c-indicators in overarching assessment practices of companies, particularly to ensure desired connections with sustainability assessment and goals. More generally, by studying companies' experiences with c-indicators, it is possible to obtain a relevant illustration of how circularity and sustainability are being operationalized and interrelated in companies. This can help advance knowledge not only for the development and adoption of c-indicators in particular but also to understand broadly how companies can work with assessment approaches in an increasingly complex context regarding circularity and sustainability activities, as well as ever more demanding expectations for performance measurement and reporting in these areas.

1.3 Scope and Delimitations

The thesis focuses on the use of c-indicators developed by practitioners, as opposed to those developed by academia. As explained in section 1.1, the former type of c-indicators has been shown to already be more adopted, thus providing better opportunities to study nuanced experiences and to identify insights that may apply in other contexts. The perspectives gathered come from companies that are applying c-indicators, as well as from other practitioners in expert organisations who support businesses in implementing CE and c-indicators.

The companies selected for the thesis operate in Chile and are all large companies. It is worth noting that large companies in the context of this study are defined following the classification used by the National Labour Agency in Chile, by which large companies are those that have more than 200 employees (Dirección del Trabajo, 2021). Large companies in Chile are relevant as they employ around 58% of workers in the country according last available data by the National Labour Agency (Dirección del Trabajo, 2021). Thus, their actions and strategies can have significant impacts in the national context.

Eight of the nine companies in the study are using a set of c-indicators developed by an external private sector association, which they started adopting in late 2021. One company is using an internally developed set of c-indicators, which they have been progressively adopting for 6 years approximately. Since the aim of the thesis is not to compare these two sets of c-indicators but to obtain illustrations of practical use, it was deemed valuable to include both perspectives as they can provide insightful lessons, even if the number of companies participating was not equal for each set of c-indicators. Nevertheless, it is important to acknowledge this difference to be aware that some patterns may arise across both types of experiences, while other perspectives or lessons may be more particular to each.

Despite the selection of Chile as a specific geography in which participating companies are operating, the study does not apply a contextual lens for the analysis. That is to say, the focus of the study is not on particular characteristics of the Chilean context which may have implications for the use of c-indicators. Nevertheless, the consideration of companies operating in Chile may contribute to validating, enriching, or contrasting insights found in European-centred literature. Furthermore, the author has a closer connection to Chile, which facilitated the access to potential participants and to interpret information more easily with a level of contextual knowledge.

Perspectives from both Chilean and European practitioners from expert organisations who are supporting companies in implementing circular strategies and c-indicators were considered.

The consideration of local and foreign perspectives was deemed valuable as selected practitioners have different types of expert knowledge, which enriches the analysis and discussion. The Chilean perspective provides a closer contextual connection to the companies in the study, while the European perspective may have a closer contextual connection to leading CE developments happening in this geography. Additionally, due to her background, the thesis' author could more easily access these two types of experts. Finally, as in the case of having perspectives coming from Chile, the addition of European experiences may contribute to validating, enriching, or contrasting insights and experiences in the Chilean context.

It is worth noting that the results' structure and narrative are more heavily guided by the companies' experiences. In this sense, other practitioners' perspectives tend to complement or contrast the views of companies. At the same time, most perspectives correspond to Chilean practitioners, thus the results may be more relevant to the country's reality. Nevertheless, this does not necessarily imply these companies' contexts and perspectives do not share similarities with companies in other geographies that are going through similar circular transitions.

1.4 Ethical Considerations

This is an independent and unfunded thesis project conducted without external influence other than the supervisor's guidance. Participation in interviews and the questionnaire was voluntary and conducted with prior informed consent. Participants were informed in written form about the study's goals and planned use of information. Their permission was also asked to record and transcribe the interviews. To account for potential confidentiality or reputational issues, participants and their organisations are kept anonymous. Collected data was securely stored on the author's personal cloud.

1.5 Audience

The outcomes of the thesis can be useful for academics seeking to contribute to the field of circularity and sustainability assessment, by pointing into relevant areas for further research regarding the development of c-indicators and support for their adoption at company level, which can guide circular transitions that contribute to more sustainable outcomes. The results can also be useful for practitioners, particularly current and potential users of c-indicators, and those developing indicators or seeking to contribute to the fields of circularity and sustainability assessment; by providing actionable insights and suggestions that can facilitate the development or uptake of indicators.

1.6 Disposition

This thesis is structured in 7 chapters. Chapter 1 introduced the research background and specific research problem, aims and questions, along with the scope, ethical considerations, and audience. Chapter 2 presents key concepts needed to study c-indicators, as well as a conceptual framework generated from selected literature components, which guides the overall study. Next, Chapter 3 presents a more in-depth literature review encompassing previous empirical insights, factors influencing c-indicators' use, and the interaction with sustainability assessment. Chapter 4 outlines the research design and specific methods used for data collection and analysis, which are used to generate the findings presented in Chapter 5. Chapter 6 elaborates on discussion points, linking the findings to previous literature and reflecting on the studies' contributions and limitations. Finally, chapter 7 provides conclusions emerging from the study, as well as practical implications and directions for future research.

2 Conceptual Foundations

This section provides the fundamental concepts and descriptions to study and discuss c-indicators in company settings. The section is divided into two parts. First, key concepts needed to discuss c-indicators are introduced, followed by a conceptual framework focused on characterising c-indicators.

2.1 Defining Circularity Indicators

As outlined by Chen et al. (2020), companies can be supported in their transition towards implementing circular strategies by utilizing several analytical tools that facilitate the assessment of their circular initiatives. These tools vary in objectives and relevant stages of application. In their study, exemplified tools include qualitative checklists, case studies, business model canvas, material flow analyses (MFAs), LCAs, and the application of circularity indicators (Chen et al., 2020). Within this heterogeneous landscape of alternatives regarding circularity assessment, a widespread interest in the development and analysis of circularity indicators has been highlighted by previous reviews (Corona et al., 2019; De Pascale et al., 2021; Parchomenko et al., 2019).

To define circularity indicators, it is useful to first have a clear understanding of CE as a concept. Furthermore, to explain how CE materialises in specific actions, the term circular strategies will also be introduced below. Finally, based on the understanding of CE and circular strategies, the concept of circularity will be presented and applied to indicators.

This study will follow the CE definition provided by Kirchherr et al. (2017, p. 229), which was based on the review of 114 previous definitions, and thus it is considered a comprehensive conceptualisation effort. CE is defined as:

> An economic system that replaces the 'end-of -life' concept with reducing, alternatively reusing, recycling, and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity, and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers. (p. 229)

Furthermore, following the work by Nußholz (2017), the term 'circular strategies' can be used to encompass all actions that replace the "end-of-life" concept in the previous definition; namely reducing, reusing, recycling and recovering materials. It is also worth noting from the definition that CE operates at various scales, conceptualised as 'micro', 'meso' and 'macro' levels, which comprise from products to the global scale. Thus, circular strategies can also be applied at different scales.

Furthermore, 'circularity' can be defined as "the alignment of a material or energy flow, product, processes, or system to a set of CE strategies (…) that meet the general CE goals" (de Oliveira et al., 2021, p. 456). It is worth noting at this stage that circularity can be conceptualised as a property that is different from environmental impact (Linder et al., 2020). For instance, Saidani et al. (2019) suggest a distinction to recognise 'intrinsic circularity' and 'consequential circularity'. In essence, the first concept refers to resource recirculation, while the second refers to what are the effects that result from circularity (Saidani et al., 2019). In this context, environmental impacts would be an effect resulting from circularity. This distinction between circularity and impacts will be further explored in sub-section 3.3.

The definitions of circularity and circularity-related concepts are important due to many different understandings of such terms, specifically when connected with circularity indicators. In general terms, an indicator can be understood as "a quantitative or qualitative factor or variable that provides a simple and reliable means to measure achievement, to reflect changes connected to an intervention, or to help assess the performance of a development actor" (OECD, 2014, p.13). Aligned with the previous definition, de Oliveira et al. (2021) derive that circularity indicators are "analytical tools focused on measuring the degree of association of a system (or part of one) to practices and strategies applied to develop a CE further. In that sense, higher circularity means that a specific item or system is closer to achieving the goals set by the guiding standards of a CE" (p. 456).

It is worth mentioning that oftentimes literature utilises encompassing terms such as assessment approaches (Roos Lindgreen et al., 2020), measurement tools (Valls-Val et al., 2022), assessment tools (Chrispim et al., 2023), measurement methods (Linder et al., 2017; Moraga et al., 2019), performance measurement systems (Cagno et al., 2023; Negri et al., 2021), and monitoring evaluation tools (Saidani et al., 2019) as interchangeable terms referring in practice to c-indicators. Furthermore, terms such as metric, variable, measures or index are oftentimes used as synonyms of indicators, or as conveying a similar meaning in terms of the way in which they support the analysis of CE (de Oliveira et al., 2021; Kristensen & Mosgaard, 2020; Parchomenko et al., 2019; Roos Lindgreen et al., 2020). Regarding these somewhat interchangeable terms, Saidani et al. (2019) note that the term "indicator" has been more commonly used in literature and can provide a better understanding. According to this idea, this study will use the term circularity indicator (c-indicator).

Lastly, it is worth noting that the term "framework", in the context of indicators, can be used to refer to a purposefully set of indicators that altogether provide a comprehensive picture of what is being analysed (Gudmundsson, 2003). Carlsson et al. (2022) have referred to the same concept as an "indicator system". In this thesis, the terms "framework", "indicator framework", and "set of indicators" are therefore used interchangeably.

2.2 Conceptual Framework for C-indicators

A great number of c-indicator frameworks have already been developed by both academia and practitioners (Corona et al., 2019; De Pascale et al., 2021; Parchomenko et al., 2019). Based on eight selected academic reviews analysing different frameworks, a synthesis of how c-indicators have been characterized can be found in Figure 2-1. The table on top of the figure presents the academic reviews considered for this analysis, showing the number of c-indicators critically reviewed in each of them. The table at the bottom is a synthesis of ten categories derived from the academic reviews to characterise c-indicators.

Selected Reviews of C-indicators

Reference	Number of c-indicators reviewed*
Corona et al. (2019)	19 sets of metrics
Moraga et al. (2019)	20 sets of indicators
Saidani et al. (2019)	55 sets of indicators
Roos Lindgreen et al. (2020)	74 assessment approaches
Kristensen y Motgaard (2020)	30 sets of indicators
Negri et al. (2021)	74 contributions
Vinante et al. (2021)	365 firm-level metrics
Chrispim et al. (2023)	34 tools

**Terms as referred in paper (metrics, indicators, etc)*

Categories to Characterise C-indicators

Category	General description	Further explanation and examples
Scale	At what level of analysis are the c-indicators used	Micro: Company or product level Meso: Industrial level Macro: National or global level
Transversality	Sector specific or generic	Indicators are sector specific, or can be used across sectors and activities
Type of metric	What type of metrics or data are being used	E.g., Continuous or ordinal; Percentage or physical unit
Methodological aspects	Connections with existing methodologies for calculation or new methodological developments	E.g., using LCA or MFA
Temporal focus	Retrospective or prospective	Retrospective: assess past performance Prospective: asses future performance
Source of development	Who developed the c-indicators	Academia, companies, other practitioner organisations
Purposes	What are the potential purposes that c-indicators can fulfil	Monitor performance and set targets, common language, support communication, facilitate data exchange
Circularity strategies assessed	What type of CE strategies can the c-indicators be applied to	E.g., maintaining and prolonging value, remanufacturing/reusing, and recycling
Usability	Factors that influence the practicality and usability of the indicators in practice	E.g., identification of organisational units involved, consideration of participatory approaches for frameworks' development
Integration of sustainability impacts	Assessment of only circularity vs integration of effects associated with it	A framework may be composed of indicators to measure circularity only or it can include indicators to assess economic, environmental, and social impacts

Figure 2-2-1. Conceptual Framework

Source: Own elaboration based on literature synthesis

The first category refers to the scale at which the indicators can be applied, which is recognised by several authors (Corona et al., 2019; Moraga et al., 2019; Negri et al., 2021; Roos Lindgreen et al., 2020; Saidani et al., 2019; Vinante et al., 2021). This category can be described through the same scales of action outlined by Kirchherr et al. (2017) in the definition of CE. Based on these scales, c-indicators are developed to assess circularity at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation

and beyond). As introduced in the previous section, this study focuses particularly on micro-level c-indicators and use cases. In terms of the indicators' scale, it is noted that important linkages exist between the company level and industrial systems for circularity efforts. Thus, it has been advocated that c-indicator frameworks that integrate these two levels may provide better guidance to allocate resources to the most impactful initiatives (Chrispim et al., 2023; Negri et al., 2021). While some efforts exist in this aspect, most c-indicators tailored to companies have a firm perspective only (Chrispim et al., 2023; Negri et al., 2021). It is also found that c-indicators targeting companies are often straightforward to use when evaluating products, but if the goal is to assess the whole company's circular performance, it is not clear how to scale them up (Negri et al., 2021).

The second category, transversality, reflects whether indicators are sector-specific, or they can be used indistinctly across sectors and activities (Negri et al., 2021; Roos Lindgreen et al., 2020; Saidani et al., 2019). The third category, metric type, refers to the type of metrics that are used to carry out an assessment (Corona et al., 2019; Kristensen & Mosgaard, 2020; Moraga et al., 2019; Negri et al., 2021; Saidani et al., 2019; Vinante et al., 2021). Within this category, there are various features different authors focus on, ranging from whether the metrics are qualitative or quantitative (Saidani et al., 2019), to the type of measurement units used, for instance, if they present information in percentage terms or as absolute units (Kristensen & Mosgaard, 2020; Moraga et al., 2019). For example, from the review by Vinante et al. (2021), a metric in percentage terms would be the percentage of recycled materials/components in products.

In turn, the fourth category, methodological aspects, indicates what type of methodology is used to calculate the value of an indicator (Negri et al., 2021; Roos Lindgreen et al., 2020). These could be established methodologies such as LCA or MFA, but it could also be newly developed methods. Regarding calculation methodologies, it has been shown that similar metrics from different c-indicators frameworks may yield disparate results regarding circular performance (Roos Lindgreen et al., 2021; Saidani et al., 2022). Thus, different choices of the c-indicator frameworks may result in different guidance for decision-making.

The indicators can be used to assess past or future performance, which is captured in the fifth category referred to the temporal focus (Saidani et al., 2019). While some indicators have been explicitly proposed to assess either future or past performance, in the review by Saidani et al. (2019), it is noted that identified c-indicators with an explicit focus on past performance could also be applied to forecast hypothetical performance.

The sixth category refers to the indicators' source, i.e., if they were developed by academia or practitioners (Kristensen & Mosgaard, 2020; Roos Lindgreen et al., 2020; Saidani et al., 2019). The latter category covers both indicators developed internally by companies as well as frameworks developed by other types of non-academic organisations. An example of a c-indicator framework developed by academia for the micro level is given by Pollard et al. (2022), who generated a set of c-indicators for the electrical and electronic sectors. In turn, two examples of c-indicator frameworks developed by practitioners are the EMF Circulytics tool (Ellen McArthur Foundation, 2022), and the WBCSD Circular Transition Indicators (CTI) (WBCSD, 2021). As outlined earlier, this study focuses on c-indicators developed by practitioners.

The seventh category refers to indicators' potential purposes. One first evident purpose is to monitor circular performance (Kristensen & Mosgaard, 2020; Linder et al., 2017; Saidani et al., 2019; Serna-Guerrero et al., 2022) and based on results, set quantitative targets in order to obtain improvements (Saidani et al., 2019). C-indicators can also facilitate the use of a common

language around CE, based on the properties outlined by frameworks (Parchomenko et al., 2019). They can also support external communication to stakeholders (Linder et al., 2017; Roos Lindgreen et al., 2022), and facilitate data exchange among actors in value chains (Serna-Guerrero et al., 2022). Lastly, c-indicator frameworks can provide information that is useful to verify the environmental, social, and economic effects arising from circular strategies (Cagno et al., 2023; Roos Lindgreen et al., 2022; Serna-Guerrero et al., 2022).

The eighth category refers to what circularity strategies can be assessed with the indicators (Chrispim et al., 2023; Kristensen & Mosgaard, 2020; Moraga et al., 2019; Saidani et al., 2019). The specific list of strategies varies depending on the concepts chosen by each review, but it refers to, for instance, whether a set of indicators can assess strategies encompassing maintaining and prolonging value, remanufacturing/reusing, and recycling (Saidani et al., 2019). In terms of circularity strategies assessed by existing frameworks, it is highlighted that they tend to focus on the closing of material cycles (Chrispim et al., 2023; Parchomenko et al., 2019), associated to lower level circular strategies like recycling and resource efficiency (Parchomenko et al., 2019). This is considered a weakness, as focusing on only certain strategies can lead to decisions that create a burden-shifting (Corona et al., 2019). Related to this, it is noted that in general c-indicators do not aid in the prioritisation of strategies according to their ability to support value preservation (Chrispim et al., 2023; Corona et al., 2019; Parchomenko et al., 2019). This means, for instance, that the consequences of downgrading materials are not reflected in the indicators (Corona et al., 2019), and the greater benefits of other strategies such as value retention and longevity are not captured (Parchomenko et al., 2019). Related to c-indicators' scope, another factor that many times is not evaluated in c-indicators is the scarcity or criticality of materials (Chrispim et al., 2023; Corona et al., 2019).

Category nine, usability, captures the importance of considering factors that influence the practicality and usability of c-indicators. For instance, Roos Lindgreen et al. (2020) note that connections between academia and practitioners regarding the practical implementation of CE assessment approaches are lacking; in terms of understanding companies' needs and contexts and including human and organisational aspects. Vinante et al. (2021) also refer to organisational aspects, highlighting the need to involve all areas of a company to measure circularity performance, which is reflected in the fact that certain metrics can be thought of as impacting various business functions. Stakeholder engagement in the development and application phase of tools has also been highlighted as a factor to be considered to increase the usability of c-indicators (Chrispim et al., 2023; Roos Lindgreen et al., 2022; Saidani et al., 2019). Lastly, in order to promote and guide the uptake of c-indicators by companies, Saidani et al., (2019) highlight the importance of showcasing best practice examples and fostering experimentation with c-indicators in real scenarios.

The last category, integration of sustainability, refers to whether c-indicator frameworks assess sustainability-related impacts (Chrispim et al., 2023; Corona et al., 2019; Kristensen & Mosgaard, 2020; Moraga et al., 2019; Negri et al., 2021; Roos Lindgreen et al., 2020; Saidani et al., 2019; Vinante et al., 2021). That is to say, whether a framework is composed of indicators to measure circularity only (i.e., related to materials and resources), or if it also includes indicators to assess economic, environmental, and social impacts resulting from the application of circular strategies.

It should be noted that the syntheses presented in table 2 aim to be indicative and non-exhaustive. Likewise, it should be noted that in practice authors do not always refer to the same category by the same name, and differences can be found in the way they apply certain criteria.

The following section will focus on synthesising literature that explicitly addresses c-indicators at the micro level, and that dives deeper into a selection of topics related to the RQs. It should be noted that in some cases, referenced studies also address c-indicators beyond the micro scale, but sources have only been considered if their findings are explicitly relevant to this scale.

3 Current Knowledge on C-indicators: Application and Linkages with Sustainability

This section presents the synthesised literature review for selected topics related to RQs. Section 3.1 outlines empirical perspectives that are relevant to the use of c-indicators. Then, section 3.2 provides a structured review of specific factors that can influence c-indicators' application, found in critical reviews and conceptual discussions. These two sections expand mainly in the category "usability" presented in the conceptual framework.

Section 3.3 introduces the conceptual discussion about the linkages between CE and sustainability, and how this applies in the context of assessment approaches. Based on this, section 3.4 then provides empirical insights regarding the linkages of circularity assessment to sustainability assessment and goals. These two sections expand mainly on the category "integration of sustainability impacts" presented in the conceptual framework.

3.1 Insights from use-cases

Empirical insights regarding the application of c-indicators in real scenarios are not extensive, not the least because their uptake by companies is quite recent. In this context, apart from presenting the findings of two studies particularly focused on circularity assessment, this section provides three additional perspectives that can provide direction to learn about c-indicators' use in practice: i) tests and validation exercises, ii) companies' reporting practices, and iii) sustainability indicators' literature.

Regarding empirical studies on c-indicators application, the closest insights come from two studies. Droege et al. (2021) focused on the co-development of c-indicators with the Portuguese public sector, but the inputs may be valuable for the exploration of company cases. They stress the importance of sector-specific c-indicators to facilitate assessments and contribute to the evolution of the CE concept in particular contexts. Generic c-indicator frameworks may not be relevant for all contexts, or they require methods of assessment that are too complex and thus unfeasible to apply. Additionally, the balance between capturing complexity and remaining user-friendly was also an encountered challenge. From their case, it is suggested that selected c-indicators must be constantly tested and readjusted, progressively increasing complexity as companies gather more data and knowledge. Lastly, stakeholder engagement is discussed, as those participating in their case voiced the need to include users in the development of metrics for a successful implementation, in terms of acknowledging sector specificity and user friendliness.

The second empirical study that is more closely related to c-indicators application is provided by Roos Lindgreen et al. (2022), who collected insights from European companies that are considered frontrunners in CE implementation, inquiring about their circularity assessment practices, and identifying benefits and barriers associated with it. The most common perceived benefits associated with conducting some type of circularity assessment were improving and optimising CE strategies, marketing and reputation, and reporting to stakeholders. Perspectives on barriers were obtained from companies that are currently not conducting circularity assessments. Among others, highlighted barriers are complex assessments, lack of standards and benchmarks, and limited internal capacities. This paper covers to some extent topics similar to the ones addressed in this thesis. Nevertheless, they did not focus particularly on the application of c-indicators and did not explore barriers encountered in practice, as barriers were only discussed with companies who stated not applying any kind of assessment.

As introduced above, another source of insights that can be connected to c-indicators' use in practice corresponds to validating exercises, which have been conducted to test proposed c-indicators, frameworks, or supporting tools. Nevertheless, these types of studies sometimes are constrained to calculating c-indicators' results with real company data, without including users' perspectives (Cayzer et al., 2017; Saidani et al., 2017; Veleva et al., 2017). Others capture users' insights but refer to hypothetical use, not actual implementation. To name some examples, Cagno et al. (2023) generated a framework with pre-selected circularity, sustainability and industrial symbiosis indicators and discussed its potential usability with companies. The main issue identified was that the framework could be too complex, in terms of the number of indicators considered, as well as the data needs required, especially when referring to supply chain aspects. Nika et al. (2021) carried out a participatory approach to validate the relevancy of c-indicators with expert practitioners, being able to rank them to aid their selection in the Water-Energy-Food- Ecosystems nexus. Negri et al. (2021) reviewed papers focused on the validation of proposed c-indicator frameworks, finding that they usually consider a limited number of case studies, and many have a narrow focus in terms of sector, geography, or company size; thus, strong empirical validations are lacking.

Furthermore, another perspective connected to empirical insights comes from the assessment of companies' reporting efforts. In this context, it has been noted that improvements are needed for the communication of CE-related topics as no consistent data or narratives are used for this and provided information remains mostly unquantified (Dagiliene et al., 2020; Fortunati et al., 2020; Ibáñez- Forés et al., 2022; Opferkuch et al., 2022) In this sense, Opferkuch et al. (2022) found that companies often address CE by simply linking the term to sustainable development goals (SDGs), or commit to targets without reporting measured progress. In terms of topics addressed in reporting, it is noted that end-of-life management and sourcing strategies are the most covered topics, while circular products and business models are less addressed (Stewart & Niero, 2018). Along the same line, for half of the companies assessed by Opferkuch et al., (2022), the concept of CE is used in relation to waste and resource management issues only, while for the other half the CE meaning goes beyond these issues; which calls for more attention to CE hierarchy. These findings resemble the critical reviews made of available c-indicators' scope, as outlined in section 2.2.

Lastly, some empirical learnings from the use of sustainability indicators are collected which may inform the topic of c-indicators' application. For instance, Park & Kremer (2017) contribute to the discussion around specificity vs generality of indicators, as they evidenced that companies in their study assessed indicators' utility- conceptualised as usefulness and practicality of indicators- differently depending on their industry sectors and market locations. For the authors, this finding supports the idea that indicators should be tailored to a company's reality to facilitate implementation, and they should be categorised according to these criteria to facilitate their selection by companies, based on their empirically evaluated utility level. Furthermore, they note that in general, more empirical inputs are needed to understand what is perceived as useful and practical by companies, as these aspects may be impacting their decision to use indicators or not. Their results also show that indicators with a higher adoption rate are those that are easy to understand, measure, and calculate, such as those referring to material use. On the contrary, indicators that require sophisticated knowledge and techniques for measurements and data collection are the least adopted, such as ozone depletion and acidification potential. These findings relate to data availability and skills, which are required to calculate more sophisticated indicators.

Also in the realm of sustainability indicators, Trianni et al. (2019) concluded from studying companies' perceptions, that the ideal number and type of indicators measured varies

according to company characteristics, which needs to be considered in efforts to develop standardised frameworks that still consider different needs among companies, which remains a challenging task. For instance, SMEs tend to measure fewer indicators due to limited resources.

3.2 Factors Affecting C-indicators Application

This section presents more in-depth and structured insights regarding factors that can influence companies' uptake and use of c-indicator frameworks. These insights have been generated mainly by authors who have conceptually reviewed existing c-indicators' alternatives.

3.2.1 Fragmentation

Micro-level c-indicators exhibit a high level of fragmentation (Corona et al., 2019; De Pascale et al., 2021; Kristensen & Mosgaard, 2020; Moraga et al., 2019; Saidani et al., 2019; Valls-Val et al., 2022; Vinante et al., 2021). This brings as a consequence a lack of broadly accepted and standardised c-indicators (De Pascale et al., 2021; Parchomenko et al., 2019; Roos Lindgreen et al., 2021; Valls-Val et al., 2022). Roos Lindgreen et al. (2021) note that this fragmented landscape of c-indicators with an absence of common standards and definitions hinders the ability of companies to adopt them and obtain meaningful insights from them. First, because it does not allow for consistent results across users for comparison (De Pascale et al., 2021). It also makes it confusing for companies to navigate the options (Kristensen & Mosgaard, 2020; Negri et al., 2021). Additionally, it does not support the validation and verification of CE efforts (Kristensen & Mosgaard, 2020).

High fragmentation is reflected in how diverse the alternatives of c-indicators are. This diversity is present in different aspects. One of them is indicators type, where alternatives range from stand-alone single indicators to composite indexes, to indicator frameworks (Ibáñez-Forés et al., 2022; Kristensen & Mosgaard, 2020; Roos Lindgreen et al., 2021). Another source of diversity is found in the calculation methods (Kristensen & Mosgaard, 2020; Roos Lindgreen et al., 2021; Vinante et al., 2021). Additionally, the focus of analysis also varies, as some c-indicators are conceived to focus on one circular strategy, whereas others focus on circularity as a whole or can be applied to different strategies (Ibáñez- Forés et al., 2022; Kristensen & Mosgaard, 2020; Parchomenko et al., 2019; Roos Lindgreen et al., 2021). Lastly, c-indicators also vary in their consideration of sustainability impacts in their measurements (Kristensen & Mosgaard, 2020; Vinante et al., 2021). This last issue will be further explored in section 3.3. In general, fragmentation is suggested to be a consequence of different understandings regarding the CE concept (Corona et al., 2019; Kristensen & Mosgaard, 2020), and what is considered as part of CE assessment (De Pascale et al., 2021).

Related to the issue of fragmentation, it has been noted that while many tools have been developed by academia to assess circularity, they have not been adopted in practice by industry (Das et al., 2022; Roos Lindgreen et al., 2022). At the same time, preliminary insights have shown that c-indicators developed by practitioners- either externally by organisations or internally by companies- have been more highly adopted than those developed by academia (WBCSD, 2018).

3.2.2 Business Reality

Another relevant aspect that influences the application of c-indicators is the consideration of companies' reality, as this affects their needs and ability to conduct assessments. Thus, attention should be paid to the level of maturity that companies have attained regarding CE topics (Negri et al., 2021), geography (Negri et al., 2021), business sector (Roos Lindgreen et

al., 2022), and assessment priorities (Chrispim et al., 2023). In this sense, it is advised that c-indicators are tailored to each business's needs, while also ensuring certain common bases (Negri et al., 2021; Neri, 2021; Roos Lindgreen et al., 2022).

Regarding industry sectors, Chrispim et al. (2023) note that most existing metrics are better suited to assess manufacturing companies and product levels, while alternatives for the service sector are scarcer. When considering the level of maturity regarding CE topics, Negri et al. (2021) note that c-indicator frameworks can start with few metrics for new CE adopters. As companies make progress, increasing their resources and competencies, then frameworks can be expanded as they become more manageable. It is also highlighted that different c-indicators and frameworks may be needed simultaneously or complement each other (Chrispim et al., 2023; Saidani et al., 2019). This coexistence can help address different assessment purposes and phases of activities, as well as overcome identified weaknesses of specific c-indicators (Chrispim et al., 2023), but it is not yet clear how to combine different options in practice (Saidani et al., 2019).

3.2.3 Complexity vs user-friendliness

Another relevant challenge related to applicability is how to balance the indicators' ability to represent realistic scenarios- which can be highly complex- while ensuring indicators are simple enough to be practically used (Chrispim et al., 2023; Kristensen & Mosgaard, 2020; Negri et al., 2021). In the sustainability assessment literature, a related reflection was provided by Park & Kremer (2017), who propose two dimensions of the utility of an indicator, composed of its usefulness (how valuable the indicator is for the company) and its practicality (how costly and timely it is to learn and implement the indicator). In this regard, Saidani et al. (2019) emphasize the importance of ensuring that c-indicators are easily understandable and that the information they provide can be readily translated into actionable insights and recommendations. Furthermore, it is noted by Chrispim et al. (2023), that the level of usability and simplicity of different c-indicators or frameworks cannot be stated in general terms, as different business contexts and users with various skill levels will assess alternatives differently. Thus, which alternative fits better in a specific scenario needs to be defined in practice

3.2.4 Knowledge, Skills, and Subjectivity

Users' knowledge and skills are important factors for the application of c-indicators. An understanding of the CE concept and its principles is needed, as well as having the capacity to collect the data and calculate the metrics (Chrispim et al., 2023; Saidani et al., 2019). In this sense, clearly defining potential users and their needs, and involving them in the process of developing c-indicators and calculation tools can help increase their ability to use them (Chrispim et al., 2023).

Additionally, it is noted that for the correct use and interpretation of c-indicators, explicit definitions should be provided to the users regarding what is CE, its principles, and what each indicator is actually measuring (Chrispim et al., 2023). Related to this, it is important to deal with subjectivity and ensure a verifiable level of quality through for instance cross-checks and evidence back-ups, as c-indicators calculation require companies to self-assess (Chrispim et al., 2023).

3.2.5 Data Issues

Another discussed aspect is the role of data in the calculation of c-indicators (Chrispim et al., 2023; De Pascale et al., 2021; Saidani et al., 2019). This is currently considered a barrier, given that ensuring the proper availability, quality and volume of data requires great resources,

interaction between different business actors and addressing confidentiality issues (Serna-Guerrero et al., 2022). In this scenario, it has been suggested to advance collaborative efforts to ensure availability through open and standardised data banks (Serna-Guerrero et al., 2022). Related to the data challenges, the potential of digital technologies has also been noted to facilitate data management, communication and optimal decision-making (Chrispim et al., 2023; Saidani et al., 2019).

3.2.6 Supporting Tools for C-indicators Use

Research has also focused on suggesting procedures or tools to aid the selection and application of available circularity assessment approaches, including c-indicators. For instance, based on their categorisation of 55 selected C-indicators, Saidani et al. (2019) proposed a tool which can help practitioners identify indicators that are more relevant in their context, through a fillable Excel file. Franco et al. (2021) developed a measurement framework, which includes six phases that an organisation can follow to calculate and analyse their circularity performance. The framework considers specific decision-making methodologies to identify and select existing C-indicators, based on companies' value propositions and circular strategies. Cagno et al. (2023) also developed a measurement framework by pre-selecting indicators which integrate sustainability, CE and industrial ecology paradigms and can be used at different scales and types of companies. From assessing current alternatives, Chrispim et al. (2023) conclude that these types of complementary tools that support the selection of indicators, provide guidelines, help identify opportunities and provide successful cases could be further developed.

3.3 C-indicators Linkages to Sustainability

This section approaches the discussion about c-indicators' interrelation with sustainability assessment and goals. To do so, it first introduces the linkages between CE and sustainability as concepts. Then, it outlines how interactions between sustainability and CE are considered in critical reviews of c-indicators. Finally, it provides perspectives regarding further integrations of c-indicators and sustainability assessment proposed by literature.

3.3.1 Conceptual Linkages Between CE and Sustainability

The academic discussion about the commonalities and differences between CE and sustainability has been quite prolific in the last few years. While there are numerous definitions for sustainability (Geissdoerfer et al., 2017), the concept is often associated with balancing economic, environmental and social dimensions (Kristensen & Mosgaard, 2020). The Brundtland report provides a widely accepted and common understanding regarding sustainable development, which is defined as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 41).

As shown in the review by Geissdoerfer et al. (2017), sustainability and CE have been shaped by literature in a way that they share similarities and exhibit differences. Among others, they share similarities in terms of integrating intra and intergenerational interests, emphasizing global scale issues and the importance of coordination, and including non-economic aspects into development. In turn, they have been distinguished among other aspects in their origins, goals, prioritised aspects, and perceptions of responsibilities. Lastly, the authors find that different types of conditional, beneficial and trade-off relationships have been used to describe the relationships between the concepts, ranging from seeing CE as the main solution to more sustainable systems to CE having potentially negative effects in relation to sustainability.

The "trade-off" type of relationship introduced above highlights the fact that some actions may increase circularity but create negative impacts from a sustainability perspective (Walzberg et al., 2021). This is reflected for instance in rebound effects. These have been conceptualised as a risk of circular strategies, which can cause differences between expected and realised environmental benefits (Zink & Geyer, 2017). If circular strategies are not displacing primary production in absolute terms, then environmental benefits are reduced (Zink & Geyer, 2017).

A stream of literature has stressed the perspective that circularity should be promoted only under the condition that it contributes to the three pillars of sustainability; environmental, economic and social (Corona et al., 2019; Negri et al., 2021; Roos Lindgreen et al., 2020). In that sense, there is a perception that strategies aimed at increasing circularity should also be monitored regarding their contribution to sustainability performance (Das et al., 2022; Opferkuch et al., 2022; Stewart & Niero, 2018; Walker et al., 2022). That is to say, to what extent do these strategies result in environmental, social, and economic changes. It is worth noting that some definitions of CE integrate this perspective (such as the one presented in this thesis), but most definitions proposed up to 2017 did not incorporate a comprehensive aim towards the three dimensions of sustainability, usually prioritising economic prosperity and in second place environmental quality (Kirchherr et al., 2017).

3.3.2 Existing Linkages Between C-indicators and Sustainability Assessment

Based on the discussion presented in the previous sub-section, researchers have analysed how potential synergic and opposing interactions between sustainability and CE should be considered for the development and use of circularity assessment, within which c-indicators are located.

The first important aspect to consider is the definition of sustainability assessment. According to Kravchenko et al. (2019), sustainability assessment aims to evaluate to what extent practices contribute to progress towards sustainability by improving the economic, social and environmental dimensions. In this context, the use of indicators to assess sustainability is one of the approaches that can be applied to detect, monitor, quantify, assess, and interpret the expected or actual sustainability impacts of systems or parts of them (Kravchenko et al., 2019).

In this scenario, Chrispim et al. (2023) note that c-indicators and sustainability indicators may overlap. For instance, c-indicators may address resource-efficiency qualities, which can also be found as an aspect covered in sustainability indicators (Kristensen & Mosgaard, 2020). Likewise, a sustainability framework may consider the ratio of reused components, which is also directly linked to circularity (Saidani & Kim, 2022). Moreover, the assessment of job creation may be considered within sustainability and circularity assessment (Cagno et al., 2023). From this analysis, it could be argued that the integration of certain aspects as part of achieving "sustainability", "circularity" or both, depends on the definitions used to understand each concept, its goals, and guiding principles. Additionally, in the context of measuring environmental sustainability, it can be understood that the assessment of aspects related to resource use provides an indirect and prelusive evaluation only, as the direct assessment of environmental aspects refers to impacts in earth systems through for instance CO2 emissions, ecosystem quality and acidification (Kristensen & Mosgaard, 2020). Similarly, even though c-indicator frameworks may measure resource efficiency, this aspect itself is not considered a circular strategy, as it does not affect flows and loops (Bocken et al., 2016; Kristensen & Mosgaard, 2020).

Despite the aforementioned overlaps and ambiguities, a key point of discussion regarding the application of c-indicators refers to the distinction between measuring intrinsic circularity and measuring the impacts arising from circularity (Roos Lindgreen et al., 2022; Saidani et al., 2019). In this sense, a c-indicator framework may consider only intrinsic circularity, while others may consider both aspects. In the latter case, some metrics in the framework would be resource-focused, to measure intrinsic circularity by assessing the closing and slowing of resource loops, while others may focus on economic, environmental, and social impacts that arise from implementing circularity. Moraga et al. (2019) refers to this as the distinction between measurement scopes, whether an indicator measures the physical properties of technological cycles or the sustainability effects arising from these cycles.

Some authors approach this discussion by reviewing whether existing c-indicator frameworks consider the integration of metrics specifically to measure sustainability impacts, or if they just measure intrinsic circularity (Kristensen & Mosgaard, 2020; Roos Lindgreen et al., 2020; Vinante et al., 2021). Authors conclude that a high number of identified c-indicator frameworks evaluate intrinsic circularity, without considering metrics for sustainability impacts (Roos Lindgreen et al., 2020; Saidani et al., 2019). The notorious underrepresentation of social aspects is highlighted in various studies (Cagno et al., 2023; Kristensen & Mosgaard, 2020; Roos Lindgreen et al., 2020; Saidani et al., 2019), while results vary in the level of inclusion of environmental and/or economic aspects. In general, the latter aspects are included with different levels of comprehensiveness and the way they are integrated may be related to more maturity of certain indicators through known standards (Kristensen & Mosgaard, 2020).

Roos Lindgreen et al. (2020) raise the question of whether it is worthwhile for an organisation to measure intrinsic circularity if this is not supporting a pathway towards sustainability improvements, and it may even pose the risk of shifting the focus from sustainable outcomes to resource-efficiency goals per se. Overall, there is an understanding that if c-indicator frameworks are only measuring intrinsic circularity- which may be seen sometimes as a proxy of environmental impact- there is a risk that they will drive action based on circularity only, without considering whether the chosen course of action improves environmental performance (Harris et al., 2021; Roos Lindgreen et al., 2022; Saidani et al., 2022). Moreover, Kristensen & Mosgaard (2020) highlight that if c-indicators include sustainability dimensions but give them disparate weights, then the focus for sustainability improvement may become too narrow. It is also noted that in general, indicators do not provide ways to prioritise CE principles according to their contribution to sustainability, which means they end up regarding all circular strategies as equal in terms of potential benefits (Kristensen & Mosgaard, 2020).

From another perspective, researchers have studied how c-indicators' results compare to other analyses such as LCA (Roos Lindgreen et al., 2021; Saidani et al., 2022) and sustainability indicators (Saidani et al., 2022), as a way to assess how useful c-indicators are to inform decisions regarding both circularity and sustainable performance. These studies show that different c-indicators may yield disparate results regarding circular performance (Roos Lindgreen et al., 2021; Saidani et al., 2022) and may not provide proper insights to assess environmental impact, thus being unable to offer a complete analysis (Roos Lindgreen et al., 2021; Saidani et al., 2022). For instance, Roos Lindgreen et al. (2021) tested c-indicators for circular products and found that in some cases, products that obtained a higher circularity performance using the c-indicators did not yield lower environmental impacts when using LCA. In this sense, LCA is seen as a much more comprehensive tool which may be better suited to provide a basis for assessment, on top of which more specific metrics can be added to quantify circularity efforts (Roos Lindgreen et al., 2021). Nevertheless, at the same time, LCA can be less practical due to its complex calculation methods and difficult interpretation

of results (Roos Lindgreen et al., 2021; Saidani et al., 2022); as well as difficulty in properly modelling and scoping circular systems (Roos Lindgreen et al., 2021). Related to this last issue, Kravchenko et al. (2020b) note the inability of LCA methodologies to correctly assess circular strategies based on sharing models or service-based provision of value.

3.3.3 Proposals for Further Linkages Between C-indicators and Sustainability

Authors have proposed solutions or procedures to address the need to comprehensively measure circularity performance and its associated impacts. As summarised by Saidani et al. (2022), as it is acknowledged that circularity does not ensure more sustainability per se, it is advocated that comprehensive procedures and frameworks should be established to ensure that the assessment of circular strategies monitors intrinsic circular performance complemented by the evaluation of sustainability impacts.

In this sense, authors have analysed how to use and combine existing assessment approaches and tools to ensure comprehensive assessments. For instance, some suggest that integrative frameworks should be developed, covering both circularity and sustainability impacts (Cagno et al., 2023; Kristensen & Mosgaard, 2020; Negri et al., 2021; Vinante et al., 2021). In this line, Cagno et al. (2023) developed an integrative framework with a collection of existing indicators to measure intrinsic circularity, industrial ecology and sustainability impacts. Furthermore, Kravchenko et al. (2019) inventoried suitable sustainability indicators developed by academia that can be applied to a range of circular strategies. From this, a step-by-step procedure to facilitate companies' selection of appropriate sustainability indicators for specific circular strategies was proposed and tested by Kravchenko et al. (2020a).

On a similar line, authors have suggested that c-indicators frameworks focused on intrinsic circularity can be complemented with existing methodologies such as LCA, Life Cycle Costing (LCC), and Social-LCA (S-LCA) to provide a comprehensive picture (Harris et al., 2021; Opferkuch et al., 2022; Roos Lindgreen et al., 2020; Saidani et al., 2019). In this sense, Roos Lindgreen et al. (2022) suggest that intrinsic circularity assessment can be seen as a precursor of sustainability assessment. Through streamlined data collection processes, circularity assessment can capture insights about resource flows which inform about circularity performance and can subsequently be used to calculate sustainability impacts. They note that this procedure can rely on current MFA-based methodologies combined with existing sustainability impact assessment methods.

Similarly, Harris et al. (2021) notes that both c-indicators (which are based on value or mass) and environmental indicators (which approach impacts on the environment) are needed to assess progress towards circular transitions. Using c-indicators as proxy indicators of environmental impact would simplify assessments, but for this the correlation between specific c-indicators and impacts need to be further mapped and understood (Harris et al., 2021)

3.4 Application of CE and C-indicators to Sustainability Goals in Practice

This section presents empirical insights that are most useful to understand practitioners' perceptions of linkages between CE, sustainability, and assessment practices.

Regarding the perception of CE and sustainability as concepts, insights collected by Walker et al. (2022) show that some practitioners understand CE as a tool to achieve sustainability. In turn, other practitioners do not necessarily differentiate between CE and sustainability,

highlighting that clarifying semantics is not as important as making progress and overcoming practical barriers (Walker et al., 2022). A subgroup of the latter perspective also sees CE as inherently sustainable and an evolution of the sustainability concept. On a similar line, Cagno et al. (2023) note that companies find it difficult to systematically distinguish between CE and sustainability.

Empirical inputs regarding how companies link and differentiate circularity assessment and sustainability assessment are scarce. From the perspective of analysing corporate reports, Opferkuch et al. (2022) find that information tends to be presented in a compartmentalised manner. Therefore, CE topics are not sufficiently connected to interconnected social, economic, environmental, and financial aspects. If linkages are made, they mostly remain within the impact of circularity in the environmental dimension. This is shown for example by the fact that CE topics are frequently only associated with SDG 12, which refers to ensuring sustainable consumption and production patterns (United Nations, n.d.).

From the perspective of sustainability assessment literature, Trianni et al. (2019) found a similar compartmentalisation issue as stated above, when studying the use of sustainability indicators by companies. Companies were not recognising the interrelations among the social, environmental, and economic pillars of sustainability. Furthermore, they observe that different companies classify indicators under different categories. For instance, indicators to measure resource consumption are considered to belong to eco-efficiency by some companies, while others relate them directly to the environmental dimension

In the case studied by Droege et al. (2021) in the Portuguese public sector, it is noted that the c-indicator framework co-developed with users as part of the study does not explicitly assess the impact of circular activities on sustainability. Rather, it is assumed that improved circular performance would increase sustainable outcomes. Acknowledging the risk of creating burden-shifting and rebound effects, the authors conclude that this c-indicator framework would need to be complemented by an assessment of the impact of circular activities on sustainability.

Roos Lindgreen et al. (2022) more explicitly focus on studying how companies are linking sustainability assessment and circularity assessment. In their sample of European companies who are frontrunners in the application of CE, they found that usually companies do not clearly distinguish between circularity assessment and sustainability assessment. Nevertheless, a majority of companies seemed to perceive sustainability assessment to have a wider scope, emphasising the social dimension and environmental aspects that are not directly related to resource use, and tended to agree that sustainability should be the final goal, and not circularity per se. It was also found that companies perceived a need for additional support to link circularity and sustainability indicators, and to correctly model and calculate impacts from circular activities. This paper covers to some extent topics similar to the ones addressed in this thesis. Nevertheless, in their study they did not know in advance which assessment practices the companies were using (if any), and most of their sample corresponds to CE frontrunners who are micro companies in the European context.

3.5 Summary of what is known about c-indicators

The literature review evidenced that more empirical insights are needed regarding the application of c-indicators in companies. It is acknowledged that a great focus has been directed to developing frameworks, while case studies to test or study the actual application of these remain low (Chrispim et al., 2023; Negri et al., 2021; Roos Lindgreen et al., 2022; Saidani et al., 2022). Thus, there is still not enough validation of the approaches and there is a lack of clear understanding of how specific c-indicators can be valuable for users (Chrispim et al.,

2023; Negri et al., 2021). As noted by Roos Lindgreen et al. (2020), it can be argued that CE assessment approaches only have value in the real world if they are actually applied. It is suggested that this lack of attention to actual implementation may be contributing to a low uptake by industry (Faludi et al., 2020; Roos Lindgreen et al., 2020; Saidani et al., 2022).
In particular, the motivations that companies have to adopt c-indicators and the benefits they can actually obtain from them need to be taken into consideration to facilitate their uptake (Roos Lindgreen et al., 2022). Likewise, more inputs are needed regarding factors that can affect companies' ability to make use of c-indicators; including barriers or limitations (Chrispim et al., 2023; Roos Lindgreen et al., 2022; Valls-Val et al., 2022). Within these factors, empirical insights about the type of resources and capabilities that are needed to be able to carry out the assessments are highlighted (Chrispim et al., 2023; Roos Lindgreen et al., 2022). This type of empirical insight would also help identify which existing frameworks are better suited to what type of companies, depending on their context, needs, and capabilities (Chrispim et al., 2023). In turn, this information could help develop tools supporting companies' selection of c-indicators, as suggested by Saidani et al. (2019).

Furthermore, more empirical contributions are needed regarding companies' perceptions linking the concepts of circularity and sustainability (Walker et al., 2022), and how in practice their assessment of circularity and sustainability are connected (Opferkuch et al., 2022; Roos Lindgreen et al., 2022). Similarly, previous research highlights the need to increase the empirical understanding of the links between CE and sustainability assessment. From one perspective, there is a lack of empirical information regarding how companies implementing CE activities assess their sustainability impacts (Das et al., 2022; Stewart & Niero, 2018). Furthermore, little is known about how companies are simultaneously conducting and potentially connecting sustainability and circularity assessments (Roos Lindgreen et al., 2022). Related to this, it is noted that the academic discussion regarding how the concepts of CE and sustainability interact requires more inputs from companies engaged with the concepts (Geissdoerfer et al., 2017; Walker et al., 2022).

4 Research design, materials, and methods

This chapter presents the methodology used to answer the research questions. First, the research design is outlined. Next, details explaining the methods for data collection and analysis are presented. Finally, an outline of limitations is provided.

4.1 Research design

The research design follows a qualitative exploratory approach. According to Creswell & Creswell (2018), a qualitative approach refers to a form of inquiry that focuses on understanding the complexity of a situation by interpreting the meaning of data that is often in text form and involves flexibility in terms of questions and procedures. Additionally, as stated by Stebbins (2001), an exploratory approach is focused on generating empirical generalisations that are novel or help expand the scope of earlier studies. It is particularly well-suited, among other scenarios, when a situation has received little empirical scrutiny.

As explained in previous chapters, the development, application, and study of c-indicators are recent phenomena where there is a lack of empirical information. Thus, the qualitative exploratory approach was deemed appropriate, as it guides the research to obtain a nuanced understanding and enables the identification of relevant patterns by paying attention to various aspects of a phenomenon, that may be of interest to answer the research questions (Stebbins, 2001). Furthermore, the research design follows a combination of a deductive and inductive strategy. A deductive strategy starts with certain theoretical arguments that guide data collection and analysis, which then enables relating the findings back to the initial theoretical arguments (Blaikie, 2010). In turn, an inductive strategy is a logic of inquiry that aims to establish descriptions of phenomena (Blaikie, 2010). In this thesis, a deductive strategy is used to define a conceptual framework which identifies key elements guiding a subsequent in-depth literature review, data collection and codification. Then, data collection tools and codes were expanded upon and readjusted utilising an inductive strategy which enabled the integration of emergent topics through iterative processes.

As outlined in the research problem, aim, and RQs; the phenomenon of interest refers to the adoption and use of c-indicators in companies. Thus, following the aforementioned design, the research questions will be answered by exploring perceptions of two types of practitioners who are engaged in the processes of adopting and applying c-indicators: i) practitioners within company settings, and ii) practitioners who are supporting companies from an external perspective (ie. expert organisations such as consultancy, think tanks, agencies etc). It is considered that these two perspectives are the most relevant sources to capture the factors that affect the use of c-indicators in practice, as well as the way in which they interact with sustainability.

Data was gathered mainly through a questionnaire and interviews. The sampling followed a purposeful approach. This is a non-probability form of sampling in which participants or cases are selected in a strategic manner (Bryman, 2012). The aim of purposeful sampling is not empirical generalization, but to select information-rich cases that yield insights and in-depth understanding (Patton, 2002). The selection of companies was guided by two criteria; i) they must have adopted c-indicators developed by practitioners, and ii) they must be operating in Chile. The selection of practitioners from expert organisations also followed two criteria: i) they must have supported or are currently supporting businesses in the adoption and use of c-indicators, and ii) they are based in Chile or Europe.

4.2 Methods used to collect data

4.2.1 Literature review

An initial literature review was conducted to provide an understanding of the scope and characteristics of circularity indicators, which formed the main components of the conceptual framework. An additional literature review was then conducted that focused on strengthening the knowledge related to key topic areas. The key topic areas are related mainly to two categories in the conceptual framework: i) Usability (factors that influence the practicality and usability of the indicators to industry) and ii) integration of sustainability impacts. Moreover, in this additional literature review, there was a special focus on finding empirical cases in the use of c-indicators by practitioners. The two key topics and the focus on empirical findings were selected as the focus of the additional literature review because they connect more directly to the RQs.

To accomplish its objectives, this additional literature review followed mainly a snowball and citation search. Through this process, relevant articles were identified from reference lists in the initial literature review, as well as from identifying articles that cited other relevant studies. The emergent themes obtained from this additional literature review can be connected to the conceptual framework as sub-categories. Lastly, from this additional literature review, the descriptions of most categories in the conceptual framework were also further complemented and nuanced.

4.2.2 Questionnaire

The questionnaire was directed to practitioners within companies and was conducted before the interviews. The questionnaire's aim was to support the collection of preliminary qualitative information, while also enabling to obtain some complementary insights from companies that were not participating in the interviews. In the following, a description of the respondents is provided, followed by a description of the questionnaire development and content. It is worth noting that the results of the questionnaire are of qualitative nature and do not aim to be statistically representative. The questionnaire was prepared in Google Forms and sent through a link to potential participants' emails. The questionnaire was developed in English. It was reviewed by the supervisor and peer-tested by an Environmental Management and Policy master's student. The questionnaire was translated into Spanish to be sent to potential respondents, and it had an estimated completion time of approximately 10 minutes.

Based on the criteria for purposeful sampling outlined in section 4.2, 25 companies operating in Chile were invited to respond to the questionnaire. These were all large companies which represent two distinct perspectives. The first is a group of companies participating in a collaborative programme supported by a public-private partnership and managed by a non-profit private sector organisation (from now on, referred to as "the programme"). This programme started in 2021 and aims to support and accelerate circular transitions in businesses. As a tangible tool, companies in the programme are guided in the utilisation of the CTI framework. As mentioned in Chapter 2, this is a set of publicly available c-indicators generated by the WBCSD. This program was discovered through an online search focused on identifying potential cases of interest in Chile. The second perspective comes from a company from the energy sector with operations in Chile, that has developed and is using its own c-indicator framework. This case was identified with the help of the authors' work connections in Chile. Both types of cases are relevant for the thesis, as they give the possibility to explore the use of two kinds of frameworks, one developed by an external organization and applied by companies, and one developed internally by a company. While the intention is not to provide

a comparison of the frameworks, the ability to capture different insights and highlight commonalities and differences as part of the discussion can be enriching for this exploratory study.

The questionnaire was sent directly to the company using its own framework, and through the programme leaders to all other companies. Overall, 12 completed questionnaires were obtained. One of the companies in the programme sent three questionnaires responded to by different employees, thus two responses were removed from the analysis. The questionnaire that was kept was responded by the employee who was reportedly more involved in the programme. There were two respondents representing a parent and subsidiary company. The subsidiary company's response was removed from the analysis because they were not directly using the c-indicators. Thus, 9 responses were used for the analysis. Table 4-1 presents the respondents' profiles. It also provides companies' self-reported level of maturity in integrating CE. In turn, table 4-2 presents the definitions used in the questionnaire for companies to self-report their level of maturity in integrating CE.

Table 4-1. Questionnaire respondents' characterisation

Sector	**Role**	**Self-reported maturity in CE**	**Framework**
Beverages	Corporate affairs and positive impact coordinator	3. Developing	CTI
Furniture	Sustainability lead	2. Starting	CTI
Solutions for mining industry	Operations VP	3. Developing	CTI
Steel	Environment and CE lead	4. Leading	CTI
Cement	Innovation and sustainability manager	4. Leading	CTI
Recycling services	Sustainability specialist	3. Developing	CTI
Energy	Sustainable development lead	1. Discovering	CTI
Energy	Environmental specialist	3. Developing	CTI
Energy	Head of Sustainable & Circular Ecosystem	4. Leading	Internal framework

Table 4-2. Circular transition maturity stages for self-reporting in the questionnaire

	Stage	**Description**
1	**Discovering**	CE topics are being discussed and analysed
2	**Starting**	Isolated projects and actions are being developed or implemented regarding CE
3	**Developing**	CE is being integrated in plans, strategies, and policies. Projects and activities are being implemented
4	**Leading**	The company recognises itself as a pioneer in CE topics. There are clear projects, activities, strategies and policies

The scope of the questions in the questionnaire was guided by themes identified in the literature review. Additionally, specific questions developed by previous academic and grey literature for their data collection instruments, which were connected to the identified scope were selected for their integration and modified to better fit the context of the study. The full questionnaire is presented in Appendix A and references are included when questions were extracted from previous' authors' data collection tools. It should be noted that the wording in the questionnaire for the company using its own framework was slightly adjusted to reflect this difference.

The questions in the questionnaire first aim to get background information regarding companies' CE development. Then, the questions focus on how the concepts of CE and sustainability are understood. It also inquires about current practices regarding assessment, and how these practices are perceived as either measuring circularity, sustainability, or both. These questions serve to understand what is the broader landscape that companies navigate regarding assessments, how c-indicator frameworks fit into this landscape, and how they distinguish (or not) different scopes regarding circularity or sustainability. Then, the questions address the perceived purposes, and suitability of c-indicators, as well as the perceived barriers in their use.

4.2.3 Interviews

Semi-structured interviews were conducted after the questionnaire, encompassing practitioners within companies and from expert organisations. The interviews' aim was to further explore topics outlined in the questionnaire by having a more detailed discussion, as well as expanding to other relevant dimensions beyond what was addressed in the questionnaire. In the following, a description of the participants is provided, followed by a description of the interview guide's development and content.

Seven interviews were held with practitioners within five companies, representing a sub-group of those participating in the questionnaire. Table 4-3 presents the companies and number of interview participants per company. Appendix B provides additional details regarding the list of interviewees. For three companies, two representatives participated in the interviews, while for the other two companies, there was only one participant. It is worth noting that the second interview with Company A was held with a foreign representative, who does not work in Chile. Nevertheless, the insights from this interview are fully applicable to the company's operations in Chile, as the focus was in further understanding their internal c-indicator framework and complementing insights already collected through the first interview.

Table 4-3. Characterisation of companies participating in interviews

Name	Sector	Number of people interviewed and role	Self-reported maturity in CE	Framework
Company A	Energy	2 (separate interviews)	4. Leading	Internal framework
Company B	Steel	2 (separate interviews)	4. Leading	CTI
Company C	Beverages	2 (same interview)	3. Developing	CTI
Company D	Furniture	1	2. Starting	CTI
Company E	Energy	1	1. Discovering	CTI

Companies were invited to take part in the interviews through direct emails as well as an invitation in the questionnaire. Direct invitations were sent to nine companies, from which 4

companies accepted to participate within the time constraints of the thesis. Additionally, 1 company accepted to participate through the questionnaire within the time constraints of the thesis.

Direct invitations were subject to contacts that were available to the thesis author. Thus, even though it was considered useful to obtain variety regarding the industrial sector and level of development of CE topics, these were not criteria that could be completely controlled. Regardless, the final list of participants did ensure variety in both aspects. According to Patton (2002), this diversity can help document both: i) patterns that are especially relevant because they emerge even in the presence of heterogeneity, and ii) unique aspects and descriptions that help understand the complexity of different contexts. Within each company, interviewees were chosen due to being actively involved in decision-making processes regarding CE topics, and the adoption and use of the c-indicators.

To capture complementary information about companies' needs and experiences regarding c-indicators, interviews were also carried out with practitioners from expert organisations. The purposeful sampling considered the inclusion of three experts from Chile and three from Northern and Western Europe. Table 4-4 presents the interview participants from expert organisations.

Table 4-4. Characterisation of expert organisations participating in interviews

Expert organisation	**Abbreviation in findings**	**Participant's role**	**Type of organisation**	**Area of support**	**Location**	**Duration**
Local organisation 1	L1	Programme leader	Non-profit private sector organisation	Managing programme for CTI adoption	Chile	45 min
Local organisation 2	L2	CE projects director	Public-private collaboration platform	Supporting macro level CE transition	Chile	30 min
Local organisation 3	L3	Sustainable production and consumption subdirector	Public-private collaboration organisation	Support in mining sector and national CE roadmap	Chile	30 min
Foreign organisation 1	F1	Research analyst	Global impact organisation	Integration of c-indicators in businesses	Europe	30 min
Foreign organisation 2	F2	Programme manager	Public-private collaboration platform	Collaborative projects for c-indicators	Europe	30 min
Foreign organisation 3	F3	Sustainable business expert	Research and innovation organisation	Integration of c-indicators in businesses	Europe	25 min

These external experts did not need to have worked with the same companies being studied, since the intention was to capture their own perspectives as additional inputs. Nevertheless, one of the practitioners from Chile corresponds to the perspective of the organisation managing the programme described earlier (named "local organisation 1" in the table below). The two other Chilean experts were identified based on information in the National Circular Economy Roadmap (MMA et al., 2021) regarding their involvement in promoting circularity

assessment tools and evaluating the potential for circular transitions in industry. Lastly, the three European experts were identified with the help of the thesis supervisor.

The scope of the questions in the interview guides for companies and expert organisations were supported by themes identified in the literature review. The interview guide was adjusted for each interview to consider the participants' reality. Through time, the interview guides were further adjusted to integrate relevant emerging inputs. The interview guides were first developed in English to be reviewed with the supervisor. Then, they were also translated into Spanish to conduct the interviews with Chilean interviewees. The preliminary versions of the two interview guides are presented in Appendix C.

In the case of companies, the questions in the interview allowed to cover similar topics as the questionnaire, particularly regarding background information on CE development; linkages between CE and sustainability; how assessment practices are perceived as either measuring circularity and/or sustainability; perceived influencing factors in c-indicators application; c-indicators' suitability; and lessons learned overall. While the answers given in the questionnaire were visible in each interview guide, in case they were useful to further explore answers, an effort was made to avoid posing leading questions in the interviews, and thus allow spontaneous responses irrespective of what was previously answered in the questionnaire. Additionally, the interview explored companies' perspectives regarding how to measure sustainability impacts from circular strategies, which was not approached in the questionnaire.

For the expert organisations' interviews, questions were more general, although care was taken to ensure they remained aligned to inputs that can help enrich RQs answers, with a special focus on perceived challenges and opportunities in the application of c-indicators. Interviews with expert organisations were also useful to the broader learning of the thesis' author about the topic.

4.3 Methods used to process information

The questionnaire was processed by downloading responses in Microsoft Excel. For each question, the number of answers allocated to each provided choice were quantified. From the quantification, charts were generated which allows to visually analyse commonalities and variety in the answers.

Interviews' audio was recorded and transcribed with the transcription software FreeSubtitles. The transcription was manually reviewed when needed. To process information from the interviews, the study carried out content analysis, aided by the content analysis software Quirkos. Based on Creswell & Creswell (2018), the procedure of content analysis considered preparing and reading the content, coding the text, generating descriptions and themes, and presenting these outcomes in writing.

The initial codes used for the analysis were supported by a deductive strategy. First, relevant themes for each RQ were identified based on the in-depth literature review which carried out guided by the conceptual framework. Within each theme, specific codes were generated from literature findings. From this starting point, the codes evolved inductively as findings from the data emerge. The complete initial and final coding list is presented in Appendix D.

It is worth noting that when reporting the findings, they were allocated to companies and expert organizations, without making a distinction between representatives of the same company in the cases where more than one interview or representative was involved. This reporting approach was chosen as the perspectives among representatives of the same

company were highly aligned, providing a robust and cohesive description of their experiences without any contradictory positions. Lastly, findings obtained from the questionnaire and interviews are presented jointly in the results according to the topic addressed, as they complement each other to answer the RQs.

4.4 Limitations

The thesis aims to provide insights for a recent area of study, attempting to obtain a richer understanding of the topic of c-indicators in certain contexts, without aiming for statistical representativeness. In this sense, a qualitative approach seems appropriate. At the same time, it is important to acknowledge that obtained insights would be contextual and non-generalisable. Similarly, the number of valid responses in the questionnaire is only 9. This relatively low number of responses was expected, as the questionnaire was only shared with 26 potential respondents. Nevertheless, it was still deemed valuable to apply the questionnaire because the aim was to obtain qualitative insights, with no intention of generalisation or statistical representativeness. Likewise, as it was already discussed in section 1.3, all but one companies participating in the questionnaire and interviews belong to the same collaborative programme and are using the same c-indicator framework. This provides a rich analysis of their cases to identify common lessons and challenges. At the same time, it has to be acknowledged that there is only one other company representing the use of another framework, which means patterns and differences among companies in the findings need to be analysed considering this imbalance in perspectives. In any case, including both perspectives was considered enriching for the aim of exploring companies' use experiences. A explained earlier, adding diversity in the perspectives can help identify patterns that emerge despite heterogeneous contexts, as well as capture the nuances of different cases (Patton, 2002). Lastly, using more than one method for data collection and capturing information from various sources can help ensure internal validity (Creswell & Creswell, 2018). Thus, the inclusion of both a questionnaire and interviews are expected to contribute to this aspect. More reflections about choices in this study can be found in section 1.3 and 6.2.

5 Findings

This chapter presents the empirical results obtained from the nine questionnaire's responses, the seven interviews with companies and the six interviews with expert organisations. There are six sections in this chapter. First, general descriptions are provided of the two c-indicator frameworks utilised by companies participating in the study. Next, how companies connect CE and sustainability as concepts is outlined, as well as insights about companies' practices to assess the sustainability impacts from circular strategies. Then, the results turn to linkages between c-indicators and sustainability assessment in practice. Afterwards, a review is provided of companies' motivation to adopt c-indicators and their current implementation. Next, perspectives on the purposes that c-indicators provide to companies are presented. Lastly, the findings outline perspectives on the factors that influence companies' application of c-indicators.

5.1 Description of frameworks used in companies

This section provides an initial overview of the two c-indicator frameworks utilized by the companies in the study, summarised in table 5-1. This overview is mainly based on public secondary materials and some inputs obtained from interviews. The detailed sources can be found at the bottom of the table. While the main focus of the findings is on the application experience of c-indicators, this overview allows a basic understanding of the type of indicators that are being used and the explicit purposes, usability aspects, and consideration of impacts with which they were conceived. To characterize the frameworks, the categories presented in the conceptual framework in section 2.2 are used, along with an additional category regarding the explicit definitions of CE considered by the frameworks. The goal is not to compare the frameworks, but to have this information as a useful starting point to learn about companies' perspectives. It should be noted that in the case of the internal framework used by Company A, the descriptions provided refer to a general conceptual model which has been further adapted by specific business units. Thus, the information provided here is the basis of further developments.

Table 5-1 Characterisation of c-indicator frameworks used by companies in the study

Category	CTI V2.0	Internal Framework (Company A)
Definition of CE	CE is an economic model that is regenerative by design, which aims to retain the value of the circulating resources, products, parts, and materials by creating a system with innovative business models that allow for renewability, long life, optimal (re)use, refurbishment, remanufacturing, recycling, and biodegradation	Circular economy is a growth catalyst that can promote and accelerate sustainable development Circular Model based on five pillars: i) Circular inputs, ii) New life cycles, iii) Product as a service, iv) Sharing platforms, v) Useful life extension
Scale (within micro)	Metrics can be applied across levels within companies: product, product lines, specific business units, facilities, and corporate level	Based on a common conceptual framework, metrics can be adjusted to be applied across levels within the company: product, product lines, business units, facilities, projects, and corporate level
Transversality	Applicable across productive sectors	Applicable across productive sectors (but developed within a specific sector)
Type of metric	Quantitative set of metrics in percentage and ratio terms, monetary units, and monetary per mass units	Quantitative set of metrics in terms of index, ratios, and fractions E.g.:

	E.g., Basic module "close the loop": % of circular inflow, % of circular outflow, % of water circularity, % of renewable energy More granular metrics can be compounded to calculate other synthetic indicators	-Ratios comparing time of use in circular strategy vs business as usual -Circular inflow fraction and circular outflow fraction -EBITDA vs tons of resources consumed More granular metrics can be compounded to calculate synthetic indicators
Methodological aspects	Material flows assessment, also considering energy used. Water is assessed separately MFA could be used to support the calculations, but it is not required. The analysis can be complemented with resource-efficiency and value-added measurements	-Consideration of closed loops: Material flows assessment of inputs and outputs, also considering energy used -Consideration of life extension of assets through calculation of time extended vs business as usual scenario, which results in a load factor, representing circular use
Temporal focus	Both retrospective and prospective	Both retrospective and prospective
Source of development	Business network organisation: WBCSD	Company A
Purposes	-Identify opportunities and risks -Set baseline and monitor progress -Communication with stakeholders -Collaboration with value chain actors -Attract new business	-Provide comprehensive picture of circular performance -Monitor and improve activities in the field of CE, associated to defined circularity pillars in company's strategy -Set KPIs and targets at different levels of the company
Circularity strategies assessed	Any circular strategy where it is possible to identify mass flows: Recycle, reuse, repair, refurbish, remanufacture, repurpose, biodegradation. The assessment covers sourcing to waste management	Based on 5 pillars outlined earlier, strategies covered by metrics are: reuse, recycle, regeneration, repair, upcycling, product as a service, sharing platform, modular design, maintenance
Usability aspects	-Public and free framework co-developed with industry. The framework explicitly aims to be easy to implement, versatile in scope, and non-prescriptive -A general guide and detailed user manual is publicly available -A paid online tool exists to support companies with data gathering and calculations	-The conceptual framework methodology is publicly available, which breaks down all calculations and rationales. This guide was published for study and research purposes -There is no further public statement of usability considerations, which is likely to reflect the fact that the framework was developed for internal and clients' use
Integration of sustainability impacts	-The user guide notes that the indicators do not measure the environmental or social impacts of circular activities. It focuses on mass flows and resource use, and it considers the economic dimension by including two metrics to relate circularity to monetary value -The user guide states that circularity should not be the only goal of companies. Thus, the framework is expected to complement existing sustainability frameworks. It is noted that the calculation of the indicators may provide information that can contribute to calculate impacts	The framework itself does not measure the environmental or social impacts of circular activities, but the broader assessment practices of the company complement the framework with environmental and social metrics. It considers the economic dimension with indicators relating circularity with monetary value

Sources: Own elaboration, based on the following materials: WBCSD, 2021; Company A, 2023; Company A, n.d.; interviews with Local Organisation 1 and Company A

5.2 Connecting CE and Sustainability

This section presents findings that relate to practitioners' perspective about the linkages of CE and sustainability conceptually and in practice. The section is divided in three parts. The first part summarises practitioners' perceived CE meanings. Then, it presents perceived conceptual linkages between CE and sustainability. These first two parts serve as an introduction to approach the third part, that explores the way in which companies acknowledge and assess sustainability impacts from circularity initiatives.

5.2.1 Conceptualising CE

There were several different understandings of CE brought up by participants in interviews. CE is identified as encompassing the principles of reduce, reuse, and recycle (L3); and also associated with the three principles proposed by the Ellen McArthur Foundation (Company D), namely the elimination of waste and pollution, circulating products and materials, and regenerating nature.

CE is also seen as an accelerator to reach strategic goals, whose contribution is to decouple activities from resource consumption (Company A). Previous to the programme, there were companies that associated CE to waste issues and recycling only, without considering their resource consumption as an aspect where circularity could be applied (L1).

Practitioners from expert organisations highlight the systemic nature of CE, which encompasses various scales, sectors, actors, and topics (L3, F1, F2, L2). This feature of CE implies that it cannot be discussed in company contexts in an isolated manner, as it relies on broader changes, beyond the company level, related to the way an economy is organised (F1). Furthermore, as CE is an overarching concept that covers aspects such as water, energy, and materials; when integrating it at company level, it has to be linked to other existing initiatives and strategies that connect to it (L3). Efforts to coordinate CE action are considered very complex to manage, as it requires orchestrating actors and organisations at many levels (L2).

5.2.2 Perceived linkages between CE and sustainability

The conceptual linkages that practitioners perceive between CE and sustainability were explored, as these relationships may be connected to the way in which they interpret assessments results and decide paths of action. Insights were obtained from the questionnaire and the interviews.

As shown in figure 5-1, the main message obtained from the questionnaire is that the majority of respondents strongly perceive CE as a beneficial tool towards sustainability, especially related to its positive impact regarding environmental aspects. The level of agreement with the idea that CE may be the *main* tool to achieve sustainability is less strong, as most respondents either disagree or have a neutral view regarding this statement. Respondents also consider CE to have mostly positive connections to economic and social impact, although this level of agreement was not as apparent as the perceived connection of CE's potential to contribute to the environmental dimension of sustainability.

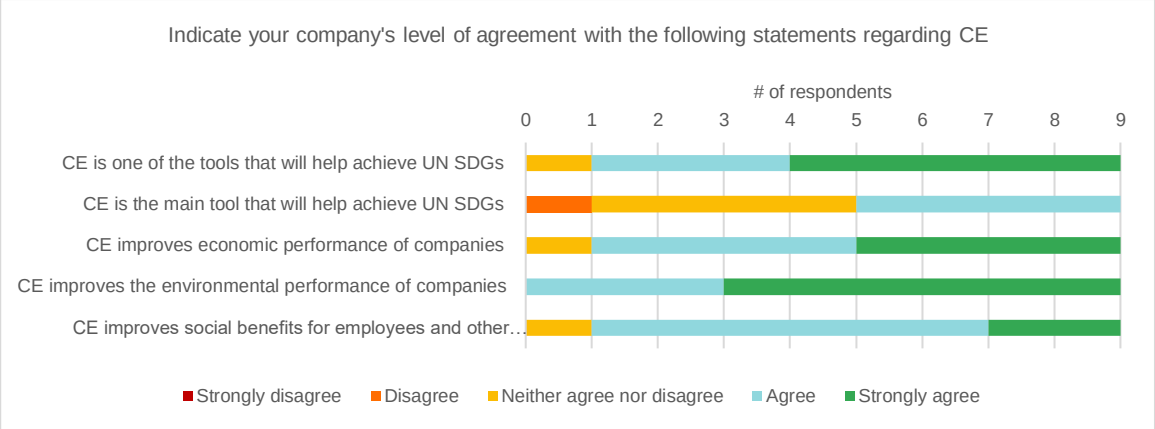

Figure 5-1. Respondents' perceptions of CE in relation to sustainability

The conceptual linkages between CE and sustainability were also explored in the interviews. Each of the found relationships will be further detailed below. It should be noted that the recognitions of various type of relationships may co-exist in a participant's narrative. Thus, they are not mutually exclusive. It should be noted that "CE" and "circularity" were used in the interviews indistinguishably. For the purposes of learning from practitioners' perspectives, using either term was deemed equally useful in signalling their perceptions.

Before presenting specific inputs collected from participants, it is worth noting that, as reflected in the questionnaire, the main message obtained from the interviews is that companies implement circularity as a way to achieve sustainability improvements, mainly connected to the environment. Additionally, some participants note that circularity may be implemented without being subordinated to sustainability goals. Particularly, when reflecting on how circularity may help achieve sustainability improvements, three main types of relationships can be distinguished in participants' perspectives: i) beneficial, ii) trade-off, and iii) ambiguous. It is worth noting that relationship types i) and ii) have been named based on conceptual relationships proposed by Geissdoerfer et al. (2017). In turn, relationship type iii) can be linked to Walker et al. (2022). The connection of the findings with previous literature will be further explored in Chapter 6. In the next two sub-sections, specific inputs collected from participants regarding relationships between CE and sustainability will be further explained.

Circularity implemented to achieve sustainability

According to participants' perspectives, in general terms circularity is implemented at the company level as a means of achieving sustainability improvements related to the environment, particularly with regard to Greenhouse Gas (GHG) emissions and water usage. In particular, insights obtained can be classified as representing beneficial, trade-off, and ambiguous relationships between circularity and sustainability.

Regarding beneficial relationships, CE is perceived as one alternative, among others, that can be beneficial towards sustainability aspects, with no conditionality attached to it. That is to say, there is not an explicit statement that CE is a necessary condition to achieve sustainable development. This is reflected in participants' practical experience. Once companies have identified sustainability issues and goals, they turn to practical solutions that can address the identified issues (Company D, Company C, Company A, Company B). In this search, the recognition of the roles of materials and processes leads the companies to circularity as a potential solution (Company D, Company C, Company A).

For instance, Company D highlights that their approach to circularity originated from identifying impacts in their scope 3 emissions related to purchases of materials. Thus, circular solutions are being analysed as they can help reduce these emissions, and relate to, for instance, change the type of fabrics they purchase. More broadly, Company D perceives that companies participating in the programme share an implicit understanding that circularity is being adopted to help achieve sustainability strategies. Likewise, Company A's perspective is that circularity is a tangible tool among others, to contribute to their sustainability strategic plan and commitments for climate action, which are ultimately linked to SDGs. This is because it is recognized that, even as the company increasingly transitions to renewable energy generation, there are other sources of negative impacts in materials that also need to be addressed. Therefore, projects need to be approached comprehensively. These views are supported by F1's experience working with companies, as it is noted companies' narratives, and their own narrative in promoting circularity, is very centred around how managing materials and resources through circularity can impact GHG emissions.

Regarding ambiguous relationships, circularity is seen sometimes directly as a component of the environmental dimension of sustainability, and not as a separate element that may promote sustainability. This relationship is mostly evidenced in the way circularity is being practically managed within companies. In this sense, in strategies, action plans, or reports, circularity is found under the environmental dimension of sustainability (Company D, Company C, Company E, L1). For example, Company D states that circularity is one component within the environmental aspects of their sustainability strategy, in a similar position to climate action or transport.

Lastly, regarding trade-off relationships, some participants more explicitly discuss that circularity and sustainability are not the same, and that circularity does not per se guarantee more sustainable outcomes (Company A, F3, Company B, F1, F2). For instance, Company A notes they are aware of on-going discussions about how to verify circular strategies' contribution to sustainability. It is also noted that the way circular strategies are implemented matters, there needs to be a target on more sustainable outcomes, as environmental and social burdens may arise from its application (Company A). Likewise, F3 highlights that in some circumstances circularity may not contribute towards sustainability or may not be the most efficient way to reach sustainable outcomes. A specific trade-off made visible by F1 is the difference with optimising resource consumption intensity and enabling absolute reductions in resource consumption. If material use is optimised but absolute production increases, the material footprint can increase, thus negatively affecting environmental impact.

CE and sustainability can exist as separate

Outside of the discussion about how circularity benefits sustainability, two participants also note that even though circularity can be tightly linked to sustainability, in essence it can also be a stand-alone way of organising systems (Company B, Company D). This is illustrated by Company B, noting that semantically, sustainability refers to something that can be sustained in time, whereas CE relates to a way of managing design, processes, or business models. Circularity means defining a specific value creation model that utilises certain strategies related to use, reuse and reduce (Company B).

5.2.3 Measuring sustainability impacts of circularity

This section presents companies' and expert organisations' perspectives regarding how to assess sustainability impacts from circularity initiatives. This point is relevant in the discussion of c-indicators because, as introduced in the literature review, ensuring that circular strategies

contribute to sustainability is a current topic of discussion, and c-indicator frameworks may or may not directly support these type of impact assessments. In the case where they do not directly support these assessments, then the question arises on how to combine c-indicators with other approaches to ensure that circularity is not promoted just for circularity's sake. The c-indicators frameworks introduced in section 4.1, which are being used by the companies in the study, are focused on what has been conceptualised in literature as intrinsic circularity, with metrics covering resource flows and life extension. Thus, according to literature, the assessment of sustainability impacts in this context would need to be complemented with other indicators or assessment approaches.

From a high-level perspective, expert organisations reflect about the importance of verifying impacts. For instance, F3 mentions the relevancy of acknowledging sustainability benefits from CE are not always a given, as this gives room to explore when circularity may not be the best alternative. Likewise, F2 highlights the role of research in verifying the links between circularity and climate impact. Linked to these reflections, the next sub-sections will present the perspectives of interview participants for each type of sustainability impact: economic, environmental, and social.

Economic

Assessing the impact of decisions on a company's economic performance is an established practice. Accordingly, some participants note that the impact of circularity initiatives on a company's economic performance needs to be assessed as in any other type of project or component of a business' operations (Company B, Company C, Company A). Furthermore, Company C and Company A emphasize the importance of calculating economic impacts to demonstrate that circularity can add value to the business. This can be achieved through cost savings or new streams of revenue, for example. Company C mentions that showing economic impacts helps advocating for improvements to senior management. In this line, a related challenge Company C is working on is connecting the results of c-indicators with business opportunities and improved economic performance. Company A has made progress in integrating the two aspects. First, a new Key Performance Indicator (KPI) at company level was established to compare resources consumed with economic performance measured through EBITDA, to guide their efforts in decoupling resource consumption from economic performance. At a more operational level, a similar approach is taken by requiring a percentage of income to be linked to circularity initiatives implemented in processes or operations.
From a higher-level perspective, highlighting the potential positive economic impacts of circularity is highlighted as a way to incentivise companies to adopt a circular approach (L2). Nevertheless, it is also noted that focusing on profitability targets may prevent systems from making absolute progress regarding resource consumption, as less material intensity may not lead to less resource consumption if production as a whole keep increasing to increase economic growth (F1).

Environmental

In companies' experience, procedures to assess environmental impacts are oftentimes less clear and standardised than the ones guiding economic assessment (Company B, Company C). Furthermore, some perspectives in the interviews tend to consider circularity as a desirable final impact within the environmental dimension. For instance, Company C mentions that when assessing options, their environmental impacts should be compared, including circularity, water, and emissions. From the programme perspective, the focus is on improving circularity performance, and this does not seem to be complemented explicitly by verifying environmental impacts (Company D, Company B, L1). This may suggest an understanding that improving circularity in itself will result in environmental improvements, or that circularity

assessment is equated to sustainability assessment to some extent. As suggested by F3, this perspective of equating circularity improvements to environmental improvements can be seen a risk, as it may not be the best way to drive corporate change towards more sustainable outcomes.

At the same time, companies indicate resorting to rules of thumb to understand the environmental impacts of circular initiatives (Company C, Company E, Company B). This is based in the understanding that if resource-related improvements are conducted, they will subsequently be reflected in environmental footprints measured at company level (Company C, Company E, Company B). For example, Company B notes that they can see a direct link between improving c-indicators and other metrics they monitor on environmental aspects such as GHGs and water because there are similar variables influencing their performance. Likewise, Company D sees a link in how circularity projects that reduce waste will have an impact on carbon footprint arising from waste.

Even when in practice circularity may be managed as an environmental impact and impacts regarding more final environmental impact categories may be loosely estimated, when asking explicitly how to ensure that circularity is contributing to environmental aspects, companies tend to acknowledge that this would need to be measured beyond c-indicators' results (Company C, Company E, Company B, Company A). For instance, it is noted by Company C that theoretically, every decision could be supported by an LCA to assess environmental impact, but it requires additional resources and expertise which makes it impractical. Company E also acknowledges that circular projects should contribute to environmental targets such as emissions reductions and water. Nevertheless, since they have not established targets for these topics yet, they cannot require an impact verification of circularity initiatives to these environmental aspects.

Despite most approaches to environmental impact verification remain rather unstructured, specific efforts can be highlighted. For instance, Company A and Company C have integrated LCAs results into decision-making. Company B notes that while there are not established procedures to purposefully account for the impacts of specific circular initiatives, conventional assessment and monitoring practices in heavy industry can be applicable to these initiatives, accounting for aspects such as local emissions, waste generation and hazardous substances releases. From this study perspective, it is noted that heavy industry follows more stringent regulations in terms of assessing and monitoring environmental impacts related to their plants and operations, which may influence Company B's assessment approach of circularity-related changes, as this company belongs to the steel production sector. Furthermore, in the case of Company A, there is a clear approach to ensure delivering in circularity *and* sustainability performance. There is an integrative framework in place which is applied to projects and operations, in which circularity metrics are considered along with "complementary indicators", that measure a number of environmental, economic, and social impacts which are defined according to the particular project or operation. Additionally, there is an acknowledgement in Company A of the discussion around the possible trade-offs between CE and sustainability. This is why it is considered fundamental to support the assessment of intrinsic circularity with the assessment of environmental impacts, as it can reveal whether a chosen path was actually beneficial or not, and how it can be managed to avoid negative effects.

Social

Even though actors recognise the relevancy of the social dimension in sustainability, in the context of circularity and c-indicators, experience is limited. Company C and Company A note that the integration of social assessments is harder to incorporate as clear guidelines do not

seem to be well developed. Company A is working in integrating social aspects further in their indicator frameworks. It is recognised that CE can have the potential to create jobs, thus in some cases it may make sense to measure this aspect. Similarly, as CE is a new topic, new skills are needed that can be built internally and also shared externally, which can also be quantified. It is noted by Company A that some of the evaluated projects are very technical and thus not very connected to social aspects.

5.3 Linkages between c-indicators and sustainability assessment in practice

This section focuses on how the use of c-indicators, as a type of circularity assessment approach, interacts with the assessment of sustainability. To do so, it first identifies what assessment approaches have already been developed or considered in companies. Then, it explores how these approaches are perceived as part of circularity or sustainability assessment. Lastly, it focuses on identifying how information required for c-indicators and sustainability assessments are linked to generate results.

5.3.1 Other assessment developments

The integration of circularity indicators in the company context means adding an additional assessment approach to efforts that they may already be doing to measure aspects related to sustainability and circularity. Companies may be also in the process of planning the inclusion of other assessment approaches.

This situation was preliminary explored in the questionnaire, where respondents could state whether or not their company was using, or planning to use, a list of approaches related to assessing and reporting sustainability and circularity topics, which is shown in figure 5-2. While the list does not cover all possible approaches that companies could be using, it provides a preliminary indication of their practices. Responses show that all companies are considering GRI standards for reporting, GHG protocol for carbon accounting, and linking their activities to SDGs. The majority of companies also use (or are planning to use) their own internally developed approaches for sustainability and circularity topic. Many also consider SASB standards, and climate targets set according to the Science Based Targets initiative (SBTi). It is worth noting that since there was a purposeful sampling of companies using the CTI framework, it is expected that most companies will report using it, as it is shown in the figure. Thus, this should not be considered proof of the popularity of this approach over others.

Furthermore, by reviewing interviewed companies' available integrated annual reports and sustainability reports, it was possible to confirm that they have not only planned but have already integrated a number of assessment and reporting approaches, including at least GRI (Company B, 2023; Company C, 2022), SASB (Company A, 2023; Company B, 2023; Company C, 2022; Company E, 2023), GHG protocol (Company B, 2023; Company E, 2023), CDP (Company A, 2023), SBTs (Company B, 2023) and recognition of SDGs (Company A, 2023; Company B, 2023; Company C, 2022; Company E, 2023).

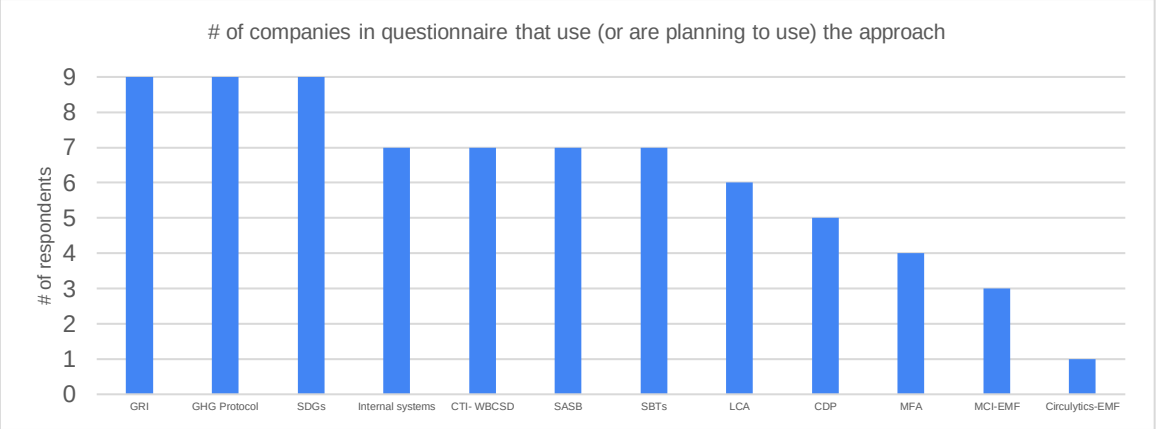

Figure 5-2. Number of respondents applying, or planning to apply, each approach

The interviews provided additional insights regarding current assessment practices. Referring to the whole landscape of assessment and reporting, the Company E notes that current assessment tasks are burdensome, as there is a long list of approaches to address. Furthermore, the list keeps evolving as ambition increases through time. Regarding specific approaches, two participants highlighted that LCAs have been conducted in their companies, which have helped guide materials selection (Company C) and identify GHG emissions' hotspots to prioritise actions (Company A). These assessments are conducted in particular cases and serve as indicative insights. For instance, Company C has not yet carried LCAs in the Chilean context. Rather, they were provided results from assessments developed in international headquarters.

Comments were also captured regarding how the c-indicators integrate into the aforementioned assessment contexts. In the programme, some companies mentioned that they had already implemented a reduced number of indicators that overlapped to some extent with the CTI metrics, regarding materials, waste recovery, and energy (Company C, Company B, Company E). But mostly, the integration of the CTI framework widens the assessment scope and provided a much clearer systemic approach focused explicitly on circularity performance, which was not considered before (Company C, Company B, Company E, L1). For instance, in the case of Company C, their supply unit already had a KPI regarding recyclability. Having this KPI meant this business unit was already managing the topic, which had a positive impact in the performance of the CTI indicators. Nevertheless, adding the CTI framework facilitated a more systemic view, to see circularity in a value chain perspective, as previously it was more fragmented.

5.3.2 Association of assessment approaches to circularity and sustainability

In the questionnaire, companies were asked whether they perceived the list of assessment and reporting approaches- which they are using or planning to use- as applied to circularity, sustainability, or both. The results are shown in figure 5-3. When looking at the results for the most adopted approaches, some variety can be observed, which suggests that among these companies there are no common interpretations. For instance, half of respondents considered the GHG protocol accounting standards to be used for both circularity and sustainability, while the other half considered it only part of sustainability. In the case of GRI, a majority of companies thought it was used to assess both circularity and sustainability, but the perception was not held by all. In the case of SDGs, slightly more companies consider it applicable to both sustainability and circularity, while a number saw it linked only to sustainability, and one respondent only to circularity. For the respondents whose companies are part of the

programme and applying the CTI, more than half consider that it is used for sustainability and circularity assessment.

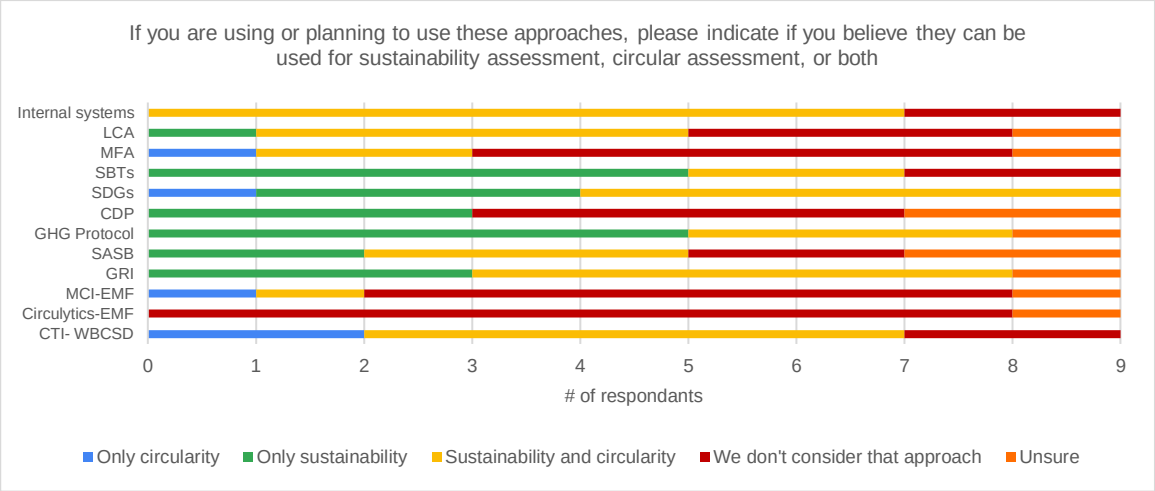

Figure 5-3. Number of respondents allocating each approach to circularity assessment, sustainability assessment, or both

5.3.3 Linkages in data use between c-indicators and sustainability assessment

In this section, the way in which companies understand the links between gathering data and calculating circularity and sustainability performance were explored. This analysis was based in previous literature outlined in section 3.3, that presents different ways in which companies could organise their data collection efforts, use the results from certain assessments as input for other types of assessment, and integrate overall results for decision-making.

Linkages were first explored in the questionnaire, where companies could state whether they were using information obtained from c-indicators' calculation to inform other assessment or reporting approaches in the company. As shown in figure 5-4, the majority of respondents state that c-indicators are either already providing information that can be used for other assessments, or they are planning to do so. Additional comments were provided by three respondents in the questionnaire to clarify what this contribution meant for them. One respondent mentioned that the company has an environmental footprint programme, thus the information collected through c-indicators can contribute to inform progress in that programme. Another respondent mentioned that the way in which c-indicators results are being used to inform reporting efforts is by showing their c-indicators' results in their annual sustainability report. A third respondent notes that c-indicators results provide a diagnosis regarding materials use, which will be considered to set targets regarding circularity. It could be argued that the second and third comments do not refer to linking c-indicators' results to other approaches, but rather to make direct use of their results. Evidently, this shows that c-indicators are supporting reporting and decision-making efforts, but do not show evidence of linking data and results to other efforts such as GRI standards or LCA. This suggests that the 6 companies that responded that c-indicators do contribute to other assessment or reporting approaches, may have had varied interpretations of what this contribution means.

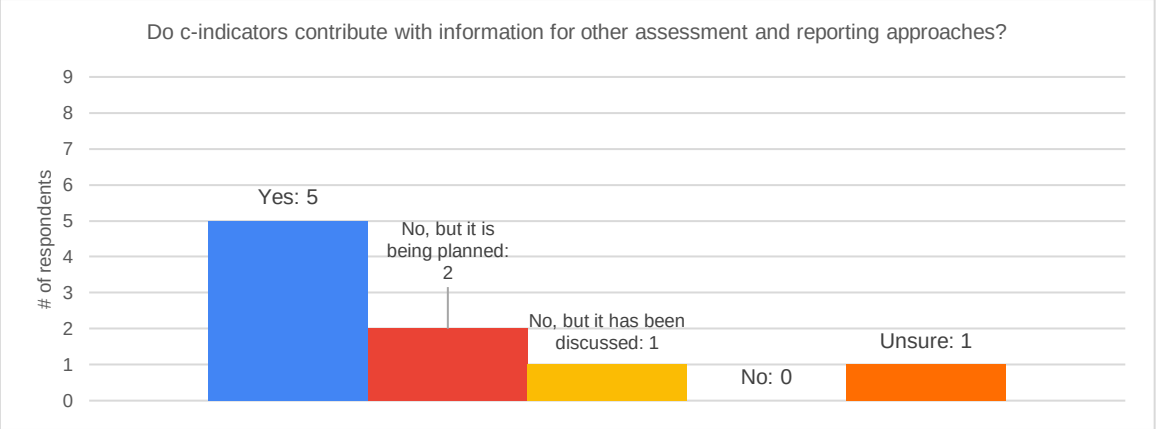

Figure 5-4. Number of respondents whose companies are using c-indicators to inform other approaches

In the interviews, potential linkages in the use of information between c-indicators and sustainability assessment were further explored. Perspectives have been classified in three categories, aligned with previous literature's perspectives, as outlined in section 3.3. The first category corresponds to sequential linkages in information. This means that one approach may act as a precursor of the other, in terms of providing preliminary information that is useful for calculating results. That is to say, circularity assessment through c-indicators may act as a precursor of sustainability assessment, or sustainability assessment may act as a precursor of circularity assessment. The second category corresponds to an integrative perspective, in which approaches may be understood as parallel components of a broader framework, thus they can be seen as an "equal" type of assessment outcome. It should be noted that sequential relationships in data and calculations are not mutually exclusive with having an integrative framework. Rather, it's two type of perspectives that may or may not be present in current assessment practices. To facilitate the analysis, these aspects are discussed separately in the two following sub-sections.

Sequential approach

The sequential approach can be first discussed from the perspective of c-indicators acting as a precursor for sustainability assessments. As shown in section 3.3, there is an understanding in literature that circularity assessment can provide preliminary data for sustainability assessment because it refers to aspects that can be further linked to potential economic, environmental, and social impacts. This perspective was not very explicit in companies' experiences conducting assessments. Nevertheless, an aspect that can be connected to this type of relationship is the fact that the latest version of the CTI framework includes a module to calculate GHG emissions based on resource flows. In this sense, the sequential assessment could be considered in CTI, as it can help calculate carbon footprints, although currently companies in the programme are not making use of this module, because they are using a previous version of the framework. As noted by L1, this sequential assessment could only partially contribute to carbon footprint calculations, as in practice, the scope remains more constrained in the application of c-indicators. Not the least because some companies have started assessing just selected processes or plants. From the perspective of this study, it could be argued that if c-indicators were adopted to map the whole resource flows at company level, then it may be equated to the scale utilised in carbon footprints and the outcomes would be similar if considering the same scope and level of detail.

The sequential approach can also be discussed from the perspective of sustainability assessments acting as precursors for c-indicators. Given a more mature approach to assessing

GHG emissions, two companies mention that this type of assessment has helped them gathering information for their circularity metrics (Company E, Company B). In this sense, previous sustainability assessment practices, particularly linked to carbon footprint, have been used as a precursor to calculate c-indicators. For instance, Company E notes that data collected to calculate the carbon footprint enabled them to have readily available information about electricity, and fuels, which contributed to calculate the c-indicators. In turn, Company B has a comprehensive and streamlined process for calculating carbon emissions in the three scopes, where they account for all inputs and outputs. They have been conducting these assessments for 12 years, and in their case, many overlaps existed between data requirements to calculate the carbon footprint and the c-indicators, which enabled them to rely on very few assumptions to obtain them.

Integrative perspective to assess circularity and sustainability

From an integrative perspective, approaches may be understood as parallel components of a broader framework, thus they can be seen as an "equal" type of outcome. Company A has developed what can be considered an integrative framework. The rationale behind their integrative approach is to obtain a holistic picture that informs both the economic performance, resource use, *and* environmental impacts, in line with their goals to decouple economic performance from resource consumption and sustainability commitments. In this framework, material flows assessments linked to c-indicators are carried out along with "complementary methods", which refer to assessing final environmental impacts. This usually includes GHG emissions and water-related aspects. In this way, the company can verify impacts associated with changing material flows. Overall, there is not a sequential logic or hierarchy in obtaining circularity and sustainability results, all indicators are calculated as part of the performance of projects or operations, and all can guide improvements through time. That is to say, both increasing circularity and sustainability are part of the companies' strategic goals. This means projects and operations may be faced with trade-offs, for instance between changes that may improve resource use but cause new environmental impacts. Balancing these trade-offs is part of the learning process and their recognition should lead to actions to avoid negative impacts (Company A).

Preliminary insights from companies in the programme suggest that in general c-indicators are considered part of environmental indicators, as circularity objectives are considered an element within environmental goals (Company E, Company B, Company D). This suggests c-indicators may be seen as one element of a sustainability framework. For instance, in Company D, circularity targets would be included within the environmental sustainability targets. Thus, in terms of hierarchy, it is understood from the perspective of this thesis that accomplishing circular goals may be seen as equally relevant as achieving other environmental targets.

5.4 Application of C-indicators: progression of implementation

To understand the context in which companies make use of c-indicators, this section presents insights related to the level of awareness companies had about c-indicators before adopting them, reasons behind implementation, and what progress they have made in their utilisation.

5.4.1 Initial awareness and motivations for c-indicators implementation

From a macro perspective, both national and international practitioners agree that companies are just starting their circularity journeys, and the documented uptake of c-indicators by companies is still very small (L2, F2, F3) and concentrated in larger companies (L2, F2). L2 acknowledges that the topic of CE is quite new in Chile, which may reflect a lack of regulatory

pressure until recently, as the National Roadmap for CE was just launched in 2021. Two interview participants also note that it has not been easy to identify suitable indicators (Company B, L3). They have searched for potential indicators from international industry associations (Company B, L3), and from local guidelines (Company B), without finding any developments specifically for circularity. In particular, L3 is supporting the Chilean mining industry. It is noted that in this sector, no specific metrics have been found available to aid circularity assessment. Thus, they are currently focused on identifying which metrics are more suitable for this industry (L3).

From the programme perspective, companies' initial motivation for participating was not necessarily to adopt circularity metrics, but rather to make overall progress in integrating circularity, as the program provided comprehensive support for a circular transition (L1). Concerns among participating companies were focused on, for instance, improving practices within the value chain to support Scope 3 goals, where they recognized the impact of materials and resources as significant sources of emissions (Company B). Other motivations included managing internal processes where no previous actions had been taken to enhance environmental sustainability (Company E, Company D), or aligning with existing voluntary commitments regarding product circularity (Company C). Additionally, companies felt compelled to respond to increasing pressures from national regulations related to Extended Producer Responsibility (ERP) (L1). In general, companies did not possess extensive knowledge of indicators specifically designed to assess circularity performance, but a few had a basic understanding or had informally tested out CTI (L1).

Based on their identified concerns, companies in the programme acknowledged that specific approaches are needed to advance circular transitions, and this was seen as complex to approach with the knowledge and tools they had (Company B, Company D, Company E). Thus, participating in the programme provided a way of having guidance to make the transition, and within this guidance, the inclusion of metrics is one of the tools they have found to support them. Thus, CTI can be seen as a tool companies gained access to due to their interest in further operationalizing CE efforts, and they could recognise its potential value, even if it was not their specific focus from the beginning.

Based on the concerns they identified, companies in the programme acknowledged the need for specific approaches to advance circular transitions. They recognized that managing these transitions with their existing knowledge and tools was challenging (Company B, Company D, Company E). Consequently, participating in the program has offered them valuable guidance and support for making the transition. Within the provided guidance, the CTI framework can be viewed as a tool that companies gained access to as they sought to operationalize their CE initiatives. They recognized the potential value of CTI, even if it wasn't their primary focus at the outset (Company B, Company D, Company E).

In the case of Company A, the motivation to introduce c-indicators stemmed from recognizing circularity as a potential catalyst for their strategic sustainability goals. This led them to establish five circularity pillars as part of their overall strategy. They identified the need to adopt indicators that would support this strategy and enable them to monitor material and energy consumption associated with their operations. At the time, there were limited available alternatives for the industry, prompting them to develop their own approach tailored to their specific strategy. An initial step towards the systematic adoption of a c-indicator framework involved initiatives focused on gathering materials and energy information from suppliers. As introduced in section 5.1, the development of these indicators began with a conceptual model,

which served as the foundation for adopting specific metrics at the product, project, and corporate levels.

Expert practitioners provide insights that align with the aforementioned motivations mentioned by companies to adopt circularity indicators. In their vision, the starting point to adopt circularity metrics is oftentimes an interest in developing circularity strategies, which is accompanied by the need to define actions and goals, for which indicators are a useful supporting tool (L3, F1).

5.4.2 Current progress in adopting and using c-indicators

Companies in the programme started adopting the CTI framework in 2022, using the indicators to calculate a baseline corresponding to the year 2021 (L1). According to L1, most companies in the programme- and all interviewed companies- had completed the required assessment by September 2022, calculating all indicators included in CTI V2.0. Two participants mentioned that this baseline measurement was constrained to certain processes or installations within the company to try out the framework and potentially in the future implement it more broadly at the company level (Company E, Company D). For example, Company E applied the indicators to the cleaning process of one of their main types of equipment. The two other participants measured their whole operations (Company B, Company C). Based on the assessment results and supported by the programme, companies are working in defining plans to address identified challenges and increase circularity overall (Company B, Company C, Company E, Company D). Within the programme, a second yearly assessment will be conducted during 2023 to track progress, and the idea is that companies could continue using the framework periodically (L1).

According to Company A, which has its own framework, they started adopting circularity metrics around 2017, originating from the conceptual framework described in section 5.1, which has been customised to the needs of different business units. The process of adjusting indicators to the business' needs and using them to guide decision making is an ongoing process where improvements are progressively made. Their methodology has been certified by a national accreditation authority, thus becoming a valid standard. One of the business units offers services to support clients' circularity assessment, adjusting the internal framework for other private and public organisations.

5.5 C-indicators' purposes

This section presents results regarding c-indicators' purposes from two perspectives. First, the level of relevancy of a number of purposes outlined by previous literature was stated. Then, purposes fulfilled in practice were discussed with interviewees.

5.5.1 Relevancy of potential purposes

The questionnaire provided an overview of how important a list of potential purposes that c-indicators could fulfil was for companies. This question inquired about c-indicators in general- without focusing specifically on the frameworks used by the companies- to allow respondents to think about what is ideally desired. Evidently, since the companies have already adopted specific c-indicators, it can be expected that they respond based on their experience, but the wording of the question allowed them to not constraint the perception to one particular framework. According to responses shown in figure 5-5, the most relevant purpose was to internally improve and optimise CE strategies, followed by gaining knowledge about broader sustainability performance, and identifying opportunities and assess collaborations.

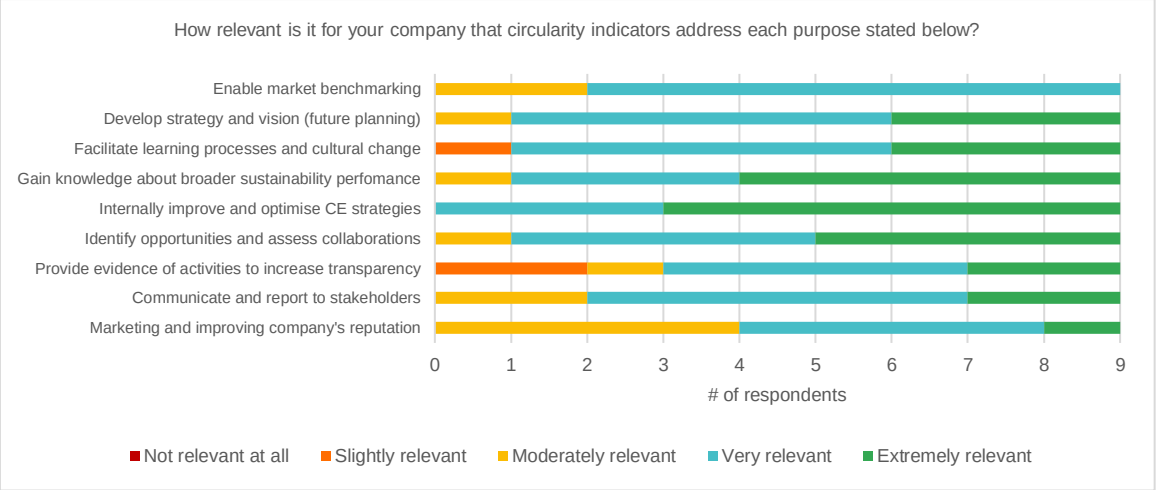

Figure 5-5. Perceived relevance of c-indicators potential purposes

The following section presents perceptions gathered from interviews regarding the purposes that c-indicators have helped fulfil in practice.

5.5.2 Perceptions of purposes fulfilled in practice

Four purposes fulfilled in practice were highlighted by interview participants. These are "performance monitoring and improvement", "facilitate learning processes and cultural change", "external communication and reporting", and "Identify external opportunities and collaborations". These purposes are quite aligned to the ones reported as more relevant in the questionnaire, presented in the previous sub-section. Nevertheless, some purposes' names were adjusted based on interviews' answers, to better convey their meanings. Insights for each fulfilled purpose will be provided below.

It is worth noting that in the questionnaire, the purpose "gaining knowledge about broader sustainability performance" was also frequently reported as extremely or very relevant. Nevertheless, since perspectives regarding linkages between circularity, sustainability, and types of assesments were already explored in sections 5.2 and 5.3, the topic is not further discussed in this section.

Performance monitoring and improvement

Aligned with the questionnaire purpose "internally improve and optimise CE strategies", this is one of the purposes that is most mentioned by companies and expert organisations. It relates to i) performance monitoring: using c-indicators to assess how circular a product, process, installation, or company is, and ii) target-setting and action: using c-indicators to support targets and actions for improved performance. Both aspects can be seen as distinct parts of an iterative process.

In terms of performance monitoring, the companies in the programme have conducted the assessment once, obtaining a baseline of their circularity performance. In this process, companies have been able to recognise strengths and weaknesses, some of which were not evident before (Company C, Company D). The baseline assessment has also helped them identify the relevancy of data from processes and materials that was being overlooked before (Company E, Company D). Overall, companies highlight being able to gain a broad perspective of analysis that they did not have previously, as the c-indicators help mapping all relevant stages and resources (Company C, Company B, Company E). The companies' reflections are aligned

with one of the main explicit purposes of CTI, outlined in section 5.1, which is providing a tool for self-assessment that facilitates establishing a baseline and monitoring progress. Lastly, Company C notes that the baseline can also be analysed from the perspective of mapping business risks. For example, in their case, water is an essential input, and the indicators help them oversee and manage water which can help decrease disruption risks. Company A also highlights performance monitoring as one of the main benefits provided by their internal c-indicator framework, as they present detailed an aggregated pictures of resource consumption and help understand the impact on circularity performance of projects which have integrated circularity initiatives. The experience of expert organisations aligns with companies' perspectives of highlighting the role of c-indicators for reviewing progress and guide improvements (F1, F3). In F1's experience supporting businesses, an initial circularity assessment is used to provide a systemic vision of a business, in which to base circular strategies and actions.

To act upon the results of monitoring, targets and action plans are put in place to drive improvements. Conversely, as these processes are iterative, it can also be understood that based on action plans and targets, monitoring helps quantify progress. Particularly within the programme, after the first step of determining the baseline, the results are being used to generate action plans that can lead to improvements, which should be reflected on c-indicators' results in subsequent measurements (L1). Some specific ways in which action is guided through the indicators are that they help identify opportunities for cost-savings and new revenue streams (Company C, Company D), and that they provide guidance for prioritisation and harnessing low-hanging fruits (Company E). Prioritisation of action is further supported by the digital calculation tool provided by CTI which can help test different action scenarios to estimate their potential (L1). Concrete actions emerging from the baseline results include finding a purpose for expired products and stored capital (Company C), water consumption reductions (Company E), reusing containers (Company E), and finding new alternatives for input materials and resources (Company B, Company D). Similarly, Company A with its own internal framework, highlights that they have establish KPIs at different levels in the company including projects and corporate results. They are increasingly sophisticating their targets, for example by establishing a KPI at the corporate level that relates circularity with economic performance.

The central role of c-indicators' in performance monitoring and improvement is also reflected in F2's work developing guidelines specifically to orientate companies in the utilisation of existing c-indicator frameworks and standards to set meaningful circularity targets. Indicators provide the key information needed to both determine the appropriate target, and then to check how much progress is done in reaching these targets. The importance of standards is also mentioned for target setting. Thus, there is not only a need to measure a baseline and targets, for which indicators are useful, but also it is important that the underlying concepts are clear and comparable, for which recognised standards such as ISO can be useful, to ensure everyone understands the same when a concept is used (F2).

Facilitate a learning process and cultural change

Learning about circularity and facilitating cultural change through indicators' inputs and associated language was another identified purpose. This was particularly highlighted by the companies in the programme. First, because the indicators direct the companies' attention to factors that went overlooked before. Concrete examples of these previously overlooked factors are criteria to assess sourced inputs (Company B); the importance of considering all type of sourced materials (Company B); considering water sources and release (Company D); mapping all sources of waste (Company E); identifying under-used fixed capital (Company C); and

ensuring materials' information is not understood and managed by technical experts only (Company D). Second, the indicators have helped companies acquire a more systemic view of circularity, identifying that all value chain stages, resources and materials are encompassed by it. For instance, recognising the importance of energy sources and water within circularity, as before there was an emphasis only on materials (Company B, Company D, L1); going beyond downstream activities, waste, and recycling (Company B, L1); and being able to practically distinguish between virgin and nonvirgin material (Company B). These realisations help companies to move from assumptions to evidence-based information of their overall circularity performance, impacting in their ambition level and assumed challenges (L1).

The indicators also help share the CE message across companies' business units and levels. They facilitate going from abstract concepts to the business reality, thus allowing those leading circular initiatives within a company to be specific about what is needed from different business units, and to support common understandings when discussing concepts related to circularity (Company D, Company C). Company D highlights how the framework supports conveying the importance of the topic through concrete concepts and results, making circular impacts visible. For example, they can show how moving to renewable sources of energy can have an impact on c-indicators, which contributes to transversal buy-in regarding the relevancy of circularity and sustainability topics (Company D). Related to this, indicators' results have motivated Company C to establish new types of interaction within the company to think about solutions collaboratively. For instance, field meetings with representatives from logistics, sales and sustainability have emerged due to the identification of potential areas of improvement. They have also motivated an effort to widen perspectives across the organisation, which materialises in voluntary work sessions in interdisciplinary teams, accompanied by establishing new voluntary targets for certain business units such as logistics.

External communication and reporting

While less mentioned, another purpose associated to the use of c-indicators is the ability to communicate externally. Company A, which has its own internal framework, has implemented public targets based on circularity metrics. For instance, a public global target has been launched to increase the participation of circular resources in EBITDA. The purpose of communicating externally is to signal the commitment to the market, particularly to investors, and inspire others to follow suit.

Companies in the programme, who have just completed one iteration of assessment through c-indicators, have not really yet approached this aspect, but it has been part of discussions, as noted by L1, which provides a number of reflections on this matter, outlined next. One aspect to consider is that CTI does not allow for comparability with other companies or the market, as the focus of the methodology is internal. For comparability, standards need to be ensured so methodologies and concepts used are clear and transparent. In that sense, in L1's view, the launching of ISO standards may support the ability of companies to disclose results. Furthermore, L1 also notes that many companies are working on improvements to reduce the number of assumptions used in the calculations, which is something to be solved in order to share more robust results. Related to this, companies are aware of risks of greenwashing and collective discussions within the programme have emphasised the need to thoroughly review public statements to avoid unintended greenwashing (L1).

Another point related to external communication was shared by F1, noting that companies seem to value external frameworks and support, even when they are fairly well-equipped to carry out assessments independently, because it helps somewhat validate the results obtained. Finally, while it was not mentioned in the companies' experiences, another possible benefit

regarding external communication is the ability to use it as market communication towards customers (F3).

External opportunities and collaboration

The possibility to identify new opportunities and collaboration with external actors was also mentioned by participants. In the programme, indicators' results allowed companies to connect results to solutions involving providers. For instance, to incentivise a provider of cleaning services to reuse containers which were previously treated as disposable (Company E); and discussing new materials' compositions for purchases currently made from virgin materials (Company D). One collaboration was identified with academia to find innovative solutions for complex waste streams (Company D). These initiatives are aligned with the programme's desire to support companies in finding synergies to increase circularity. Company A started working with providers early on in their integration of c-indicators, rewarding those who voluntarily disclose information related to materials through environmental product declarations. This procedure has supported the identification of opportunities for improvements with providers which can in time materialise in projects such as working with local providers, developing new skills or technological solutions to circular procurement challenges (Company A).

5.6 Factors influencing c-indicators' applicability

This section refers to the factors that affect companies' ability to make use of c-indicators. The first sub-section outlines companies' perspectives on experienced barriers, reported in the questionnaire. The second sub-section presents users' assessments of c-indicators characteristics, reported in the questionnaire and interviews. Finally, the third sub-section provides insights regarding companies' internal factors which influence their use of c-indicators.

5.6.1 Relevancy of potential barriers

The exploration of influencing factors began with the questionnaire, where companies were asked about the relevance of several potential barriers, as identified in the literature, in their experiences of implementing and using c-indicators. As shown in figure 5-6, the majority of respondents identified "new skills or competences" and "limited availability of data" as highly relevant or extremely relevant barriers in their experiences. Additionally, "assessment fatigue" and "lack of standards or benchmarks" were also highlighted as problematic. On the other hand, fewer issues were reported regarding the suitability of c-indicators to specific contexts or sectors, as well as the clarity of data requirements. However, two companies expressed significant concerns about the framework not aligning well with their particular context or sector, emphasizing this issue through optional comments. One of these companies mentioned the absence of available examples to guide the application of the methodology in their industry, which is energy generation. They even noted they do not think they will continue using the framework given its low suitability for their context. The other company added that the lack of standards and benchmarks made it challenging to interpret whether indicator results were favourable or unfavourable compared to other actors in the same industry.

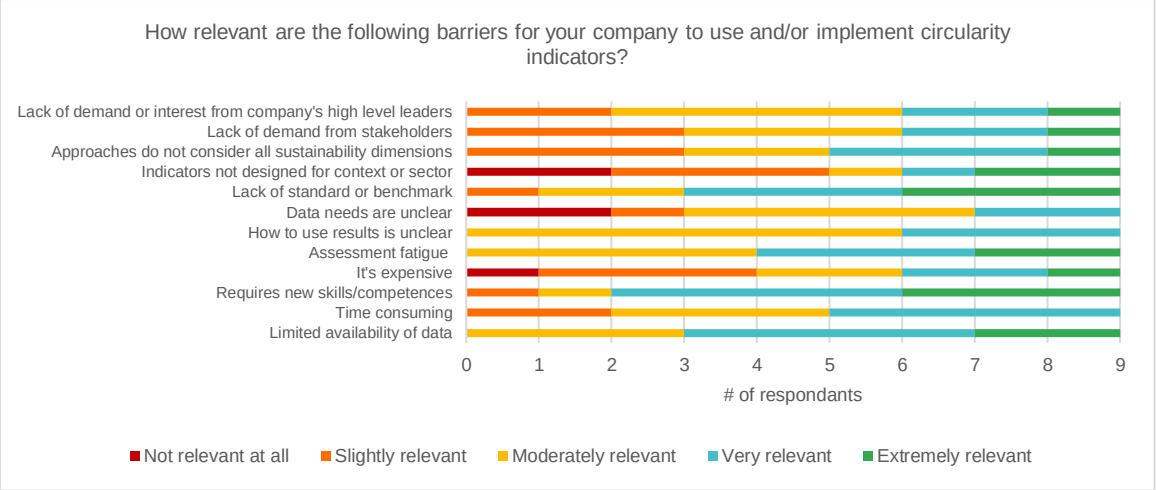

Figure 5-6. Perceived relevance of potential barriers associated to c-indicators application

5.6.2 C-indicators characteristics influencing use

This section emphasizes the assessment that companies make regarding the features of the c-indicator frameworks, along with expert organizations' perspectives on the subject. Both positive aspects and areas for improvement are identified.

In the questionnaire, companies were asked about the usefulness and practicality of the c-indicator frameworks applied. "Usefulness" was inquired by asking how useful the applied framework was regarding its contribution to strategic and operational performance in relation to circular economy. In turn, "practicality" was inquired by asking how practical the applied framework was regarding costs and time associated to learning and implementing it.
The results from these assessments in the case of the companies in the programme are presented in figures 5-7 and 5-8 below. The responses suggest there is a level of agreement among the programme's participants that the framework is most useful for operational performance, and slightly less for strategic performance. In terms of practicality, there is a more positive assessment for time required to learn and implement it, as cost seems to be an aspect in which the framework is less practical in relative terms.

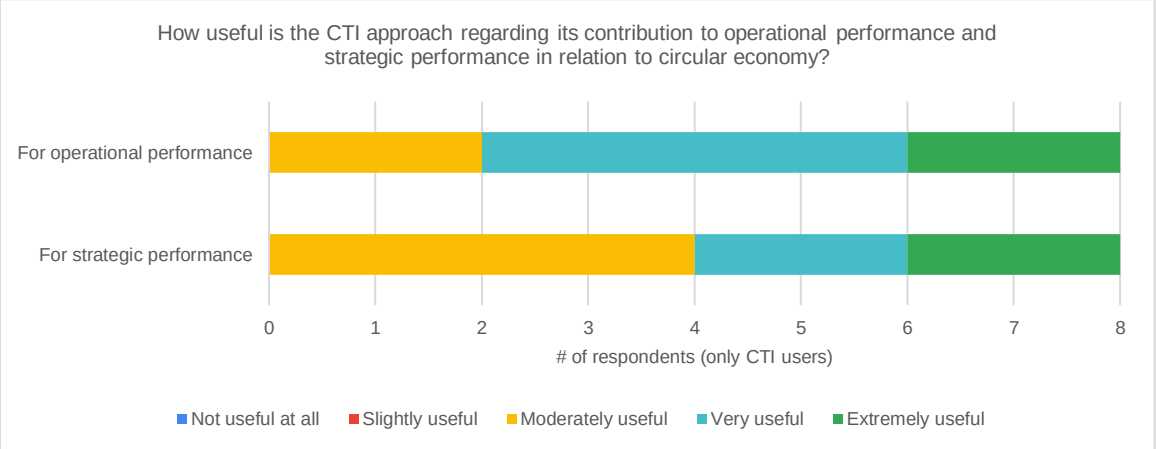

Figure 5-7. Perceived usefulness of CTI by users

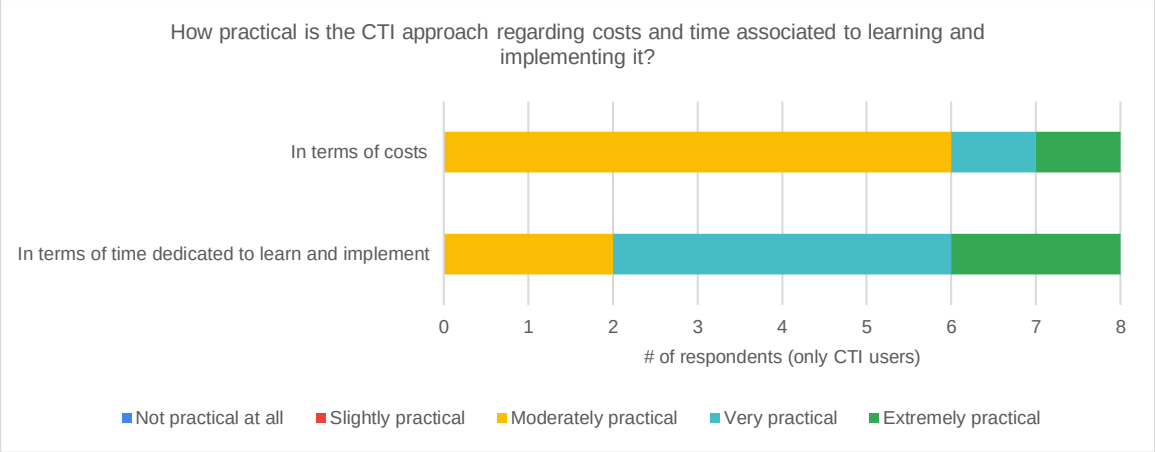

Figure 5-8. Perceived practicality of CTI by users

More comments about the c-indicators' characteristics were gathered during the interviews. Table 5-2 presents the synthesised comments for companies utilizing the CTI framework. These comments are also organised in the questionnaire categories: "practicality" and "usefulness". Based on interviews inputs, some highlighted aspects that contribute to CTI's usefulness are its high proximity to businesses' reality (Company D) and its structured classification of inputs and outputs, which helps gain clarity for decision making (Company B). Furthermore, the calculation tool supports the assessment of potential scenarios by testing parameters, which helps identify most impactful actions and limitations (L1). It is also highlighted by Company B that using an externally developed framework such as CTI helps them ensure objectivity in the quantification to guide decision-making. It is noted by Company D that CTI focuses on resources flows, with less evident links regarding circular design and contributions to the regeneration of natural systems. In this sense, Company D highlights the importance of integrating other types of guidance that can complement CTI to assess these other aspects.

In terms of practicality, it is highlighted that, once the data is gathered, the metrics in CTI are easy to calculate and interpret (Company E). The calculation tool's interface is intuitive, and it is a practical support to enable collaboration within the company in collecting and checking data (Company C). In terms of aspects that reduce practicality, the indicators' data requirements can be difficult to fulfil (Company C, Company E). Furthermore, it is worth noting that while the user manual for the framework has been translated into Spanish, the calculation tool platform is currently only available in English. This limitation could potentially hinder certain employees from receiving training and actively contributing to c-indicators' calculation (L1). Lastly, regarding cost issues reported in the questionnaire, L1 reflects this may be explained by the fact that the calculation tool will be paid after the programme, which for some companies may be a barrier, depending on their budgets. Nevertheless, it is noted by Company E that the calculation tool may not be always necessary to continue applying the c-indicators, depending on the complexity of the assessed flows.

In the case of Company A, the questionnaire's responses showed that their internal framework is considered to be very useful both in terms of contributing to strategic and operational performance. Likewise, the framework is considered very practical both in terms of cost and time. Some additional comments regarding ways to improve usefulness were gathered in the interviews with Company A. First, synthetic metrics that relate circularity and economic performance could eventually be applied in more granular ways, as now they are only generated at global level, and not in regions or countries. This could add valuable information for

decision-making. Furthermore, efforts are being made to increase the scope of providers to which circularity criteria are applied using metrics, to ensure there is information about all sourced resources. Lastly, the value of increasing data specificity is also highlighted, in terms of being able to distinguish criticality levels, which can also improve the quality of decision making based on specific qualities of materials assessed.

Table 5-2. Companies' comments regarding CTI: practicality and usefulness

	CTI framework
Usefulness *support in decision making*	-Calculation tool allows to test scenarios and identify most impactful actions - Structured classification of inputs and outputs facilitates clear picture and decision-making -High proximity to businesses' reality compared to other tools -Focus on materials use and circularity of processes, less clear link to design principles for circularity and regeneration of natural systems -Externally developed framework adds objectivity to results
Practicality *convenience and simplicity*	-Calculation tool is very practical to enable collaboration within the company, its interface is intuitive - Metrics are easy to calculate and understand (once data is collected) -Data requirements are not easy to fulfil -The tool is in English, which may prevent some employees within a company from being able to contribute to it -Cost may be an issue due to paid calculation tool and different budgets

Expert organizations offer valuable insights into the characteristics of c-indicators, particularly emphasizing the importance of common definitions and standards. It is necessary to reach an agreement on concepts and utilize common standards in order to compare targets and measure progress (F2, F3). Furthermore, these agreements enable the facilitation of coordinated improvements among actors (F3), promotes the sharing of good practices (F2), and reduces companies' confusion when selecting c-indicators from a fragmented landscape where connections and differences among various alternatives are not clear (F3). In this regard, prioritizing the adoption of standards and clear definitions that translate into operational concepts should take precedence, even if it means sacrificing some level of accuracy in modelling reality and the richness of the assessments (F3). If the development of c-indicators overly emphasises modelling the complexity of reality, there is a risk that measurement approaches employed in each specific context will be different, hindering comparisons and coordinated improvements (F3). This issue is closely to the discussion of simplicity vs specificity. Simplicity is needed enable feasible data collection, interpretation, and decision making. However, simple approaches should still allow to consider contextual differences in sectors and types of flows assessed (F3).

5.6.3 Companies' internal factors influencing the usage of c-indicators

During the interviews, companies' perceptions of their own internal factors that influence the ability to apply c-indicators were discussed. Particularly, the highlighted factors can be categorised in "Data collection and management", "Knowledge, skills and resources", and "Internal and external alignment". It can be noted that the two first factors mentioned are closely connected to the barriers reported in the questionnaire in sub-section 5.6.1. The insights will be presented below for each category. Both positive aspects and areas for improvement in relation to c-indicator implementation were discussed.

Data collection and management

The ability to access and work with data stands out as a crucial factor for the effective utilization of circularity metrics. However, it also presents significant challenges in practice. As emphasized by F2, the availability of c-indicators alone will not facilitate transitions unless there is sufficient and appropriate data to input into them.

One of the obstacles mentioned is the challenge of obtaining information that is generated outside the company; for instance regarding material purchases (L1, L3, Company A), and related to downstream processes such as water treatment (Company E). Company A notes that it is difficult to obtain detailed data about materials that would contribute to decision-making but require information located several tiers up the value chain. As highlighted by L1, certain companies in the program had to develop new information requests to their providers because they were not receiving the necessary data to assess the circularity of incoming materials. This included details about qualities such as virgin, recyclable, or renewable (L1). F2 notes issues of competitiveness and transparency may also affect a company's ability to obtain external data across the supply chain.

Apart from upstream data that may not be in the control of the company, collecting data within companies has also proven challenging. In certain instances, it was found that relevant data was not being generated (L1, L3, F1). For example, data related to strategies like lifetime extension, which deviate from linear supply chain logic, are often unavailable (F2). In other cases, the challenge lies in the unavailability of data in formats suitable for circularity assessments (L1, F1). Many companies collect data in monetary terms but lack a corresponding "physical" measure that would be valuable for calculating circularity and informing decisions (F1, L1).

Furthermore, given the novelty of circularity assessment, procedures to gather and access data are not well-established yet. In the programme, various companies and L1 note that a chain of internal workers and units may be involved in the process of obtaining specific data points, as information is not available in a centralised manner and there are no streamlined processes to obtain it (Company E, Company C, Company D, L1). For instance, Company C notes that data required to generate CTI's results was scattered, as each business unit works rather independently. Thus, there is not a central location connecting all data gathered and managed, resulting in a time-consuming process of requesting different pieces of information (Company C). Related to this fragmentation of data, information sometimes remains in individual documents and can only be gathered manually (Company B), and there is still a reliance on excel sheets (Company A).

Even if data is shared through digital management systems, cumbersome procedures may still be needed as relevant data is mixed with non-relevant data, or formats are incongruent across business sections (L1). In this sense, Company E notes that in their case accessing or requesting the information is not complex, but it is time-consuming, tedious and conflicts with workers' need to attend to other tasks. There is a perception that too many indicators are requested all the time (Company E). Furthermore, it is necessary that those requesting and those providing the data have a shared understanding of concepts associated with circularity, which requires training (L1). Due to all the aforementioned issues- inaccessible external data, non-existent or inadequate internal data, and complex internal data flows- some companies in the programme have had to rely on assumptions to create their baseline (L1). For instance, Company E notes assumptions were made regarding water circularity, as downstream processes of treatment and release are controlled by the utility company.

In certain cases, data gathering efforts have been facilitated by previous developments. For instance, due to recent EPR regulation, companies in the programme have a clear mapping of waste data (L1). L3, which is supporting the mining sector, note that due to the nature of their operations, certain aspects such as water and energy are well-measured. Company B specifically highlights the advantage of accessing a centralized information management system, which enables them to obtain a significant amount of relevant information. This centralized approach prevents duplication of efforts and the need for ad-hoc information requests (Company B). Additionally, both Company B and Company E mention that their established calculation of the carbon footprint aids in acquiring data for circularity indicators and avoids redundant information requests.

Several reflections are made regarding how to address data issues and make improvements. From the programme perspective, the idea is to support the development of action plans focused on developing capabilities to source information internally and externally, ensuring common knowledge within companies and their providers (L1). L1 envisions that in the future, required data should be shared in standardised formats as it is done in more traditional aspects of businesses, outlining aspects such as type of material, origin, or water consumed. This information could be stored to aid different calculations, including c-indicators (L1).

Companies are also considering the role of digital technologies to support more seamless information flows (Company B, Company C, Company E, Company A). For instance, Company A notes that ideally data should be unified and visualised in real time. Digitising data as much as possible would increase its ability to inform strategic decision making beyond just indicating performance. Regulations such as the DPPs in the EU could contribute to make progress in these challenges (Company A). Company B has a similar vision, and based on international examples they are working on projects to enable quick, automatic, and agile information flows, in which raw data can be consolidated to enable all kinds of assessments and reports.

Complementing the points above, F1 notes that data issues are further complicated by the fact that CE is a systemic topic where many aspects and types of data need to be considered, contrasting with the approach to carbon emissions, where an equivalent unit has been agreed on (CO2eq), which facilitates measuring progress, making comparisons, and sharing information. Furthermore, F3 highlights that once there are dominant standards and data is generated, it is still necessary to reflect about what the data can be used for and what are its limitations, which is an area where academic supports can be valuable (F3).

Knowledge, skills, and resources

Building knowledge and skills, and having dedicated resources is highly mentioned as factors affecting the ability to use c-indicators. It is recognized by various expert organisations that the concept of CE is relatively new in the corporate context. As a result, the know-how and resources allocated to CE are still in the early stages of development (F1, L3, L1, L2).

One crucial area that requires knowledge development is ensuring a comprehensive understanding of the concept of CE throughout a company, going beyond a traditional emphasis on recycling (F3, L3). Having adequate knowledge about CE is considered crucial for ensuring effective data requests, data collection, and data processing within a company; as the right knowledge helps accelerate collaboration (L1, L3). L1 emphasizes that transversal training across the entire company is essential in this regard, although it may be challenging to achieve. Furthermore, training workers or hiring new talent is also needed to make sense of

the generated information and translate it into actionable plans that can impact c-indicators' results (Company C).

According to L3, companies across various industries still need to embrace a systemic view of CE in order to effectively adopt c-indicators. For instance, companies may have isolated initiatives that align with circularity principles, but they may not necessarily perceive them as such, resulting in a lack of strategic vision to advance circularity (L3). Related to the previous point, Company D highlights that the use of CTI itself has contributed to strengthening knowledge. However, it is important to simplify concepts and messages when sharing or discussing c-indicators' results and the broader topic of CE across business divisions, otherwise messages are not effectively internalised (Company D).

Company A, which has longer years of experience implementing its own framework, mentions that resources have been dedicated to continuous learning and keeping up to date regarding CE topics. This includes advancing knowledge about indicators, technologies, regulation, and business models. Company D highlights that some workers from the sustainability unit and product development have done a course on circular economy, which has allowed them to make the topic visible for product developers.

In terms of dedicated resources, in the programme, it is noted by L1 that some teams had to allocate a person specifically to the job of collecting data and calculating the results of CTI, and others even had to hire a new employee to support the assessments.

Internal and external alignment

There is a recognition of the importance of coordination and effective communication within companies and when interacting with external stakeholders to calculate c-indicators and act based on their results. This can be challenging as it requires creating common understandings and alignment (L1, F2).

Efforts to promote alignment and coordination have been advanced by companies in the programme, which have created interdisciplinary work teams to accomplish tasks related to circularity, including applying c-indicators (Company E, Company C, Company A). For instance, Company E has gathered workers from plants, purchasing units, environmental reporting, and corporate sustainability in collaborative projects. Company B recognises that they could still further involve areas in understanding circularity implications, as currently they have just shared c-indicators' results through communication releases. In this sense, awareness is not fully spread, it may happen that those that generate and own certain data at operational level, which is used to calculate c-indicators, are not aware of their contribution, as the topic remains more secluded at corporate level (Company B).

Establishing circularity targets linked to c-indicators across units is also highlighted as a way to ensure alignment needed to leverage c-indicators' use (Company C, Company A, Company D). For example, Company C aims to initiate this process by encouraging the adoption of voluntary targets within business units where circularity challenges have been identified. These voluntary commitments empower the responsible business unit to prioritise assessments and improvements, which have been overlooked before due to a lack of emphasis on these aspects of performance, as well as a lack of cost pressures.

Related to the use of targets, the case of Company A with its own internal framework provides an illustration of how to facilitate internal alignment in the application of c-indicators and the achievement of associated goals. Based on the conceptual framework of c-indicators

introduced in section 5.1, the company has established circular KPIs at different levels in the company (even though not all business lines have integrated the approach yet). In order to ensure progress in these KPIs, the company has developed a list of potential initiatives linked to circularity and sustainability that can be implemented in projects and operations. The list of initiatives is improved in time, as new ideas are developed by specific plants or projects. Thus, by having a clear target (through KPIs), and clear potential actions to achieve them (trough the list), projects and operations are able to use c-indicators to forecast scenarios and monitor the actual impact of initiatives. Internal alignment is also supported by integrating c-indicators' results in quarterly internal reports. As a result, there is a macro-overview at global level by business unit. Company A notes that if all business lines established circularity targets, greater progress could be achieved as this would bind management to deliver results and ensure resources are allocated to measuring and managing circularity.

Lastly, related to the allocation of targets and responsibilities, Company D notes that the identification of circular opportunities may result in new revenue streams (for instance, by selling by-products), which can shift responsibilities and control from the sustainability to commercial unit. From the perspective of this study, it would be interesting to observe how circularity and sustainability assessment of these opportunities is handled once responsibilities are transferred.

Another element that helps coordination and alignment is having a dedicated person or team that is clearly responsible for developing, calculating, monitoring, and overseeing targets achievements (Company C, Company A). In Company A, for instance, there is a corporate team in charge of developing strategic models and metrics related to the overall performance of the company, which includes c-indicators. Within business units and projects there are also experts in circularity assessment to develop more granular metrics and support their calculation (Company A). Furthermore, Company C notes the importance of establishing periodic measurements to represent the dynamic reality of the business.

Regarding external alignment and coordination with other actors to enable the application of c-indicators, a value chain perspective is needed. In the programme, companies were usually more familiar with downstream actions related to waste management, thus they have worked in incorporating a wider perspective regarding circularity (L1). The challenge of fully developing the value chain perspective is also acknowledged by L3, which supports the mining industry. The lack of this perspective creates a gap in measuring circularity upstream, particularly in terms of procurement. However, L3 suggests that over time, this gap can be bridged by working on defining the criteria that should be measured by procurement. This can be supported by the operational units, as they directly utilize the materials sourced, ensuring a more comprehensive measurement of circularity throughout the value chain. Lastly, as introduced earlier, Company A has taken a gradual approach to integrate providers in circularity assessment. Environmental product declarations are used to collect the information from providers who voluntarily decide to disclose. It is acknowledged there is still more work to do to ensure all procurement information is available (Company A).

6 Discussion

This chapter summarises and positions the findings according to their contribution to answering the RQs, relating the results to previous literature and reflecting on their knowledge contribution. Then, it provides a number of reflections on how different participants' perspective share commonalities and differences. Lastly, this chapter also provides reflections about limitations of the study.

6.1 Knowledge contribution

RQ1: What purposes do circularity indicators provide for companies?
Companies in the study have adopted c-indicators to support their transition to circularity. In this sense, once the CE is recognised as a topic of interest, then c-indicators are introduced to facilitate operationalisation.

In terms of purposes that c-indicators have helped fulfil, based on a joint analysis of the questionnaire and interviews, companies largely agree in the relevancy of c-indicators to improve and optimise circular strategies. In this sense, c-indicators have been used in practice to monitor performance, to establish appropriate targets, and to guide actions. Furthermore, there is a relatively high emphasis on the use of c-indicators in facilitating learning processes and cultural changes, especially related to increasing awareness about the systemic nature of CE, as well as having a language that is connected to tangible topics and businesses' realities.

These perceived purposes are aligned with empirical findings by Roos Lindgreen et al. (2022), in which practitioners frequently mentioned circularity assessment as support for performance improvement and learning processes. Nevertheless, within the benefit of improving circular performance, the thesis findings signal a much more explicit interest from practitioners in using c-indicators to support target-setting, compared to the previous study. In general, the purpose of target-setting facilitated by c-indicators was not largely discussed in previous literature, though Saidani et al. (2019) recognise the role of c-indicators in helping setting suitable targets. Target-setting in the realm of circularity may be a rather nascent practice which may explain a lack of previous emphasis.

Furthermore, the fact that c-indicators have helped companies learn about CE and acquire a language that can be shared internally and externally can be related to the reflections provided by Parchomenko et al. (2019). In their review, it is noted that c-indicators can influence how CE is shaped as a concept, as specific frameworks may emphasise particular properties and strategies connected to CE. Furthermore, authors have also noted that usually, existing c-indicator frameworks cannot comprehensively address every circular strategy and every consideration that is relevant to prioritise these strategies (Chrispim et al., 2023; Corona et al., 2019). These reflections call for caution in interpreting c-indicators' results, to avoid over-focusing only in what it is make visible by them, which may mean overlooking other courses of action that could be more beneficial, for instance in terms of value retention or avoiding burden-shifting (Corona et al., 2019). This caution was to some extent also noted by one company in the study, as presented in section 5.6.2., which also suggested companies should consider the adoption of other assessment tools that can help cover circular considerations that are not in the scope of current approaches. This last reflection aligns with suggestions by Chrispim et al. (2023), who note that by using a selection of various tools simultaneously can help overcome identified weaknesses of specific frameworks.

Regarding other purposes discussed by practitioners, in the questionnaire companies also assigned a high level of relevance to c-indicators' role in identifying opportunities for external collaboration. Nevertheless, in practice, this is not yet reflected as much as the two previous reported purposes. This may be expected, as most companies are just starting to apply c-indicators, thus the timeframe to activate collaborative initiatives has been short. Additionally, marketing and improving company's reputation seems to be relatively less relevant for companies. In contrast, in the study by Roos Lindgreen et al. (2022), practitioners emphasised circularity assessment's role in aiding marketing efforts and reputation improvement. As reflected in the discussions with practitioners, external communication- encompassing marketing purposes but also reporting to stakeholders- may become more important as assessment procedures are further established, and results reach a proper level of robustness. Furthermore, potential future regulations in the companies' context may increase the relevancy of applying c-indicators to aid information disclosure, as seen in the EU, where policies such as the CSRD and DPPs can arguably have this effect.

Across the main purposes associated to c-indicators, a feature that stands out in all of them is the ability of c-indicator frameworks to provide a broad and systemic picture of CE to support decision-making and actions. For companies in the programme, this perspective was not so explicit before, circularity was more constrained in terms of strategies, resources, and relevant internal and external actors involved. Similarly, in Company A with its own framework, the c-indicator framework supports the tangible integration of CE across value chain stages, business units and levels. This aligns with previous studies focused on the role of data to leverage circular transitions, which have highlighted the level of system perspective that is required to approach circular strategies. For instance, Serna-Guerrero et al. (2022) note that CE is associated with new demands for analysis, use and sharing of data that considers material life cycles at a systemic level. Furthermore, Kristoffersen et al. (2021), highlight that this systemic nature of CE results in the need to capture data internally and externally, from multiple sources, and with different structures. In this sense, c-indicators seem to help structure and scope these new data requirements, and thus may provide guidance to make decisions based in broader systemic perspectives. At the same time, as it was mentioned earlier, previous literature has highlighted that existing c-indicator frameworks do not usually address the whole complexity and systemic perspective of CE (Chrispim et al., 2023; Corona et al., 2019). In this regard, the findings of this thesis can be interpreted as indicating that, when companies have a rather constrained understanding of CE, the adoption of a specific c-indicator framework may help them integrate a broader perspective to increase their scope of circular action, even if this not yet reflects a fully comprehensive operationalisation of circularity. Understandably attempting to integrate circular strategies and criteria all at once may not be feasible, and in this sense more simplified c-indicator frameworks remain valuable. However, it is important to ensure that their use does not hinder further progress in understanding the holistic implications of circularity and the systemic perspective it entails.

RQ2: What factors influence the application of circularity indicators in companies?
In terms of factors influencing c-indicators application, several are identified by practitioners. These are largely agreed upon between questionnaire's responses and interviews' inputs. The most highlighted factors are data issues; requirement of new knowledge, skills, and resources; and lack of benchmark and standards.

Data collection from outside and within companies is difficult, as procedures and technology are not completely in place, which results in cumbersome processes, and the need to rely in assumptions. More fundamentally, specific data is not yet generated in some cases, or at least not in suitable formats. These findings can also be linked to literature studying data as a key

resource for advancing circular transitions, which was already mentioned in the discussion of the previous RQ. This literature has also highlighted particular data requirements and challenges due to the CE's systemic nature, which imposes new information formats, structures, and exchanges (Kristoffersen et al., 2021; Serna-Guerrero et al., 2022). Previous findings can be applied to the context of this study, which suggest that companies applying c-indicators may need to overcome a series of challenges associated to improve data management; such as hesitancy to share data which may be considered strategic with other actors, lack of trust and commitment and incompatibility of formats (Gupta et al., 2019; Luoma et al., 2021; Rajput & Singh, 2019; Serna-Guerrero et al., 2022; Tseng et al., 2018).

While access to data and proper data management is a current challenge in the application of c-indicators, at the same time, as reported by practitioners in the study, adopting c-indicators frameworks provides guidance to identify relevant data needs. This finding supports the perspective provided by Serna-Guerrero et al. (2022), highlighting that c-indicators can serve as a guidance to identify what information is relevant to assess circularity, which can promote data exchange among value chain actors. Additionally, regulation and stakeholders' pressures may also accelerate the process of standardised data generation and sharing. In the Chilean context, this is for instance reported by practitioners regarding waste topics, where ERP regulation has pushed companies to have a better information management. Moreover, previous requirements on carbon footprint accounting, have contributed to data availability for c-indicators' calculation, as information overlaps. Furthermore, initiatives such as the EU's digital product passports and ISO standardisation may also help overcome data exchange challenges.

A last point regarding data issues is the role of technology. Companies are already identifying technology opportunities to address their increasing needs to assess and report simultaneously about various topics. It is perceived that digital technologies can facilitate information flows and thus increase the potential to promptly make use of generated data for assessment and decision-making. In this sense, c-indicators' application interacts with a nascent field of study dedicated to the use of digital technologies to leverage business analytics' support for circular transitions, as seen in studies such as Kristoffersen et al. (2021) and Gupta et al. (2019).

Regarding new knowledge, skills, and resources as influencing factors, identified needs range from having a clear understanding of CE and its scope, to acquiring the specific knowledge required to interpret metrics' results and suggest actions. In this sense, ensuring training transversally within a company is highlighted. Other perceived needs are sourcing expertise and dedicating resources to c-indicators' calculation and targets, implementing plans, and keeping updated with CE-related knowledge progress. As with data issues, while successfully using c-indicators requires new skills and resources, adopting these types of frameworks also facilitates learning and common understandings within and across companies. To the best of the author's knowledge, previous literature has not identified empirical examples of skills and resources needed for the application of c-indicators before, thus this thesis provides new information in line with researchers' call for more insights about users' current knowledge and what kind of expertise is required or missing to successfully use available options (Chrispim et al., 2023; Saidani et al., 2019). Overall, the needs are in line and expand on the conceptual review by Chrispim et al. (2023), in which it is highlighted that users need to understand the concept of CE, the meaning of each circular strategy, and have the skills to conduct the required calculations.

In the questionnaire, the barrier "lack of standard or benchmark" was the second most frequently identified as "extremely relevant" for the application of c-indicators. While in the

interviews companies did not direct the conversation predominantly towards this issue, practitioners from expert organisations reflected about it, noting that common definitions and standards are much needed for companies' application of c-indicators, as otherwise issues regarding frameworks selection, comparability, coordination, and good practice sharing become difficult. These results suggest that practitioners have experienced the consequences of what in the literature was conceptualised as fragmentation around c-indicators alternatives. This is argued to hinder comparability of results across users (De Pascale et al., 2021), while resulting in a confusing set of options (Kristensen & Mosgaard, 2020; Negri et al., 2021) and preventing the validation and verification of CE efforts (Kristensen & Mosgaard, 2020).

From a broader perspective, data-related challenges and demands for new knowledge, skills, and resources are also highly related to the systemic nature of CE. The application of c-indicators requires new types of internal and external collaborations and a common language. In practice, this means that ensuring alignment and coordination among actors internally and externally have been key factors in the application of c-indicators. Companies' insights reflect a number of good practices in these areas. Internal practices highlighted are, for instance, interdisciplinary teams for circular projects; integration of indicators' results in established internal reporting systems; c-indicators' "owners" with clear responsibilities; integration of experts transversally across business units; and establishing targets associated to c-indicators across business units. Furthermore, the integration of c-indicators and targets across business units can be aided by specifying what is relevant to measure in each context, having a clear connection between targets and potential actions to increase performance, and leveraging c-indicators to compare scenarios. In turn, to incentivise external alignment- which in the context of applying c-indicators is needed to gather data and achieve improvements- setting clear criteria and targets for procurement are needed, as well as facilitating providers' provision of new data, for example through Environmental Product Declarations. These insights help contribute to the knowledge gaps highlighted by Saidani et al. (2019) regarding best practices in the application of circularity assessment. It can also be linked to Vinante et al. (2021), who, similarly to practitioners' in the study, highlight the importance of mapping business functions involved in circularity assessment and the need to allocate the responsibilities of gathering data, calculating metrics, and improving assessments.

RQ3: What are the linkages between circularity indicators and sustainability assessment in companies?

This question was approached from the perspective of situating c-indicators in the broader context of companies' assessment and reporting practices, identifying if circularity assessment and sustainability assessment are differentiated, exploring interactions in data flows, and inquiring the assessment of sustainability impacts from circular strategies.

Companies report already having in place- or planning to apply- a number of assessment and reporting approaches beyond c-indicators, such as GRI sustainability reporting standards, GHG protocol for carbon accounting, and recognition of SDGs. In this context, c-indicators are integrated to a number of other assessment tasks. Generally, the c-indicators provide a novel perspective of assessment. That is to say, the outcomes of the calculation encompass a systemic view which was not present before, providing insights that can point into new areas to be managed and improved.

At the same time, c-indicators require data that can overlap with other assessments. Particularly, for companies who were just starting the adoption of c-indicator, information gathered to generate carbon footprint results can facilitate c-indicators' calculation. In the case of Company A with its own framework, circularity and sustainability impact metrics are parallel

components of a broader assessment framework. These data interactions can be contrasted to literature. As shown in the review by Opferkuch et al. (2022), it has been advocated that a comprehensive assessment of circular strategies should consider two steps. First, intrinsic circularity should be measured through mapping resource flows, and then, the associated sustainability impacts should be quantified. The logic is that mapping resource flows provides information needed to calculate sustainability impacts (Roos Lindgreen et al., 2022). More generally, this linkages between circularity and sustainability assessment can be understood as complementing c-indicators focused in measuring intrinsic circularity with methodologies that focus on sustainability impacts (Roos Lindgreen et al., 2020; Saidani et al., 2019). This type of interaction is arguably present in the case of Company A with its own framework.

Companies who are just starting the adoption of c-indicators may be engaging in both circularity and sustainability assessments. However, the structured connection or complementary nature between these two assessments does not appear to be well-established at this point.
Furthermore, for companies that are new to adopting c-indicators, it is reasonable to observe that carbon footprint calculations serve as a precursor in terms of information flows, given that carbon footprint assessments were established earlier in practice. Nevertheless, beyond the current convenience of this relationship, and considering the point made above about a two-step approach to comprehensively assess circular strategies, it may be beneficial to structure assessment approaches understanding which one is a more natural precursor and which one is a final objective from a sustainability point of view.

Regarding their broader assessment practices, companies do not seem to agree on the goals of assessment and reporting approaches, in terms of whether they mainly provide information about sustainability, circularity, or both. Interestingly, more companies using the CTI framework perceived it as being useful for measuring both circularity and sustainability. In contrast, based on the definitions presented in this thesis and the indications in CTI's user guide, the second version of CTI- which is being applied by companies in the study- is focused on measuring intrinsic circularity only. Thus, companies' perception may be indicating that the distinction between circularity and sustainability assessment are not clearly defined, aligned with Roos Lindgreen et al. (2022) findings in the EU context, where they found the distinction between this type of assessments is blurred.

More concretely, circularity initiatives are being managed as one component within environmental sustainability strategies. Consequently, c-indicators are often perceived as one type of environmental assessment. From the perspective of this thesis, these linkages are expected and logical, because circular strategies are put in place mainly to help reduce environmental impacts related to material resources. These findings are also aligned with Roos Lindgreen et al. (2022), where circularity assessment is often seen by companies as part of a wider sustainability assessment framework.

This way of managing assessments is also aligned with conceptual understandings reported in the thesis. CE is seen as a tool to achieve more sustainable outcomes, while also being included within sustainability as an environmental aspect. This type of relationships between the concepts of CE and sustainability are aligned with the empirical findings by Walker et al. (2022). In their study, companies reported two main views. First, CE is implemented to achieve sustainability (sometimes recognising the possibility of trade-offs). Second, the difference between CE and sustainability is reportedly not relevant in practice.

Furthermore, in the thesis, practitioners do not explicitly see CE as a *necessary* condition to achieve sustainability, rather as a beneficial tool to be used when relevant. Some also recognise CE may not always ensure positive sustainability impacts. Considering the three categories to describe links between CE and sustainability proposed by Geissdoerfer et al. (2017), namely conditional, beneficial, and trade-off relationships; in the study relationships tend to focus on beneficial and trade-off interactions. Lastly, it should be noted there are also other reasons which make using circular strategies attractive beyond achieving environmental improvements. As shown by companies' examples, from a business perspective, circularity provides a way to decouple from resource consumption which can help address issues with critical materials or findings new revenue streams.

Despite the complex and multiple relationships found between assessment types and concepts, when directly asked, companies acknowledge that there is a difference between verifying circularity performance and final sustainability impacts. These reflections are mainly focused on the environmental dimension. Economic assessment of circular strategies is a basic requirement, but its associated complexities were not studied in this thesis, whereas the social dimension remains reportedly much harder to incorporate in the evaluation of circular strategies and was also not deeply explored in the study. Nevertheless, it is worth noting that previous literature has highlighted the lack of connection between social aspects and CE assessment tools (Chrispim et al., 2023). This is reflected in companies' experiences, as they do not identify clear approaches to carry out social assessments, and the current c-indicators are only focusing on intrinsic circularity. Considering the previous comments, the discussion below focuses on the connection between circularity and environmental impacts, which in practice are more connected to circularity initiatives, as shown in the previous paragraphs.

In practice, companies tend to rely on rules of thumb in which improving resource flows should lead to positive final impacts, which commonly relate to GHG emissions and water issues. This is aligned with empirical findings by Das et al. (2022) in mostly European settings, who observe that a majority of companies measured environmental impact based on various rules of thumb. At the same time, it should be noted that in literature, resource-related indicators, which are included in c-indicator frameworks, are also considered part of environmental sustainability assessment. For example, Park & Kremer (2017), who in their study only discusses sustainability indicators, with no mention to circularity; note that companies tend to integrate material use indicators more frequently within their sustainability assessment because they are straightforward to calculate and understand.

Overall, companies' recognition of assessment approaches as focused on circularity or sustainability, as well as their reliance on resource-related indicators to imply positive final impacts; demonstrate how in practice companies operationalise the concepts in the absence of streamlined methods and approaches to calculate more final impacts. In this line, Harris et al. (2021) note that c-indicators based on value or mass could act as proxy indicators to environmental impacts *if* there is proven connection between the indicators and impacts through LCA. Nevertheless, the correlation between c-indicators and final environmental impacts is not yet fully understood or mapped (Harris et al., 2021). Thus, an important point is that no matter if an assessment is perceived to belong to circularity or sustainability, caution should be exercised when drawing environmental implications from c-indicators performance. A way to address this is illustrated by Company A with its own framework, which ensures that when assessing and managing circularity performance; other "complementary assessments" are also conducted in the scope of the project or operations analysed, to keep track of more final impacts in emissions and water.

In practice, companies' perspectives suggest c-indicators and associated targets are intended to support circularity improvements as a desirable final outcome. To some extent, this focus on improving circularity as a desirable final impact can be linked to a concern outlined by previous literature. Basing decisions on c-indicators' performance may lead to circularity improvements that are not necessarily considering whether the chosen course of action improves economic, environmental and social performance (Harris et al., 2021; Roos Lindgreen et al., 2022; Saidani et al., 2022).

6.2 Reflections on common and contrasting perspectives

Although the focus of the thesis' analysis was not in making comparisons, some interesting commonalities and contrasts can be highlighted, such as the perspectives of companies using different c-indicator frameworks, the nuances of the Chilean vs European perception of circularity, and the opinions of companies vs expert organizations.

While the two c-indicator frameworks used by the companies in the study (see section 5.1) are relatively similar in terms of type of metrics, methodology and strategies addressed, users' perspectives among the two frameworks likely differed due to different levels of maturity in their adoption. Company A with its own framework has had more time to iterate the indicators and learn from their application. This has arguably resulted in more established procedures to integrate assessment practices across business units and the results of assessment in the company's decision making. This higher maturity is also suggested in the purposes of c-indicators that they highlight more. Companies in the programme (Company B, Company C, Company D and Company E) that are implementing the CTI focused relatively more on the framework's facilitation of a learning process around CE, whereas Company A with its own framework tend to mention more the role in external communication.

Another source of comparison can be identified between Chilean and European practitioners' perspectives. Apart from different regulatory scenarios which characterise their backgrounds but was not discussed in this study, the more noticeable difference was that the European perspective tended to place more emphasis on the fact that circularity and sustainability can have trade-off relationships, and thus that circularity improvements may not always be the best way to achieve sustainability improvements. In turn, Chilean practitioners were in general less explicit in reflecting about these types of trade-offs. Nevertheless, when expert organisations from Chile and Europe discussed their experiences working with companies in the adoption of c-indicators, some messages were greatly shared, particularly in the identification companies' motivations to adopt c-indicators, the distinct challenges that circularity assessment imposes due to its systemic nature, and the novelty of its application in companies.

Lastly, a contrast of perspectives was observed between companies and expert organisations. Evidently, due to their different roles in the application of c-indicators, the emphasis of their insights was different, and the intended focus of the interviews also varied. A point of difference identified was that expert practitioners tend to be more explicit in highlighting the importance of recognising the systemic nature of CE, which means circularity assessment's scope encompasses value chain stages and varied strategies. Companies were less explicit to make these recognitions in the same comprehensive manner. In any case, as shown in the findings, the c-indicators have actually helped companies in integrating the broader CE perspective. Lastly, a common point between expert organisations and companies is that they both highly emphasised the existence of data challenges associated to the use of c-indicators. This wide agreement in perspectives strongly suggests that data challenges are a common reality of c-indicators application in companies.

6.3 Limitations

There are a number of aspects that should be considered to interpret the results of this thesis. This is an exploratory qualitative study, gathering perspectives from practitioners in particular settings. The evidence provided does not aim to be conclusive or generalisable to other contexts. Rather, generated insights can be seen as a starting point that identifies potential key areas for further research and discussions with industry, contributing with more empirical perspectives linked to literature themes that have remained mostly theoretical.

Before conducting data collection, very limited information was available about practitioners' experience in transitioning to more circular practices and adopting c-indicators in the selected context. Thus, it was deemed more valuable to cover a wide range of topics within the area of study, as with no knowledge about how superficial or nuanced their experiences have been, there was not enough justification to focus in only one aspect. This meant favouring breadth over depth. This choice had implications in terms of how well relevant components were addressed, especially in interviews, because it was not always possible to cover all dimensions of research questions with all participants, due to time limits. Rather, the approach taken was to allow participants to focus on what more naturally emerged in their answers, which meant sacrificing the discussion of certain topics. Therefore, a level of fragmentation exists in insights' origins, which reduces the ability to generalise patterns even within the practitioners' shared settings. Regardless, the prioritised aim of the study was to recognise potential key topics which can signal opportunities for further research and industry action, providing a more empirical perspective to key themes identified in theoretical literature, thus the choice of breadth helped accomplish this aim.

Similarly, due to the recency of c-indicators, it is acknowledged that the literature review relies more heavily in a number of selected papers, because these were deemed as the most relevant for the areas of study, especially regarding empirical sources. Adding to this situation, since the thesis aimed to cover a wide range of topics, the literature reviewed had to balance breadth and depth in each different topic, which may have contributed to a heavier reliance in selected papers. Thus, the number of perspectives in which the study and its implications are analysed may be rather limited. In time, literature is expected to become richer, and this should be considered when contrasting the findings of this study.

The questionnaire' responses should also be carefully interpreted. The questionnaire's aim was to support the collection of preliminary qualitative information, while also enabling to obtain some complementary insights from companies that were not participating in the interviews. Thus, the responses do not provide any type of statistical evidence, and the results cannot be generalised to other contexts. Furthermore, to keep the questionnaire short and simple, instructions and explanations were concise, which may have resulted in some questions being somewhat open for interpretation.

In particular, question 7 "*If your company is using (or planning to use) any of the following measuring/reporting approaches, please indicate if you believe they can be used for sustainability assessment, circular assessment, or both*" may have been confusing. Subsequent interviews suggested that some companies may have reported using, or planning to use, specific approaches which they do not actually consider now or in the future. To overcome this, a revision of public annual reports was conducted to obtain some verifiable information about assessment and reporting approaches that are actually being used by interviewed companies.

Furthermore, also in question 7, the list of approaches provided is a combination of different types of tools. For example, LCA and MFA are calculation methodologies, while GRI and SASB are reporting standards. Thus, the intelligibility of the question may had been improved if approaches were classified according to their objective. Likewise, for question 9 "*Considering c-indicators used by your company. Do these contribute with information to other assessment and reporting approaches?",* three respondents wrote complementary comments reflecting different interpretations of the question. While the answers are still relevant to answer the RQs, future studies in this topic could better explain the types of relationships they are inquiring about, to get more precise answers.

Furthermore, none of the data collection instruments gathered explicit perspectives about how companies understand the concept of sustainability and sustainability assessment. The analysis would have been enriched if this insight was more intentionally considered. Nevertheless, this would have meant a broader scope, which was deemed not feasible. In any case, interviewees were motivated to discuss the linkages, which allowed to obtain sufficient insights. Likewise, an important contextual component to consider was the level of awareness that companies had about c-indicators before adopting them, progress made in their utilisation, and willingness to keep using them. While related insights were collected in the study, this could have been more systematically explored, by adding specific questions in the questionnaire. Nevertheless, with the aim to keep the questionnaire as short as possible to increase the probability of responses, the inclusion of this additional question may have meant sacrificing others.

Some topics were addressed both in the questionnaire and interviews. Nevertheless, when reporting the findings, some themes were renamed from original concepts used in the questionnaire. While this was deemed necessary to better convey the meanings of topics, further efforts could be made to help the reader link questionnaire results with final themes and insights from interviews.

The thesis' analysis was guided by a conceptual framework gathering elements of previous literature in the realm of c-indicators and circularity assessment. Nevertheless, it is acknowledged that the analysis of influencing factors related to companies' characteristics could have been framed within existing organisational theories. More generally, it would have been useful to further explored theoretical frameworks regarding sustainability indicators or indicators in general, which are more matured and can be related to the use of c-indicators. However, due to the breadth of the thesis this was not prioritised as the focus was on identifying preliminary empirical evidence. Subsequent studies with a more specific focus may benefit from applying a theoretical lens such as the ones indicated.

Companies in the study, no matter their level of progress, are all going through highly iterative and organic processes to improve their integration of CE. This means that the insights presented in this work reflect a point in time in this journey, which may be contrasted with past and future experiences. In this context, periodic updates of documented practitioners' experiences in these topics remain valuable.

7 Conclusions

CE offers new ways in which to organise production and consumption systems that can help face sustainability challenges. To contribute to circular transitions, companies can implement a number of circular strategies. At the same time, to support companies' implementation of circular strategies, circularity assessment approaches can be applied to verify their performance. Within circularity assessment, c-indicators are one alternative that has been increasingly developed and that is starting to be adopted by companies. In this context, through inquiry of practitioners' experiences, this study explored companies' perspectives regarding the use of c-indicators. In particular, the study identifies purposes that c-indicators can provide to companies, factors that have influenced the application of c-indicators, and linkages between c-indicators with sustainability assessment.

Insights were obtained from 9 companies through use of a questionnaire, followed by 7 interviews with 5 companies, and 6 interviews with expert organisations. The findings of this thesis are three-fold. First, c-indicators have offered valuable support mainly to monitor and improve circularity performance and facilitate learning processes within companies. They are also often recognised for their support to external communication and identification of opportunities for collaboration, although this is to a lesser extent. Second, the factors that most influence companies' application of c-indicators relate to data availability and management; new knowledge, skills, and resources; and the ability to generate internal and external alignment around the concept of CE and the relevance of assessing circularity. Lastly, given the novelty of c-indicators, circularity assessment, and the integration of circular strategies, various perspectives coexist regarding how the concepts of circularity and sustainability interrelate and how these linkages are reflected in assessment practices. Overall, two key messages from this thesis can be provided to make progress in making linkages more explicit. First, acknowledging information overlaps between circularity assessment and sustainability assessment can help streamline data management processes and facilitate calculation procedures. Second, to enhance the potential of circularity to contribute towards sustainability, it is relevant to explicitly distinguish between circularity performance and the verification of sustainability impacts arising from this circularity performance in practice, which can support the establishment of appropriate and comprehensive assessment systems.

7.1 Implications for practitioners

Based on the main identified purposes that c-indicator frameworks are providing to companies, those involved in their development can consider these examples to identify areas that can be prioritised in further improvements or new proposals. **For instance, since companies highlight that c-indicators have supported learning, special attention can be put in providing enough information to ensure users do not overlook relevant CE-related aspects that may not be addressed by the frameworks directly.** These aspects could be related to circular strategies that are not covered by the framework, or the recognition that circular strategies are not equally valuable in terms of sustainable impact, as some are better than others in retaining value and avoiding additional burdens.

Highlighted influential factors signal areas where companies, and those who support them in their circular transitions, can focus to ensure c-indicators application is successful. For instance, data related to resources' qualities and quantities is fundamental to calculate c-indicators used by companies in this study. This data needs to be generated and made available to different actors across value chains to enable circularity assessment. To aid this process of data creation and sharing, private sector networks can support discussions regarding data exchange between companies, as well as highlight good

practices in data management within companies to accelerate transitions to digitally-enabled decision making. Furthermore, technology solutions providers can make use of exemplified challenges in managing data imposed by CE's systemic nature to further develop solutions tailored to companies carrying out circular transitions. Companies can consider the difficulty of disseminating concepts and knowledge across business units by developing training initiatives and integrating experts where needed. Companies can also promote interdisciplinary teams and develop internal guidance tools to help business units connect c-indicators and targets to their reality.

Regarding the conceptual understanding of CE and sustainability, the insights may help practitioners reflect about how CE can be explicitly linked to sustainability and business goals. In this sense, it is acknowledged from the perspective of this thesis that there may be many ways in which CE can be understood with respect to sustainability, and conceptual discussions may not be the most impactful task to advance tangible progress. Nevertheless, selecting a CE definition and ensuring concepts are consistently used to refer to circularity, sustainability, and environmental aspects may support operationalisation. **Above all, beyond the concepts, it would be helpful to ensure the distinction between managing resource-related properties and environmental, social, and economic effects.** It is worth noting that the CTI framework explicitly states in its user guide that "The framework does not evaluate the environmental and social impacts of the company's circular activities. However, understanding mass flows is a major step to knowing their impacts" (WBCSD, 2021, p. 8). Thus, companies adopting the CTI framework, as well as practitioners supporting its adoption, are recommended to prioritize and emphasize this important consideration made by the WBCSD, which related to ensuring that circular performance is not equated to environmental impacts performance.

Identification of potential and existing interactions in information flows between c-indicators and sustainability assessment can support practitioners in identifying data structures that are more streamlined, following a logical order from accounting for resource flows, which can then be used as an input to calculate both circularity and environmental impact metrics. In this sense, the current scope of circularity assessment and, for instance, GHG emissions accounting, was not the same in studied companies. Nevertheless, through time, if circularity assessment becomes an established practice, its comprehensive data gathering may serve as input to calculate not only specific c-indicators, but also to inform carbon accounting, LCAs, and any other type of sustainability impact quantification; as outlined by Roos Lindgreen et al., (2022). An observation involving the CTI framework, is that in a more recent version which was not applied by the companies in the programme, the assessment considers an optional module to measure the impact of circularity in sustainability. According to the guide, this will be further developed in future versions, but for now it allows to compare GHG emissions in the actual circularity scenario versus a scenario where all inflows are recycled. If users apply this module, it would be relevant to keep in mind the hierarchy of circular strategies that can be integrated in businesses, as recycled material often does not represent the most valuable strategy in terms of sustainability impacts (Chrispim et al., 2023; Corona et al., 2019; Parchomenko et al., 2019)..

Furthermore, the study's documentation of practices (or lack of thereof) to assess the sustainability impacts of circularity initiatives, can help identify areas where practitioners within companies, as well as those supporting companies, should dedicate attention. In particular, most companies rely on the assumption that improvements in circularity performance should be positively reflected in the companies' carbon footprint, to name the environmental aspect more commonly being managed. Nevertheless, only relying

on this assumption may result in overlooking trade-offs and being unable to verify the actual impact of an initiative. In this sense, a valuable area for further improvement would be the establishment of more concrete assessment procedures associated to circular strategies, linked for instance to the aforementioned idea of streamlining data towards various quantifications. The case of Company A highlights an explicit procedure to ensure that relevant aspects are not overlooked when assessing projects and operations. **This is based in the integration of both circularity assessment and other "complementary" approaches to account for impacts. Depending on available resources, companies can put in place similar procedures or develop other ways in which to account, to the extent possible, for impacts and trade-offs. These procedures could allow a more explicit distinction between desired outcomes (improved sustainability) and means to achieve it (e.g., circular initiatives).**

Lastly, it is worth noting that, as highlighted by Siderius & Poldner (2021), while measuring and addressing the final outcomes of circular strategies is needed, **the acknowledgment of trade-offs should not lead to inaction towards more sustainable practices that could be realised through circularity.** In this sense, advancing circular initiatives can be seen as an iterative process, which can hopefully become increasingly informed by the most appropriate assessment procedures to guide decisions. In turn, assessment procedures can be improved as practitioners and academia recognise current challenges in practice and dedicate resources to find feasible solutions.

7.2 Implications for future research

First of all, as the insights presented in this work reflect a point in time in companies' adoption and use of c-indicators, periodic updates of practitioners' experiences in these topics will be valuable to understand challenges that remain difficult to overcome, as well as novel good practices, and companies' more experienced evaluation of c-indicators' utility. These future studies can also contribute to verifying whether c-indicators have had an effect on advancing positive sustainability impacts.

The thesis explored factors that influence the application of c-indicators. These factors encompassed metrics' own characteristics and companies' internal aspects. It is noted that external factors such as regulation, other stakeholders' pressures, and standardisation efforts may play an increasing role in affecting circularity assessment application. Thus, these types of external factors could be further explored in future studies, understanding how they affect companies' decision-making regarding c-indicators, and how they facilitate or hinder their utilisation.

When asking about their assessment and reporting practices in the questionnaire, most companies reported using internally developed approaches in combination to established, third-party tools. To maintain the focus on the selected c-indicator frameworks, no further inquiries were done regarding these internal approaches. Future research could explore what is considered within internal sustainability and circularity assessment approaches, and how they support or interact with other assessment practices. This may help, for instance, observe what are companies more developed capacities regarding assessment approaches, and what areas remain less developed.

Future research could investigate how companies who are collecting circularity-related data and have committed to measuring or manage a range of environmental impacts connect assessments in terms of information flows and decision making. For instance, one company in the questionnaire mentioned that information generated through c-indicators' calculation is

contributing to inform progress for their environmental footprint programme. This company did not participate in the interviews, but this input highlights a potential area to further explore companies' practices in linking circularity and sustainability.

As mentioned in the previous section, the CTI framework has integrated in its most recent version an optional module to compare GHG emissions in an actual circularity scenario versus a scenario where all inflows are recycled. This addition can arguably be seen as an effort to support companies in considering the sustainability impacts from circularity. It would be interesting to explore whether businesses make use of this feature to guide analysis and decision-making, and whether it has any effect in terms of over-emphasising recycled materials sourcing compared to other circular strategies.

As suggested by expert organisations in the study, academia is well positioned to carry out complex analyses to help explain the links between circularity and sustainability impacts in different contexts. These studies may contribute to understand when simpler indicators, such as resource-focused indicators, can be more appropriately used as proxy of more complex analysed, by providing evidence of positive links.

Lastly, another relevant point for future research relates to exploring companies' perspectives in recognising and managing relative versus absolute circularity and sustainability improvements. As seen in the study, if companies are measuring progress as "resources per unit", as opposed to absolute decreases in resource consumption, then they don't have a comprehensive guidance towards net benefits. Since it can be argued that most companies are not envisioning to intentionally worsen their economic performance, but rather decouple it from resource consumption, it is valuable to study how they perceive their role in contributing to absolute sustainability improvements, and how they can rely on assessment tools to support these contributions.

Bibliography

A European Green Deal. (2021). European Commission. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

BCG & WBCSD. (2023). *Enabling circularity through transparency: Introducing the EU Digital Product Passport*. https://www.wbcsd.org/contentwbc/download/15585/226483/1

Blaikie, N. (2010). *Designing social research: The logic of anticipation*. Polity Press.

Bocken, N. M. P., De Pauw, I., Bakker, C., & Van Der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, *33*(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Bryman, A. (2012). *Social research methods* (4th ed). Oxford University Press.

Cagno, E., Negri, M., Neri, A., & Giambone, M. (2023). One Framework to Rule Them All: An Integrated, Multi-level and Scalable Performance Measurement Framework of Sustainability, Circular Economy and Industrial Symbiosis. *Sustainable Production and Consumption*, *35*, 55–71. https://doi.org/10.1016/j.spc.2022.10.016

Carlsson, R., Nevzorova, T., Diener, D., Boyer, R., Linder, M., Vanacore, E., Lindahl, M., & Carlson, A. (2022). *TRACE CERTAINTY TRAnsitioning to a Circular Economy via CERTificAtion in INdusTrY-Testing metrics for measuring the circularity while metrics are being standardized* (No. 2020–04410). RISE- Research Institutes of Sweden. http://urn.kb.se/resolve?urn=urn:nbn:se:ri:diva-58562

Cayzer, S., Griffiths, P., & Beghetto, V. (2017). Design of indicators for measuring product performance in the circular economy. *International Journal of Sustainable Engineering*, *10*(4–5), 289–298. https://doi.org/10.1080/19397038.2017.1333543

Chen, L., Hung, P., & Ma, H. (2020). Integrating circular business models and development tools in the circular economy transition process: A firm-level framework. *Business Strategy and the Environment*, *29*(5), 1887–1898. https://doi.org/10.1002/bse.2477

Chrispim, M. C., Mattsson, M., & Ulvenblad, P. (2023). The underrepresented key elements of Circular Economy: A critical review of assessment tools and a guide for action. *Sustainable Production and Consumption*, *35*, 539–558. https://doi.org/10.1016/j.spc.2022.11.019

Circular economy action plan. (n.d.). European Commission. Retrieved 20 April 2023, from https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en

Company A. (n.d.). *Model: Methodological approach*. Company A.

Company A. (2023). *Integrated Annual Report Company A Chile 2022*.

Company B. (2023). *Reporte de Sostenibilidad 2022*.

Company C. (2022). *Reporte de Sostenibilidad 2020-2021*.

Company E. (2023). *Memoria Integrada 2022*.

Corona, B., Shen, L., Reike, D., Rosales Carreón, J., & Worrell, E. (2019). Towards sustainable development through the circular economy—A review and critical assessment on current circularity metrics. *Resources, Conservation and Recycling*, *151*, 104498. https://doi.org/10.1016/j.resconrec.2019.104498

Corporate sustainability reporting. (n.d.). European Commission. Retrieved 22 April 2023, from https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en

Creswell, J. W., & Creswell, J. D. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (5th edition). SAGE.

Dagiliene, L., Frendzel, M., Sutiene, K., & Wnuk-Pel, T. (2020). Wise managers think about circular economy, wiser report and analyze it. Research of environmental reporting practices in EU manufacturing companies. *Journal of Cleaner Production*, *274*, 121968. https://doi.org/10.1016/j.jclepro.2020.121968

Das, A., Konietzko, J., & Bocken, N. (2022). How do companies measure and forecast environmental impacts when experimenting with circular business models? *Sustainable Production and Consumption*, *29*, 273–285. https://doi.org/10.1016/j.spc.2021.10.009

de Oliveira, C. T., Dantas, T. E. T., & Soares, S. R. (2021). Nano and micro level circular economy indicators: Assisting decision-makers in circularity assessments. *Sustainable Production and Consumption*, *26*, 455–468. https://doi.org/10.1016/j.spc.2020.11.024

De Pascale, A., Arbolino, R., Szopik-Depczyńska, K., Limosani, M., & Ioppolo, G. (2021). A systematic review for measuring circular economy: The 61 indicators. *Journal of Cleaner Production*, *281*, 124942. https://doi.org/10.1016/j.jclepro.2020.124942

Dirección del Trabajo. (2021). *Informe de resultados novena encuesta laboral*. https://www.dt.gob.cl/portal/1629/w3-article-119454.html

Directive (EU) 2022/2464. (n.d.). Eur-Lex. Retrieved 22 April 2023, from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32022L2464

DNV. (2021). *DNV Viewpoint survey "Circular Economy. How are companies transitioning?"* How Are Companies Transitioning towards the Circular Economy? https://www.dnv.com/assurance/viewpoint/viewpoint-surveys/2021Q3/summary.html

Droege, H., Raggi, A., & Ramos, T. B. (2021). CO-DEVELOPMENT of a framework for circular economy assessment in organisations: Learnings from the public sector. *Corporate Social Responsibility and Environmental Management*, *28*(6), 1715–1729. https://doi.org/10.1002/csr.2140

Ellen MacArthur Foundation. (n.d.). *Circular economy introduction*. https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

Ellen McArthur Foundation. (2022). *Indicators*. Ellen McArthur Foundation. https://emf.thirdlight.com/link/1pzbxosbi6hl-ei3tq6/@/preview/3

European Commission. (2020). *Circular Economy Action Plan: For a cleaner and more competitive Europe*. European Union. https://op.europa.eu/en/publication-detail/-/publication/45cc30f6-cd57-11ea-adf7-01aa75ed71a1/language-en/format-PDF/source-170854112

Faludi, J., Hoffenson, S., Kwok, S. Y., Saidani, M., Hallstedt, S. I., Telenko, C., & Martinez, V. (2020). A Research Roadmap for Sustainable Design Methods and Tools. *Sustainability*, *12*(19), 8174. https://doi.org/10.3390/su12198174

Fortunati, S., Martiniello, L., & Morea, D. (2020). The Strategic Role of the Corporate Social Responsibility and Circular Economy in the Cosmetic Industry. *Sustainability*, *12*(12), 5120. https://doi.org/10.3390/su12125120

Franco, N. G., Almeida, M. F. L., & Calili, R. F. (2021). A strategic measurement framework to monitor and evaluate circularity performance in organizations from a transition perspective. *Sustainable Production and Consumption*, *27*, 1165–1182. https://doi.org/10.1016/j.spc.2021.02.017

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Gudmundsson, H. (2003). *Making concepts matter: Sustainable mobility and indicator systems in transport policyn*. *55*(176), p199-217. 19p. https://doi.org/10.1111/1468-2451.5502003

Gupta, S., Chen, H., Hazen, B. T., Kaur, S., & Santibañez Gonzalez, E. D. R. (2019). Circular economy and big data analytics: A stakeholder perspective. *Technological Forecasting and Social Change*, *144*, 466–474. https://doi.org/10.1016/j.techfore.2018.06.030

Harris, S., Martin, M., & Diener, D. (2021). Circularity for circularity's sake? Scoping review of assessment methods for environmental performance in the circular economy. *Sustainable Production and Consumption*, *26*, 172–186. https://doi.org/10.1016/j.spc.2020.09.018

Ibáñez- Forés, V., Martínez-Sánchez, V., Valls-Val, K., & Bovea, M. D. (2022). Sustainability reports as a tool for measuring and monitoring the transition towards the circular economy of organisations: Proposal of indicators and metrics. *Journal of Environmental Management*, *320*, 115784. https://doi.org/10.1016/j.jenvman.2022.115784

IISD. (2012). *The Sustainable Development Timeline—2012*. IISD.

ISO/TC 323—Circular economy. (n.d.). ISO. Retrieved 22 April 2023, from https://www.iso.org/committee/7203984/x/catalogue/p/1/u/1/w/0/d/0

Khitous, F., Strozzi, F., Urbinati, A., & Alberti, F. (2020). A Systematic Literature Network Analysis of Existing Themes and Emerging Research Trends in Circular Economy. *Sustainability*, *12*(4), 1633. https://doi.org/10.3390/su12041633

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Kravchenko, M., Pigosso, D. C. A., & McAloone, T. C. (2020a). A Procedure to Support Systematic Selection of Leading Indicators for Sustainability Performance Measurement of Circular Economy Initiatives. *Sustainability*, *12*(3), 951. https://doi.org/10.3390/su12030951

Kravchenko, M., Pigosso, D. C. A., & McAloone, T. C. (2020b). A Trade-Off Navigation Framework as a Decision Support for Conflicting Sustainability Indicators within Circular Economy Implementation in the Manufacturing Industry. *Sustainability*, *13*(1), 314. https://doi.org/10.3390/su13010314

Kravchenko, M., Pigosso, D. CA., & McAloone, T. C. (2019). Towards the ex-ante sustainability screening of circular economy initiatives in manufacturing companies: Consolidation of leading sustainability-related performance indicators. *Journal of Cleaner Production*, *241*, 118318. https://doi.org/10.1016/j.jclepro.2019.118318

Kristensen, H. S., & Mosgaard, M. A. (2020). A review of micro level indicators for a circular economy – moving away from the three dimensions of sustainability? *Journal of Cleaner Production*, *243*, 118531. https://doi.org/10.1016/j.jclepro.2019.118531

Kristoffersen, E., Mikalef, P., Blomsma, F., & Li, J. (2021). Towards a business analytics capability for the circular economy. *Technological Forecasting and Social Change*, *171*, 120957. https://doi.org/10.1016/j.techfore.2021.120957

Linder, M., Boyer, R. H. W., Dahllöf, L., Vanacore, E., & Hunka, A. (2020). Product-level inherent circularity and its relationship to environmental impact. *Journal of Cleaner Production*, *260*, 121096. https://doi.org/10.1016/j.jclepro.2020.121096

Linder, M., Sarasini, S., & van Loon, P. (2017). A Metric for Quantifying Product-Level Circularity: Product-Level Circularity Metric. *Journal of Industrial Ecology*, *21*(3), 545–558. https://doi.org/10.1111/jiec.12552

Luoma, P., Toppinen, A., & Penttinen, E. (2021). Role and Value of Data in Circular Business Models – a Systematic Literature Review. *Journal of Business Models*, 44-71 Pages. https://doi.org/10.5278/JBM.V9I2.3448

MMA, MINECON, CORFO, & ASCC. (2021). *Hoja de Ruta para un Chile Circular al 2040*. MMA. https://economiacircular.mma.gob.cl/wp-content/uploads/2021/07/HOJA-DE-RUTA-PARA-UN-CHILE-CIRCULAR-AL-2040-ES-VERSION-COMPLETA.pdf

Moraga, G., Huysveld, S., Mathieux, F., Blengini, G. A., Alaerts, L., Van Acker, K., de Meester, S., & Dewulf, J. (2019). Circular economy indicators: What do they measure? *Resources, Conservation and Recycling*, *146*, 452–461. https://doi.org/10.1016/j.resconrec.2019.03.045

Negri, M., Neri, A., Cagno, E., & Monfardini, G. (2021). Circular Economy Performance Measurement in Manufacturing Firms: A Systematic Literature Review with Insights for Small and Medium Enterprises and New Adopters. *Sustainability*, *13*(16), 9049. https://doi.org/10.3390/su13169049

Neri, A. (2021). Industrial sustainability performance measurement system—Challenges for the development. In *Methods in Sustainability Science* (pp. 87–104). Elsevier. https://doi.org/10.1016/B978-0-12-823987-2.00004-0

Nika, C.-E., Expósito, A., Kisser, J., Bertino, G., Oral, H. V., Dehghanian, K., Vasilaki, V., Iacovidou, E., Fatone, F., Atanasova, N., & Katsou, E. (2021). Validating Circular Performance Indicators: The Interface between Circular Economy and Stakeholders. *Water*, *13*(16), 2198. https://doi.org/10.3390/w13162198

Nußholz, J. L. K. (2017). *Circular Business Models: Defining a Concept and Framing an Emerging Research Field*.

OECD-Organisation for Economic Co-operation and Development. (2014). *Measuring and Managing Results in Development Co-operation.*

Opferkuch, K., Caeiro, S., Salomone, R., & Ramos, T. B. (2022). Circular economy disclosure in corporate sustainability reports: The case of European companies in sustainability rankings. *Sustainable Production and Consumption*, *32*, 436–456. https://doi.org/10.1016/j.spc.2022.05.003

Parchomenko, A., Nelen, D., Gillabel, J., & Rechberger, H. (2019). Measuring the circular economy—A Multiple Correspondence Analysis of 63 metrics. *Journal of Cleaner Production*, *210*, 200–216. https://doi.org/10.1016/j.jclepro.2018.10.357

Park, K., & Kremer, G. E. O. (2017). Text mining-based categorization and user perspective analysis of environmental sustainability indicators for manufacturing and service systems. *Ecological Indicators*, *72*, 803–820. https://doi.org/10.1016/j.ecolind.2016.08.027

Patton, M. Q. (2002). *Qualitative research and evaluation methods* (3 ed). Sage Publications.

Pollard, J., Osmani, M., Cole, C., Grubnic, S., Colwill, J., & Díaz, A. I. (2022). Developing and Applying Circularity Indicators for the Electrical and Electronic Sector: A Product Lifecycle Approach. *Sustainability*, *14*(3), 1154. https://doi.org/10.3390/su14031154

Rajput, S., & Singh, S. P. (2019). Connecting circular economy and industry 4.0. *International Journal of Information Management*, *49*, 98–113. https://doi.org/10.1016/j.ijinfomgt.2019.03.002

Reid, W. V., Chen, D., Goldfarb, L., Hackmann, H., Lee, Y. T., Mokhele, K., Ostrom, E., Raivio, K., Rockström, J., Schellnhuber, H. J., & Whyte, A. (2010). Earth System Science for Global Sustainability: Grand Challenges. *Science*, *330*(6006), 916–917. https://doi.org/10.1126/science.1196263

Roos Lindgreen, E., Mondello, G., Salomone, R., Lanuzza, F., & Saija, G. (2021). Exploring the effectiveness of grey literature indicators and life cycle assessment in assessing circular economy at the micro level: A comparative analysis. *The International Journal of Life Cycle Assessment*, *26*(11), 2171–2191. https://doi.org/10.1007/s11367-021-01972-4

Roos Lindgreen, E., Opferkuch, K., Walker, A. M., Salomone, R., Reyes, T., Raggi, A., Simboli, A., Vermeulen, W. J. V., & Caeiro, S. (2022). Exploring assessment practices of companies actively engaged with circular economy. *Business Strategy and the Environment*, *31*(4), 1414–1438. https://doi.org/10.1002/bse.2962

Roos Lindgreen, E., Salomone, R., & Reyes, T. (2020). A Critical Review of Academic Approaches, Methods and Tools to Assess Circular Economy at the Micro Level. *Sustainability*, *12*(12), 4973. https://doi.org/10.3390/su12124973

Saidani, M., Cluzel, F., Leroy, Y., Pigosso, D., Kravchenko, M., & Kim, H. (2022). Nexus Between Life Cycle Assessment, Circularity and Sustainability Indicators—Part II: Experimentations. *Circular Economy and Sustainability*, *2*(4), 1399–1424. https://doi.org/10.1007/s43615-022-00160-2

Saidani, M., & Kim, H. (2022). Nexus Between Life Cycle Assessment, Circularity, and Sustainability Indicators—Part I: A Review. *Circular Economy and Sustainability*, *2*(3), 1143–1156. https://doi.org/10.1007/s43615-022-00159-9

Saidani, M., Yannou, B., Leroy, Y., & Cluzel, F. (2017). How to Assess Product Performance in the Circular Economy? Proposed Requirements for the Design of a Circularity Measurement Framework. *Recycling*, *2*(1), 6. https://doi.org/10.3390/recycling2010006

Saidani, M., Yannou, B., Leroy, Y., Cluzel, F., & Kendall, A. (2019). A taxonomy of circular economy indicators. *Journal of Cleaner Production*, *207*, 542–559. https://doi.org/10.1016/j.jclepro.2018.10.014

Serna-Guerrero, R., Ikonen, S., Kallela, O., & Hakanen, E. (2022). Overcoming data gaps for an efficient circular economy: A case study on the battery materials ecosystem. *Journal of Cleaner Production*, *374*, 133984. https://doi.org/10.1016/j.jclepro.2022.133984

Siderius, T., & Poldner, K. (2021). Reconsidering the Circular Economy Rebound effect: Propositions from a case study of the Dutch Circular Textile Valley. *Journal of Cleaner Production*, *293*, 125996. https://doi.org/10.1016/j.jclepro.2021.125996

Stebbins, R. A. (2001). *Exploration: Its future in the social sciences*. SAGE Publications, Inc. https://doi.org/10.4135/9781412984249

Stewart, R., & Niero, M. (2018). Circular economy in corporate sustainability strategies: A review of corporate sustainability reports in the fast-moving consumer goods sector. *Business Strategy and the Environment*, *27*(7), 1005–1022. https://doi.org/10.1002/bse.2048

Trianni, A., Cagno, E., Neri, A., & Howard, M. (2019). Measuring industrial sustainability performance: Empirical evidence from Italian and German manufacturing small and medium enterprises. *Journal of Cleaner Production*, *229*, 1355–1376. https://doi.org/10.1016/j.jclepro.2019.05.076

Tseng, M.-L., Tan, R. R., Chiu, A. S. F., Chien, C.-F., & Kuo, T. C. (2018). Circular economy meets industry 4.0: Can big data drive industrial symbiosis? *Resources, Conservation and Recycling*, *131*, 146–147. https://doi.org/10.1016/j.resconrec.2017.12.028

United Nations. (n.d.). *Goal 12 | Department of Economic and Social Affairs*. SDGs UN. Retrieved 18 May 2023, from https://sdgs.un.org/goals/goal12

Valls-Val, K., Ibáñez-Forés, V., & Bovea, M. D. (2022). How can organisations measure their level of circularity? A review of available tools. *Journal of Cleaner Production*, *354*, 131679. https://doi.org/10.1016/j.jclepro.2022.131679

Veleva, V., Bodkin, G., & Todorova, S. (2017). The need for better measurement and employee engagement to advance a circular economy: Lessons from Biogen's "zero waste" journey. *Journal of Cleaner Production*, *154*, 517–529. https://doi.org/10.1016/j.jclepro.2017.03.177

ViewPoint DNV. (2021). *Circular economy: How are companies transitioning*. DNV. https://www.dnv.com/assurance/viewpoint/viewpoint-surveys/2021Q3/summary.html

Vinante, C., Sacco, P., Orzes, G., & Borgianni, Y. (2021). Circular economy metrics: Literature review and company-level classification framework. *Journal of Cleaner Production*, *288*, 125090. https://doi.org/10.1016/j.jclepro.2020.125090

Walker, A. M., Opferkuch, K., Roos Lindgreen, E., Raggi, A., Simboli, A., Vermeulen, W. J. V., Caeiro, S., & Salomone, R. (2022). What Is the Relation between Circular Economy and Sustainability? Answers from Frontrunner Companies Engaged with Circular Economy Practices. *Circular Economy and Sustainability*, *2*(2), 731–758. https://doi.org/10.1007/s43615-021-00064-7

Walzberg, J., Lonca, G., Hanes, R. J., Eberle, A. L., Carpenter, A., & Heath, G. A. (2021). Do We Need a New Sustainability Assessment Method for the Circular Economy? A Critical Literature Review. *Frontiers in Sustainability*, *1*, 620047. https://doi.org/10.3389/frsus.2020.620047

WBCSD. (2018). *Circular metrics landscape analysis*. World Business Council for Sustainable Development (WBCSD). https://www.wbcsd.org/Programs/Circular-Economy/Metrics-Measurement/Resources/Landscape-analysis

WBCSD. (2021). *Circular Transition Indicators V2.0: Metrics for business, by business*. WBCSD. https://www.wbcsd.org/contentwbc/download/11256/166026/1

WCED (World Commission on Environment and Development). (1987). *Our common future*. https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf

Weick, M., & Ray, N. (2022). *Regulatory landscape of the circular economy*. EY. https://www.ey.com/en_us/chemicals/circular-economy-navigating-the-evolving-global-policy-landscape#accordion-content-662144799-0

Zink, T., & Geyer, R. (2017). Circular Economy Rebound. *Journal of Industrial Ecology*, *21*(3), 593–602. https://doi.org/10.1111/jiec.12545

Appendix A: List of questionnaire questions

This appendix reproduces the content of the questionnaire, sent to companies through Google Forms in Spanish. First, the introduction is provided, then a table shows all questions, choices provided for answers, and references to literature when applicable. Finally, some observations are outlined.

Questionnaire for thesis project: Circular economy operationalisation and indicators use

This questionnaire is part of a master's thesis project for the Environmental Management and Policy programme at Lund University. The aim of the study is to explore companies' perspectives regarding the operationalisation of Circular Economy, the use of circularity indicators and the links with sustainability.

- The survey takes approx. 10 minutes to answer.
- The questionnaire should be responded by. a person with knowledge and experience working with circular economy within the company
- Your answers will be anonymised. The email address and company name will only be used for contacting purposes from the student if necessary. All data will be safely stored.
- In the questionnaire, we would like you to respond thinking of the company's current reality in Chile. The study does not aim to judge the merit of a company's current progress. Please feel free to add any clarifying comments if needed.

Thank you very much for your cooperation!

For more information, you can contact: Emilia Paredes (MSc student)- em8234pa-s@student.lu.se

#	Question	Type of answer	Choice/scale (if applicable)	Reference (if applicable)
1	**Name (only for internal use, your answers will be anonymised)**	Short text		
2	**Contact email (only for internal use, your answers will be anonymised)**	Short text		
3	**Company name (only for internal use, your answers will be anonymised)**	Short text		
4	**What is your role in the company?**	Short text		
5	**What statement best reflects your company's circular economy maturity level?**	Multiple choice	_1. Discovering: The topic of circular economy is being analysed and/or discussed _2. Starting: Isolated projects or activities are being developed or implemented _3. Developing: Circular economy is being integrated to plans, strategies or policies, and projects or activities are being implemented _4. Leading: The company can recognise itself as a frontrunner, with clear projects, activities and strategic	Adapted from ViewPoint DNV, (2021)

			plans and policies _Unsure	
6	**Please indicate your company's level of agreement with the following statements regarding the circular economy**	Linear scale	1 Strongly disagree 2 Disagree 3 Neither agree nor disagree 4 Agree 5 Strongly agree	Adapted from Walker et al., (2022)
	The circular economy is one of the tools that will help achieve the UN sustainable development goals			
	The circular economy is the main tool to achieve the UN sustainable development goals			
	The circular economy improves the environmental performance of company			
	The circular economy increases social benefits for employees and other stakeholders			
7	**If your company is using (or planning to use) any of the following measuring/reporting approaches, please indicate if you believe they can be used for sustainability assessment, circular assessment, or both**	Multiple choice	_We don't consider this approach _Both circularity and sustainability _Only sustainability _Only circularity _Unsure	Adapted from Roos Lindgreen et al., (2022)
	Circular Transition Indicators (CTI- WBCSD)			
	Circulytics (EMF)			
	Material Circularity Index (EMF)			
	GRI (Global Reporting Standard)			
	SASB Standards			
	GHG protocol			
	CDP (Carbon Disclousure project)			
	SDG indicators (Sustainable Development Goals)			
	SBTs (Science Based Targets)			
	MFA (material flow analysis)			
	LCA (Life cycle assessment)			
	Internally-developed systems			
8	**Considering the circularity indicators that your company is using: Do these contribute with information for other assessment and reporting approaches?**	Multiple choice	_No _No, but it has been discussed _No, but it is planned _Yes _Unsure	

9	**Circularity indicators can serve different purposes. How relevant is it for your company that circularity indicators address each purpose stated below?**	Linear scale	1 Not relevant at all 2 Slightly relevant 3 Moderately relevant 4 Very relevant 5 Extremely relevant	List of purposes based on Roos Lindgreen et al., (2022)
	Marketing and improving company's reputation			
	Communicate and report to stakeholders			
	Provide evidence of activities to increase transparency			
	Identify opportunities and assess collaboration			
	Internally improve and optimise circular economy strategies			
	Gain knowledge about broader sustainability performance			
	Facilitate learning processes and cultural change			
	Develop strategy and vision (future planning)			
	Enable market benchmarking			
10	**The use of circularity indicators can be hindered by several barriers. How relevant are the following barriers for your company to use and/or implement circularity indicators?**	Linear scale	1 Not relevant at all 2 Slightly relevant 3 Moderately relevant 4 Very relevant 5 Extremely relevant	List of barriers based on literature review, with greater emphasis on Roos Lindgreen et al. (2022) and Chrispim et al. (2023)
	Barrier: limited availability of data			
	Barrier: It is time consuming			
	Barrier: Requires new employee skills/competences			
	Barrier: It is expensive			
	Barrier: Assessment fatigue (company already conducts several other assessments)			
	Barrier: How to use circularity indicators' results is unclear			
	Barrier: Data needs of tools to make calculations are unclear			
	Barrier: Lack of standard or benchmark			
	Barrier: Indicators not designed for context or sector			
	Barrier: Available circularity indicators do not consider all sustainability dimensions			

	Barrier: Lack of demand for circularity assessment from stakeholders			
	Barrier: Lack of demand or interest for circularity assessment from company's high level leaders			
11	**How useful is the CTI approach regarding its contribution to operational performance in relation to circular economy?**	Linear scale	1 Not useful at all 2 Slightly useful 3 Moderately useful 4 Very useful 5 Extremely useful	Adapted from Park & Kremer, (2017)
12	**How useful is the CTI approach regarding its contribution to strategic performance in relation to circular economy?**	Linear scale	1 Not useful at all 2 Slightly useful 3 Moderately useful 4 Very useful 5 Extremely useful	Adapted from Park & Kremer, (2017)
13	**How practical is the CTI approach regarding costs associated to learning and implementing it?**	Linear scale	1 Not practical at all 2 Slightly practical 3 Moderately practical 4 Very practical 5 Extremely practical	Adapted from Park & Kremer, (2017)
14	**How practical is the CTI approach regarding time needed to learn and implement it?**	Linear scale	1 Not practical at all 2 Slightly practical 3 Moderately practical 4 Very practical 5 Extremely practical	Adapted from Park & Kremer, (2017)
15	**Any other comments that you would like to share about the topics included in the questionnaire (optional)**		Short text	
16	**If you would like to take part on a short follow-up online interview to further discuss the topics, please state below. Your help and interest are much appreciated**	Multiple choice	_Yes _No	

Observations

- Questions 7 to 14 allowed respondents to include optional written comments to complement their choices

- Linear scales in questions 6, 9, 10, 11, 12, 13 and 14 were presented in the following type of template:

- For question 8, the following clarifications were included:
    - Circularity indicators definition: In the context of this questionnaire, they refer to indicators that measure intrinsic circularity, i.e., recirculation, resources use intensity and resources use extension
    - It is understood that your company is using CTI/internal framework, which comply with the aforementioned definition. To respond these questions and the following, please consider the use of CTI/internal framework, but you can

also consider any other indicators that from your company's perspective are used to measure intrinsic circularity.

- An example on how circularity indicators may contribute to other measuring or reporting approaches: A company may be using information generated through their circularity indicators, to report information on GRI standards

Appendix B: List of interviewees

Interview #	Company name	Sector	Interviewee role	Framework	Interview duration
1	Company A	Energy	Head of Sustainable & Circular Ecosystem	Internal framework	90 min
2	Company A	Energy	Head of Strategy and models	Internal framework	30 min
3	Company B	Steel	Head of environment and circular economy	CTI	60 min
4	Company B	Steel	CEO in subsidiary and previous head of environment and circular economy	CTI	30 min
5	Company C	Beverages	Head of corporate affairs	CTI	60 min (Joint interview)
5	Company C	Beverages	Corporate affairs and positive impact coordinator	CTI	60 min (Joint interview)
6	Company D	Furniture	Head of Sustainability	CTI	30 min
7	Company E	Energy	Head of Sustainable Development	CTI	45 min

Appendix C: List of preliminary interview questions

Questions in preliminary interview guide for companies

1- Can you tell me what your role is regarding CE and sustainability?

2- What are the companies' current and future projects regarding CE?

3- Which business units are in charge of CE projects?

4- How has c-indicators' implementation progressed?

5- What are your motivations to use circularity indicators?

6- In which areas have the circularity indicators been more useful?

7- In your experience, what aspects have contributed to making use of circularity indicators in your company?

8- What are the differences and links between measuring sustainability and circularity for your company?

9- How are you integrating or would like to integrate in the future your circularity indicators with other assessments?

10- Are you setting environmental goals or targets for your circular economy projects?

11- What is needed from your perspective to better measure the circularity of the company?

12- What aspects are the most challenging when adopting or using circularity indicators?

13- What is your assessment of the c-indicators that you are using? What is highlighted and what would you improve?

14- What would be the most important features of circularity indicators?

15- In the future, what other tools/methods/metrics would you like to apply for circularity?

Questions in preliminary interview guide for expert organisations

1- What are companies' motivations to use circularity indicators

2- What are challenges and enabling factors experienced by companies when trying to adopt or use circularity indicators

3- What kind of guidance, resources and knowledge are companies needing to address their gaps in being successful in using circularity indicators?

4- Perspectives on integrating/differentiating intrinsic circularity and sustainability impacts measurement

4- Implications of new regulations and standards for the development, selection, and adoption of circularity metrics: ISO and CSRD

5- Role of academia

6- What is your vision regarding the use of circularity indicators; what type of progress would you like to see?

Appendix D: Initial and revised coding framework

Initial coding framework

Definitions and meanings

Purposes
Communication and reporting:
Performance monitoring and improvement

Barriers and enablers
Data
Resources and capabilities
Context
Content

C-indicator frameworks assessment
Practical
Useful

Circularity assessment positioning

Links: CE and Sustainability
Conditional
Beneficial
Trade off

Links: CE and sustainability assessment and goals
Precursor
Integrative/parallel
Social aspects
Economic aspects
Environmental aspects

Revised coding framework

Meanings: *Definitions and meanings. How companies interpret the concepts of CE, sustainability etc*

Background and motivations

- Indicators familiarity
- Indicators uptake motivations
- Indicators current progress

Fulfilled purposes in practice: *What are circularity indicators useful for according to companies*

- External communication and reporting
- Performance monitoring and improvement
    - Baseline and progress
    - Target-setting and action
- Learning and cultural change

- External opportunities and cooperation

Influencing factors: Internal context

- Data
- Resources and capabilities
- Organisational aspects
    - Assessment procedures and coordination
    - Culture
- Business characteristics: sector, structure, size

Application experience: *How users assess their experience with specific metrics*

- Content
- Practical
- Useful

Positioning: *Positioning of c-indicators in broader assessment practices*

- Previous efforts/overlaps
- Other assessment approaches

Conceptual links: *between CE and sustainability*

- Conditional
- Beneficial
- Trade-off
- Difference unclear or not important
- Others

Assessment links: from circularity assessment to sustainability assessment and goals

- Procedural links
    - Precursor
    - Integrative/Parallel
    - No apparent linkage/distinction

Assessment links: from sustainability assessment to circularity assessment

- Measuring impacts
    - Social
    - Economic
    - Environmental
- Procedural links
    - Precursor
    - No apparent linkage/distinction