MEASURING CIRCULARITY IN THE CRADLE TO CRADLE PRODUCT STANDARD

Compliance of the indicators for product circularity in the Cradle to Cradle product standard with scientific quality criteria

Carla Wendt, MSc Industrial Ecology
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Universiteit Leiden
TU Delft
EPEA
PART OF DREES & SOMMER

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Author: Carla Wendt

Student number Universiteit Leiden: s2971755
Student number TU Delft: 5435374

Joint master programme Industrial Ecology
Universiteit Leiden/TU Delft

First supervisor: Dr. Stefano Cucurachi, Universiteit Leiden,
Institute of Environmental Sciences (CML)
Second supervisor: Prof. Dr. Ruud Balkenende, TU Delft,
Department for Industrial Design Engineering (IDE)

In contribution with EPEA, part of Drees & Sommer
External supervisor: Jan Christoph von der Lancken

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Preface

I already did several research projects on Cradle to Cradle and the circular economy before writing this report. But I always had the feeling that they were tackling just a minor issue, barely scratching the surface of what was needed to transition to a real circular, cradle to cradle economy. For my thesis, I wanted to go deeper, to the core, so to say. So, I contacted EPEA – Part of Drees & Sommer, with whom I had already great experiences in collaborating in the past. I wanted to see whether we could find an interesting topic that is both academically interesting and practically useful for them. They immediately agreed on working together, and quickly we narrowed down the topic to the evaluation of the circularity indicators they were using for their product assessment. This is how I came to write my master thesis about a methods topic, which was new for me, as I usually prefer the 'hands-on' approach tackling real-world problems. But, reviewing my initial goal of wanting to go deeper into the topic, this only makes sense. Improving the 'production process' itself potentially requires a deeper understanding and overview than improving the products one by one.

My hope is that this report does not only offer a small contribution to the academic research on product circularity indicators, but that it is also of real use to EPEA and can help them ease and improve their assessment processes. Furthermore, I hope that the results of this report somehow find their way to the Cradle to Cradle Products Innovation Institute, and that they are willing to engage in a discussion about my findings.

Last, I want to thank the following people:

First of all, I want to express my gratitude to both of my supervisors, Stefano Cucurachi and Ruud Balkenende. You were a great team and gave me so much support, thank you for that (also in rough times, for example when the laptop crashes and all data is lost…).

Second, I want to thank Jan von der Lancken, my supervisor from EPEA, who dared to engage with me in a critical discussion about Cradle to Cradle, provided me with information and always had inspirational feedback for me.

Finally, I want to thank my family and friends for supporting me, motivating me and cheering me up when things were not going as planned. Thank you for being in my life.

Carla Wendt, Leiden, 12-08-2022

Executive summary

Increasing global problems such as resource scarcity, waste accumulation and overstepping of the planetary boundaries demand a quick transition towards a more sustainable development. A promising way for achieving this is the circular economy approach. For tracking the progress made in achieving a circular economy, circularity indicators are used. One of those indicator-sets on product circularity is published by the Cradle to Cradle Products Innovation Institute (C2CPII). Although their approach was majorly developed by scientists, no external evaluation of the quality of the used underlying indicators has been conducted yet. Thus, this report elaborates on the question how far those indicators for product circularity in the C2CPII standard comply with scientific quality criteria, and how their scientific quality can be improved. The goal was to identify shortcomings in the indicator-set and to formulate tangible improvements and recommendations to the C2CPII and to EPEA, the commissioner of this research.

In the course of this research, 13 indicators were extracted from the C2CPII indicator standard. To get a better understanding of them, all indicators were visually put into relation to each other, and three indicator clusters were identified, which together build the basis for assessing product circularity: (1) Circularly sourced content, (2) Cyclability and (3) Active cycling. Next, an assessment framework for indicators was developed, based on the five scientific quality criteria Construct Validity, Reliability, Practicality, Generalisability and Transparency. Subsequently, the framework was applied to the extracted indicators. Each indicator was evaluated on scale from 1 (barely fulfilled) to 3 (fully fulfilled). It got evident that the weighted end scores of all clusters were medium and close to each other, but that the active cycling cluster slightly performed best (see table below).

Results from the assessment of the C2CPII indicators

Cluster	CV	R	P	G	T	Weighted end score
Circularly sourced content	2.3	1.2	1.8	3.0	3.0	2.1
Cyclability	2.2	1.6	2.1	2.0	3.0	2.1
Active cycling	2.1	1.9	2.2	2.0	3.0	2.3

CV = construct validity, R = reliability, P = practicality, G = generalisability, T = transparency

The Reliability was lowest for all clusters, which was mainly because of the sub-criterion Objectivity, while the Effectivity (belonging to the Construct Validity) and Time of Determination (belonging to the Practicality) scored high. The Transparency and Generalisability were both assessed with high values for all clusters as well. Two out of the three main indicators scored insufficiently regarding their Construct Validity, Reliability and Practicality, where the Reliability and Practicality were most contributing

to this. Indicators 5 and 12 were the only indicators that overall scored sufficiently and almost do not need improvement.

In the last step, alternative product circularity indicators were researched and used as an inspiration to find improvements to the indicator-set from the C2CPII. Those improvements were displayed in visuals again, and mainly comprise the proposal to (1) differentiate more between the r-strategies (reuse, remanufacture, refurbish, recycle) in all clusters and to (2) find more objective ways to measure the indicators. Furthermore, it is recommended to (3) improve the language and structuring of requirements in the C2CPII standard in all clusters, and to (4) add normative requirements and stricter boundaries to most indicators. Also, different additional indicators are suggested to increase the Reliability and Construct Validity of the cluster, such as (5) influencing factors for the renewable content, (6) by-product use, (7) virgin material use, (8) criticality, (9) differentiated sub-indicators for the biological cycling pathways, (10) accounting for the nutrient quality, and (11) collection rates. Additional major suggested improvements are (12) a redefinition of high value cycling for the cyclability and (13) an addition ensuring that downcycling is prohibited for the active cycling rate, as well as (14) the use of the ISO 22095 norm for the chain of custody documentation and (15) the application of a weighting for the calculation of the main indicators (for example, weighting renewable content less than cycled content).

The main limitation of this research is the subjectivity of the indicator assessment, which was intended to be lowered through following predefined criteria that can be challenged, and a structured and transparent application of them. Future research is recommended on the re-check and further progressing of the suggested improvements, the inclusion of financial indicators, the definition of requirements for nutrient quality, the development of an index combining the three main indicators (Mass % of circularly sourced content, Mass % of high value cyclable content and Active cycling rate) and the application of the developed framework on the other assessment categories in the C2CPII standard (or other indicator-sets). Special attention should also be paid to the development of a new cluster with indicators accounting for the amount of collaboration and common infrastructure for establishing a globally functional circular economy.

For improving the applicability and scientific quality of the C2C certification criteria, the provided indicator-based cluster structure and visuals could be re-checked and added to the C2CPII standard. This could help applicants who want to certify their product to better understand C2C and the underlying implications of a certification. On the other hand, the visuals could also be a worthwhile addition for the development of an interactive webtool that could make the application process quicker and easier for all participants.

Table of Content

List of Figures

List of Tables

List of Abbreviations

Abbreviation	Meaning
CP	Clearness of language
C2C	Cradle to Cradle
C2CPII	Cradle to Cradle Products Innovation Institute
CV	Construct validity
CVC	Efficiency
CVV	Effectivity
EP	Ease of determination
EPEA	EPEA GmbH – Part of Drees & Sommer
EWC	Equally weighted criteria
EWI	Equally weighted indicators
G	Generalisability
OR	Objectivity
P	Practicality
R	Reliability
SWC	Specifically weighted criteria
SWI	Specifically weighted indicators
T	Transparency
TP	Time of determination
TRR	Test-retest reliability

1 INTRODUCTION

1.1 Problem Statement

The current population and economic growth are leading to an ever greater consumption of resources (Rockström et al., 2009). With a linear economy being the currently dominating form of economic activity in the world, this causes two major problems. First, economic activities are mostly based on the extraction of resources that are not quickly renewable. In the long run, this causes a resource scarcity, which increasingly puts pressure on our societal systems (European Commission, 2014). Already today, fighting for resources is the second most frequent cause of conflict worldwide (Richter, 2018). Second, consuming resources linearly means that there is no intelligent end-of-life management in place, which causes an enormous accumulation of litter. In 2016, more than two billion tonnes of waste were produced worldwide, an amount expected to grow by 28% until 2030 (Kaza et al., 2018). Those two problems of resource scarcity and waste accumulation lead to a third issue: resources are extracted, used and discarded in a way that makes humanity massively overstep their safe operating space on the planet. Reports by Rockström et al. (2009) and Steffen et al. (2015) show that the planetary boundaries are increasingly exceeded in most of the impact categories. Only ozone depletion and ocean acidification are still within the safe boundary, whereas biosphere integrity and the natural regulation of nitrogen and phosphorus cycles are threatened at a high level. Continuing our current way of living would cause a collapse of most of the ecosystems on the planet in the long run and increasingly extinguish life on earth (Rockström et al., 2009).

To keep the integrity of the earth's ecosystems, a sustainable development that takes into account the needs of both present and future generations is necessary (World Commission on Environment and Development, 1987). A promising way for achieving this sustainable development is the circular economy approach (European Commission, 2020). It strives for a shift towards an economic system where economic growth is decoupled from finite resource extraction through high quality material loops (Ellen MacArthur Foundation, 2022; Ghisellini et al., 2016).

For tracking the progress made in achieving a circular economy, a scientifically sound set of indicators is needed (De Oliveira et al., 2021). There is a great variety of indicator-sets for measuring circularity on a product level both from scholars and practitioners. One of those sets is the Cradle to Cradle product standard published by the Cradle to

Cradle Products Innovation Institute (C2CPII). Although their approach was developed majorly by scientists (C2CPII, 2022b), no external evaluation of the quality of the used underlying indicators has been conducted yet, which diminishes their credibility.

1.2 Introduction of the Stakeholders

Two stakeholders are important for this scientific research:

The C2CPII was founded by Michael Braungart and William McDonough and is an independent institute for certifying products fit for a circular economy in the sense of the Cradle to Cradle (C2C) approach. The institute claims to "power the shift to a circular economy by setting the global standard for materials, products and systems that positively impact people and planet" (C2CPII, 2022a). The C2CPII has its own catalogue of criteria for evaluating products, structured in five categories: Material Health, Product Circularity, Clean Air & Climate Protection, Water & Soil Stewardship and Social Fairness (C2CPII, 2021a). The requirements in those five categories can be seen as the standard to which C2C products should be optimised. (C2CPII, 2021a). All those requirements are published in the most recent C2CPII product standard version 4.0 (C2CPII, 2021a).

The EPEA GmbH – Part of Drees & Sommer (further referred to as EPEA) acts as the commissioner of this research. The company is a consultancy for businesses to transition to a circular economy in the sense of the C2C approach, with their products and business models. Originally, it had been founded by Michael Braungart, too. In 2019, EPEA was sold to Drees & Sommer, an international company in the construction sector (EPEA GmbH - Part of Drees & Sommer, 2021b). The company's main service is to use the product standard from the C2CPII to make products more circular in the sense of C2C, and eventually get them a C2C certificate. EPEA's aim regarding this research is to accumulate more knowledge about the scientific quality of the indicators for product circularity in the C2CPII standard, and to be informed about possible improvements. Those improvements could either be implemented by themselves while applying the standard or be suggested to the C2CPII to improve the product standard itself. This way, EPEA aims to double check the quality of their consulting activities and to enhance their credibility and scientific justification among customers, peers and the public.

1.3 Research Aim and Course

The academic aim of this research is to evaluate the scientific quality of the current product circularity indicators used in the C2CPII product standard 4.0, and to suggest improvements to the identified shortcomings to develop a scientifically sound indicator-set. Thus, the main research question is:

How far do the indicators for product circularity in the most recent C2CPII product standard comply with scientific quality criteria, and how can their scientific quality be improved?

This main question can be broken down into the following sub-questions:

1. *What are the indicators used for measuring product circularity in the most recent C2CPII product standard?*
2. *What are suitable criteria to measure the scientific quality of indicators?*
3. *How far do the indicators used for measuring product circularity in the most recent C2CPII product standard comply with the scientific quality criteria?*
4. *What are other indicators used to measure product circularity?*
5. *How can the scientific quality of the indicators used for measuring product circularity in the most recent C2CPII product standard be improved?*

To answer those questions, first a literature review on circular economy, C2C, circularity indicators and scientific quality criteria is conducted (chapter 2). Subsequently, chapter 3 shows a research flow diagram, accompanied by explanations of the phases and methods used in this research. In chapter 4, first the indicators are extracted from the C2CPII product standard 4.0, clustered and displayed in a restructured way. Second, an assessment framework for assessing those indicators is developed, based on the scientific quality criteria researched in chapter 2. Last, the framework is applied to the indicators from the C2CPII, and their shortcomings are identified. Chapter 5 researches on product circularity indicators that are comparable to the ones from the C2CPII. In chapter 6, those indicators are used as an orientation to tackle the shortcomings of the C2C indicators and to propose improvements. Chapter 7 discusses the methods, results and limitations of this research, while chapter 8 summarises the main findings. Chapter 9 concludes this report with recommendations for the C2CPII and EPEA.

2 LITERATURE REVIEW

In this chapter, first the backgrounds and connections of the two major concepts used in this research are given: C2C and circular economy. The latter can be seen as the overarching concept, the goal that shall be reached, while the C2C approach is one way to get there. There are many other approaches to reach the goal of a circular economy, which in this research are just summarised under the term circular economy. Second, a short introduction to circularity indicators is given to build a common understanding of the term for the course of this research and to find classification criteria for them. Last, scientific quality criteria to assess indicators are introduced.

2.1 The Circular Economy Approach

The concept of circular economy originally derives from the fields of ecological economics, environmental economics and, above all, industrial ecology. Many, more recent considerations of circular economy also find inspiration in C2C or other approaches such as the performance economy, biomimicry, natural capitalism, the blue economy, or regenerative design (Antikainen et al., 2018).

Both among scholars and practitioners, there is a great variety of definitions of the term circular economy. The original definition that is used by many practitioners is the one from the Ellen MacArthur Foundation, an NGO dedicated to promoting the worldwide implementation of a circular economy:

> "[Circular economy is a] systems solution framework that […] is based on three principles, driven by design: [1] eliminate waste and pollution, [2] circulate products and materials (at their highest value), and [3] regenerate nature. It is underpinned by a transition to renewable energy and materials. Transitioning to a circular economy entails decoupling economic activity from the consumption of finite resources. This represents a systemic shift that builds long-term resilience, generates business and economic opportunities, and provides environmental and societal benefits"(Ellen MacArthur Foundation, 2021).

Kirchherr et al. (2017) did a thorough analysis of further 143 existing circular economy definitions from both scholars and practitioners, and tried to come up with a definition themselves that covers all relevant aspects:

"[Circular economy is] 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" (Kirchherr et al., 2017).

As this definition is based on an analysis of a majority of the previously existing definitions, it is assumed that it is a fitting definition of circular economy to be used in this research. For visualising the idea of a circular economy, the so-called butterfly diagram by the Ellen MacArthur Foundation is commonly used (Figure 1).

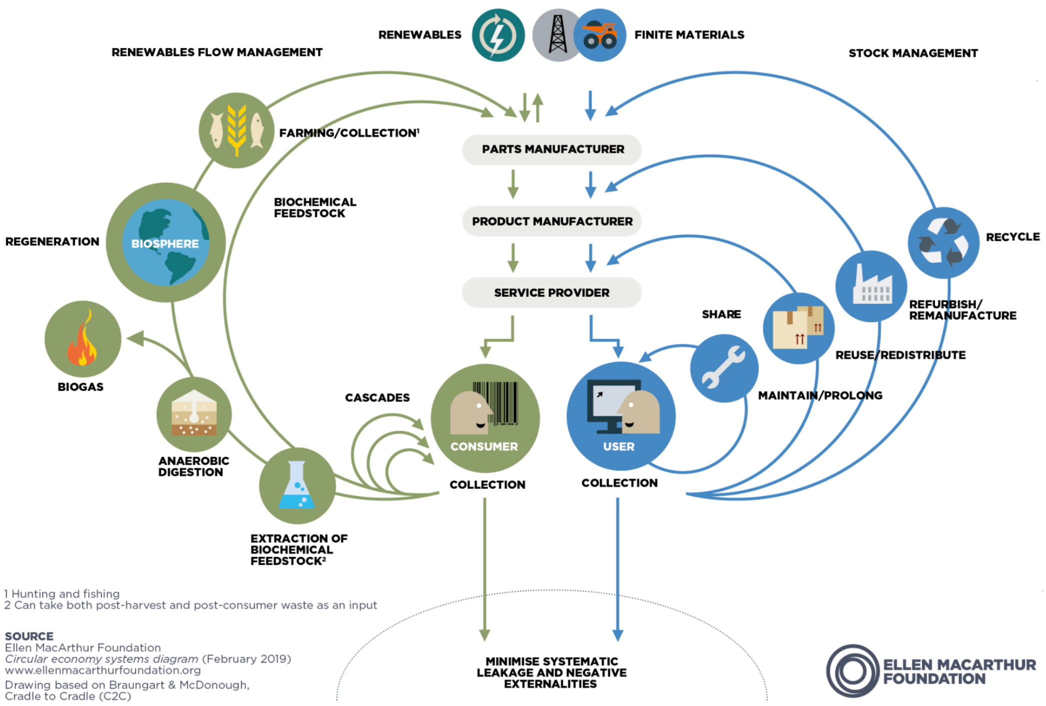

Figure 1: Butterfly diagram for visualising a circular economy (Ellen MacArthur Foundation, 2019)

2.2 Eco-Effectivity and Cradle to Cradle

A different approach within the circular economy thinking is the eco-effectivity philosophy. It was developed by the chemist Michael Braungart and the architect William McDonough and firstly published in 2007 (Braungart et al., 2007). In this book, they describe eco-effectivity as a concept that, in contrary to eco-efficiency, supposes to "utilize materials in a way that maintains or increases their value and productivity over time”, which they call upcycling. This way, they want to set a “positive agenda for the conception and production of goods and services that incorporate social, economic, and environmental benefit […]”. As the concept aims for a “positive recoupling of the relationship between economy and ecology”, it still allows for future economic growth and innovation and enforces the idea of “celebrat[ing] the relationship between man and nature as mutually beneficial” instead of assigning humanity a feeling of guilt for their existence (Braungart et al., 2007).

The so-called C2C approach is putting the eco-effectivity philosophy into practice. C2C is a design framework for products and industrial processes that sees materials as nutrients, which should be held in infinite metabolic cycles. Products of consumption, such as shoe soles, the abrasion of which is released into nature over the years, are hereby treated as biological nutrients that are to be biodegradable and safe for living systems (biological cycle). Products of service, such as washing machines, which purpose it is to clean laundry, are treated as technical nutrients and should be made to “remain safely in a closed-loop system of manufacture, recovery, and reuse ([…] technical [cycle]), maintaining its highest value through many product life cycles” (Braungart et al., 2007). A recent visualisation of the two nutrient cycles can be seen in Figure 2.

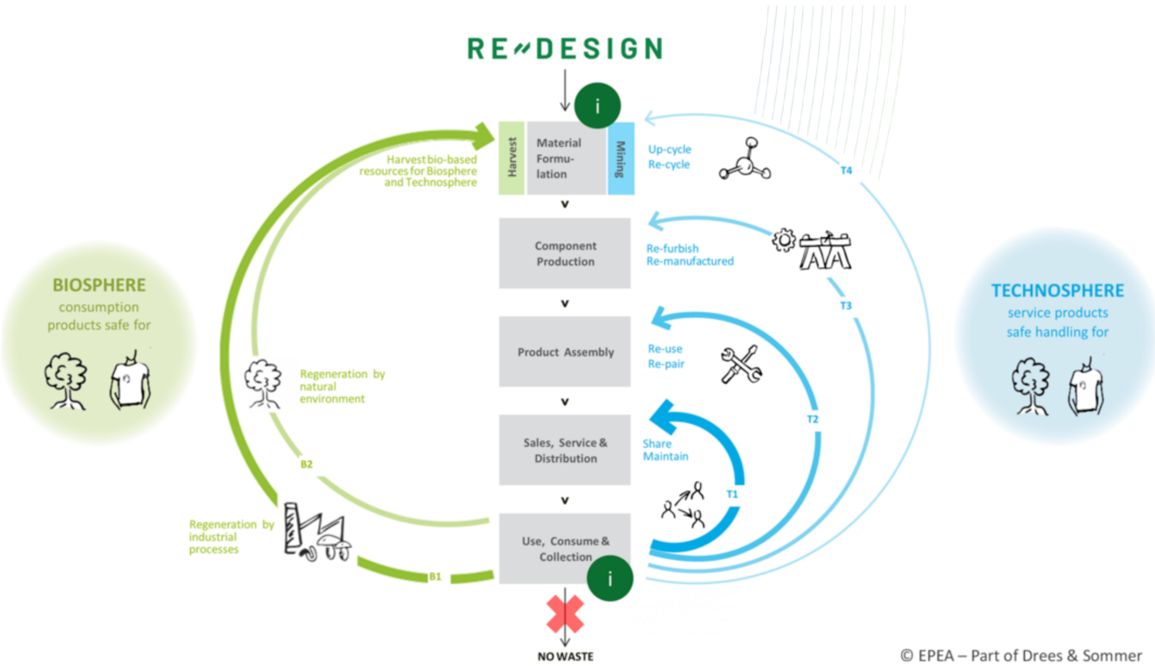

Figure 2: The two nutrient cycles in C2C (EPEA GmbH - Part of Drees & Sommer, 2021a)

The terms C2C and eco-effectivity are often used interchangeably both in literature and among practitioners, which is why in the further context, the term C2C is used as an equivalent for the whole eco-effectivity philosophy.

The initial concept of C2C has been developed further by several actors and has recently been summed up in three principles (EPEA GmbH - Part of Drees & Sommer, 2021a):

1. Nutrients remain nutrients (referring to the two high value nutrient cycles)
2. Use of renewable energy (referring mainly to production processes)
3. Support diversity (referring to biological, cultural, social and conceptual diversity during the design and production process to get context specific solutions)

Especially comparing the principles and the two visualisations of the approaches (Figure 1 and Figure 2), it gets clear that C2C and the 'traditional' circular economy are similar in many ways and basically have the same goal. They just differ in their origin and their approach to achieve that goal.

2.3 Introduction to Circularity Indicators

To monitor status and progress in reaching circularity targets within both the C2C and the circular economy approach, a scientifically sound set of circularity indicators is necessary (De Oliveira et al., 2021). An indicator can be defined as a simplified way of „tracking, monitoring, and measuring the progress and performance of specific systems or processes" (De Oliveira et al., 2021). The terms metric, measure or index can be used interchangeably (Saidani et al., 2019).

Indicators can be measured at different scale levels (Bhattacherjee, 2012). **Nominal** measurement scales are used for categorical data, which is not possible to assign meaningful values to, such as the gender or the employment of a person or a binary yes/no scale. **Ordinal** scales require data as an input that can be rank ordered but the actual or relative values of attributes cannot be determined, as for example a student's grades or the Likert scale. In **interval** scales, the values are "equidistant from adjacent attributes" (Bhattacherjee, 2012), thus have a quantifiable distance to each other and can be added or subtracted. Examples include the IQ score or temperatures in Celsius or Fahrenheit. Finally, **ratio** scales include all the properties of the prementioned scales and additionally can include a meaningful value of zero, meaning the "lack or nonavailability" (Bhattacherjee, 2012) of the measured indicator. This is the case for the majority of indicators in natural science, such as mass, speed, percentages etc.

In the last decade, the number of publications on circularity indicators has increased both among scholars and practitioners (De Oliveira et al., 2021; Kristensen & Mosgaard, 2020; Saidani et al., 2019). There are several reviews on this topic with slightly different focusses. The six most recent reviews are from De Oliveira et al. (2021), De Pascale et al. (2021), Kristensen & Mosgaard (2020), Parchomenko et al., (2019), Corona et al.

(2019) and Saidani et al. (2019) and cover the years 2019-2021. Depending on the review and its focus, different circularity indicators were identified. Two studies found that 60-70% of those circularity indicators were published by scholars and 30-40% by companies and organisations (De Oliveira et al., 2021; Saidani et al., 2019). For a better overview and an easier application, the authors of the reviews classified the indicators following a variety of approaches. The parameters for that are summarised in Table 1.

Table 1: Parameters for classifying circularity indicators

No.	Parameters	Explanation	Attributes	Sources
1	Application level	On which level are the indicators applicable?	Nano (products), micro (company), meso (industrial parks), macro (governments)	De Oliveira et al., 2021 De Pascale et al., 2021 Moraga et al., 2019 Parchomenko et al., 2019
2	Sustainability dimensions	Which sustainability dimensions do the indicators cover?	Environmental, economic, social	De Oliveira et al., 2021 Corona et al., 2019 De Pascale et al., 2021 Kristensen & Mosgaard, 2020
3	Life cycle stages	Which life cycle stages do the indicators cover?	Full life cycle, take, make, use, recover	De Oliveira et al., 2021 Moraga et al., 2019
4	Kind of assessment	Is it a single indicator, a group of indicators or a whole assessment framework, such as LCA?	Indicator, indicator group, assessment framework	Corona et al., 2019 Saidani et al., 2019 Moraga et al., 2019
5	R-loops	Which r-loops are covered by the indicator?	Reduce, reuse, recycle, recover, remanufacture, redesign	De Pascale et al., 2021 Moraga et al., 2019 Kristensen & Mosgaard, 2020 Parchomenko et al., 2019
6	Performance	Does the indicator measure the intrinsic circularity of an entity, or the impacts resulting from that?	Intrinsically, impacts	De Pascale et al., 2021
7	Perspective	Does the indicator measure actual or potential circularity?	Actual, potential	Saidani et al., 2019
8	Usages	Who is the target group of the indicators?	Decision-making, communication, learning	Saidani et al., 2019
9	Transversality	Is the indicator generalisable or sector specific?	Generic, sector-specific	Saidani et al., 2019
10	Units	Is it a quantitative or qualitative indicator?	Qualitative, quantitative	Saidani et al., 2019
11	Format/ equation type	Which input format does the indicator (set) have?	Web based tool, Microsoft Excel sheet, formula	Saidani et al., 2019 Moraga et al., 2019 Kristensen & Mosgaard, 2020
12	Sources	Who developed the indicator?	Scholars, companies, organisations	Saidani et al., 2019 Kristensen & Mosgaard, 2020

2.4 Scientific Quality Criteria

For assessing the scientific quality of product circularity indicators, a set of well-defined criteria is necessary. In this subchapter, approaches from different research fields are explained and fitting criteria are chosen and related to the course of this research.

2.4.1 Identification of relevant scientific criteria

There are different approaches to evaluate the scientific quality of indicators. In the circular economy research field for example, Corona et al. (2019), Elia et al. (2017) and Pauliuk (2018) just focus on the criterion of (construct) validity for assessing circularity indicators. Linder et al. (2017) on the contrary suggest to assess product circularity indicators regarding their (construct) validity, reliability, transparency, generality and (the existence, consistency, and validity of) aggregation principles. Saidani et al. (2017) came up with a whole product circularity indicator assessment framework, including the criteria Systemic by design, Integrated & Operational, Adaptive & Flexible, Intuitive User Interface and Connection to Sustainable Development Pillars.

In the field of health care, Bannigan & Watson (2009) suggest the three criteria validity, reliability and utility for assessing indicators. Leung (2015) suggests similar criteria, just uses generalisability instead of utility.

In the field of data science, Smartbridge (2020) proposes six criteria for assessing data quality: Completeness, Timeliness, Integrity, Accuracy, Conformity and Consistency.

Even though this list is not exhaustive, Table 2 gives a comprehensive overview of the scientific quality criteria for assessing indicators as described in the sources named above.

Table 2: Overview of possible assessment criteria for circularity indicators

Assessment criterion	Short description	Field of research	Sources
(Construct) Validity	Degree to which an indicator measures what is intended to measure	CE, health care, data science	Bannigan & Watson (2009) Corona et al. (2019) Elia et al. (2017) Pauliuk (2018) Leung (2015) Linder et al. (2017) Saidani et al. (2017) Smartbridge (2020)
Reliability	Scientific rigor, objectivity, consistency, accuracy	CE, health care, data science	Bannigan & Watson (2009) Leung (2015) Linder et al. (2017) Saidani et al. (2017) Smartbridge (2020)

Practicality	Utility, flexibility, easiness to apply	CE, health care	Bannigan & Watson (2009) Saidani et al. (2017)
Generalisability	Independency of the interpretation of the indicator of industry and technology	CE, health care	Linder et al. (2017) Leung (2015) Saidani et al. (2017)
Transparency	Robustness against opportunistic behaviour	CE	Linder et al. (2017)
Completeness	Expected comprehensiveness	Data science	Smartbridge (2020)

The criteria offered in the framework by Saidanie et al. (2017) are assumed to be covered by different parts of the other criteria and are thus not mentioned explicitly. The criteria timeliness and conformity were left out in the table as they refer to specific qualities of data that are not considered important for assessing the quality of the indicators at hand.

2.4.2 Definition of the chosen criteria in this research

In this research, all criteria summed up in Table 2 are used, except for completeness. This criterion is covered by the suggested improvements in the chapter after the indicator assessment, so it is left out as an extra criterion to prevent double argumentation. Thus, the assessed criteria are Construct Validity, Reliability, Practicality, Generalisability and Transparency. In the following, every criterion is shortly defined and then related to the course of this research.

Construct Validity

In literature, Construct Validity is described as a criterion to assess how far an indicator measures what it is intended to measure (Bagozzi et al., 1991). But as this report has a research subject that includes normative dimensions ('it is *good* to achieve a circular economy') and thus also implies normative dimensions in the corresponding indicators ('an indicator value of x is *good*, an indicator value of y is *bad*'), this definition is slightly adjusted. Construct Validity in this report is thus defined as an assessment of how far an indicator helps achieve to build a (C2C) circular economy. For a more differentiated analysis, the criterion is divided into two sub-criteria: (1) The Effectivity assesses the general fit of the indicator to help build a circular economy, while the (2) Efficiency evaluates how far the set-up of the indicator supports this goal.

Reliability

Reliability refers to the consistency to which an indicator measures what it is intended to measure (Riege, 2003). This includes (1) the degree to which an indicator gives the same result if measured several times (Test-Retest Reliability), (2) the degree to which different indicators measuring the same concept lead to the same results (Internal Consistency/Split Halve Reliability) and (3) the degree to which different people measuring an indicator at the same time acquire the same results (Interrater Reliability/Objectivity). For most accurate results, those three sub-criteria are tested statistically, based on empirical research (Bhattacherjee, 2012). But due to the scope and nature of this research, the evaluation regarding the indicators is based on theoretical considerations only. The Internal Consistency is not assessed in this research, as only one set of indicators is evaluated, which does not contain indicators accounting for the same information. So, an assessment of the Internal Consistency would not make sense.

Practicality

Practicality or utility gives an indication of how practical it is for a person to determine an indicator. This includes three sub-criteria: (1) Time of determination, (2) Ease of Determination and (3) Clearness of Language (Bannigan & Watson, 2009). For the evaluation in this report, it is assumed that the administrator assessing the indicators is somewhat familiar with the C2CPII standard and has used it for assessment before.

Generalisability

The generalisability assesses how far an indicator can be interpreted independently of the industry and technology (Linder et al., 2017). The C2CPII standard is explicitly written for products, which are defined as "any physical item[s] that can be routinely and individually purchased from the certification applicant by other entities. This definition includes materials, sub-assemblies, and finished products" (C2CPII, 2021a). Thus, in this research it is assessed per subcategory how far the C2CPII standard is applicable for different kinds of products and how far exemptions are considered.

Transparency

Transparency can be defined as robustness against opportunistic behaviour (Linder et al., 2017). It evaluates how far the indicator and its determination is assessable to all readers (Prager et al., 2019). So, in this research, it is assessed where the C2CPII standard is published, and how far this place is accessible to the public.

3 | METHODOLOGY

All research in this report is qualitative. The methods used are literature research and analysis. Figure 3 shows the flow in which the research is conducted, and in which chapter in this report each phase can be found. Phases 2a and 4a have already been conducted in the literature review and can thus be seen as a preparation for 2b and 4b.

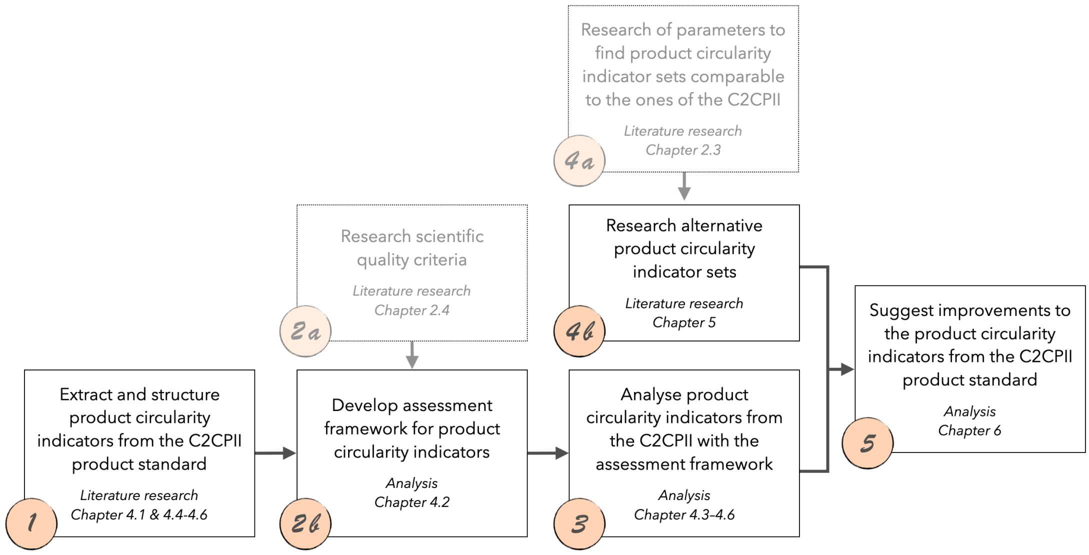

Figure 3: Research flow diagram

Phase 1 (chapter 4.1 and 4.4-4.6)

In this phase, the following sub-research question was answered: *What are the indicators used for measuring product circularity in the most recent C2CPII standard?*

The used method was a literature research and analysis of the documents provided by the only institution publishing the C2C indicator-set, the C2CPII. Those documents comprise the most recent C2CPII product standard version 4.0, the respective user guidance, (which is a more extensive version of the product standard and is further referred to as the C2CPII standard in this report) and complementary Microsoft Excel files, as well as a specific Excel checklist for assessment bodies. Just the sub-category Product Circularity was assessed. Material Health, Water, Energy and Social aspects were out of the scope of this research. All assessed documents are publicly available on the website of the C2CPII, except for the Excel checklist, which is internal information from EPEA.

As the C2CPII standard does not directly name indicators but rather describes checklist-like criteria necessary to get a certification, the specific indicators needed to be extracted. This was done by first reading thoroughly trough each sub-category in the C2C standard and the Excel checklist. Second, the underlying indicator-set was extracted, based on the descriptive requirements text, the further explanation box and the required documentation box. The so found indicators were then double-checked with the Excel checklist, deleting all indicators that were not main points of the checklist (coloured in grey) and which seemed double or only of minor relevance. The output of this data extraction process was a Microsoft Excel file with all indicators of the product circularity category in the C2CPII standard, with an indication of their assumed scale level, type of required input and unit. These results are elaborated in chapter 4.1.

To deepen the understanding of the indicators and to improve the indicator selection for the subsequent assessment, further analysis was done regarding their interrelations. For this, it was attempted to separate the indicators into different thematic clusters. For each cluster, a graphical representation of how the included indicators interrelate to each other, and which set of requirements and verification documents are needed to determine each indicator was created (displayed per cluster in chapter 4.4-4.6). This cluster information was also transferred to the Excel file with the indicators list. Eventually, through this analysis some indicators were renamed, merged or deleted.

Phase 2 (chapters 2.4 and 4.2)

In this phase, the following sub-research question was answered: *What is a good way to measure the scientific quality of a set of indicators?*

This phase consisted of two steps: The first step was the research and analysis of literature on scientific quality criteria for indicators. Sources for finding suitable academic literature were the Leiden and Delft University catalogues and Google Scholar. To also cover approaches from the non-academic world, additionally the search engine DuckDuckgo was used. The following search terms were covered: *scientific quality criteria; scientific quality criteria, indicators; scientific quality criteria, metrics.* Literature was perceived as suitable if it dealt with scientific quality criteria that are compatible for the assessment of indicators. The extracted data was a selection of suitable scientific quality criteria. This step has already been covered in chapter 2.4.

The second step was the development of an assessment framework, based on the criteria selected in the first step of this phase. An indicator scoring system from 1 (barely fulfilled) to 3 (fully fulfilled) was introduced, accompanied by factors influencing the score per criterion and an explanation of what every number means. It is noted that those numbers are still a qualitative estimation to find trends and increase the transparency and structure of the assessment and must not be seen as a true quantification of scientific quality. Additionally, it was attempted to account for the assumption that not all criteria are equally important, and neither are all indicators. Therefore, a specific weighting scheme was added to the framework. This second step of phase 2 is elaborated in chapter 4.2. Further information on the scores and influencing factors per criterion can be found in appendix 1 and the supplementary Microsoft Excel file.

Phase 3 (chapters 4.3-4.7)

In this phase, the following sub-research question was answered: *How far do the indicators used for measuring product circularity in the most recent C2CPII product standard comply with the scientific quality criteria?*

The method used in this phase was data analysis, as it comprises the synthesis of the two previous phases. The assessment framework developed in phase 2 was applied to the indicators found in phase 1. The results are found in chapter 4.3-4.7. It is noted that the assessment is based on logical considerations only, no empirical evaluation was conducted. For scope reasons, only points are mentioned that did not comply to the pre-defined criteria for the reasoning for the score of each indicator. Thus, what is not explicitly described as criticism is assumed to be compliant with the criterion.

For a clear understanding of this phase, some terms need to be defined: The *administrator* is the person who determines the indicator. The *applicant* is the company who wants to assess their product's circularity. The administrator and the applicant can theoretically be the same person or belong to the same entity, or they can be separate people/entities. Classically, the administrator comes from a C2C-certified accreditation body (such as EPEA) assessing the product for one of their applicant clients.

Furthermore, the terms *material* and *homogenous material* need to be defined. In the C2CPII standard, they are used as synonyms and defined as "a material of uniform composition throughout that cannot be mechanically disjointed, in principle, into different materials" (C2CPII, 2021b, p. 264). Thus, the term homogenous is more meant in a physical, not in a chemical way.

Phase 4 (chapters 2.3 and 5)

In this phase, the following sub-research question was answered: *What are other indicators used to measure product circularity?*

This phase consisted of two steps again. In the first step, literature research and analysis were used to get an overview of existing circularity indicators and to find ways of categorising them. This literature was again found in the Leiden and Delft University catalogues and Google Scholar for academic literature and in the search engine DuckDuckgo for approaches from the non-academic world. The following search terms were used: *measuring circular economy; measuring cradle to cradle; measuring eco-effectivity; indicators, circular economy; indicators, cradle to cradle; metrics, circular economy; metrics, cradle to cradle; product circularity, indicators.* Only recent litertaure reviews were considered as suitable results, and only the ones containing indicators measuring (preferably product) circularity. So, the output of this step was an overview of the most recent literature reviews on the topic of circularity indicators, and parameters for categorising them, covering the years 2019-2021. This step has already been done in chapter 2.3.

The next step was to use those parameters to find other circularity indicators that are comparable to the ones by the C2CPII. The method used here was the research and analysis of literature on alternative product circularity indicators. This literature was found in the reviews discovered in the previous step of this phase. The attributes of the parameters that had been found in the previous step as well were set in a way that they fitted the indicators from the C2CPII. Then, the same attributes were used to find comparable indicator-sets in the literature reviews on circularity indicators as described in chapter 2.3. The so found comparable product circularity indicators were then used as an orientation to find improvements to the shortcomings of the indicators of the C2CPII in the next phase. This step of this phase is covered in chapter 5.

Phase 5 (chapter 6)

In this phase, the following sub-research question was answered: *How can the scientific quality of the indicators used for measuring product circularity in the most recent C2CPII product standard be improved?*

There was no specific method used in this phase, as this was the synthesis of the results of phases 3 and 4 and the objective was to deduce improvements to the indicator-set of the C2CPII. In cases where it was fitting, additional literature research was conducted to find improvements to very specific shortcomings. This literature was again found in the Leiden and Delft University catalogues and Google Scholar. The findings were visualised in modified versions of the cluster diagrams developed in phase 1, building the base for recommendations to EPEA and the C2CPII. This phase can be found in chapter 6.

4 INDICATOR ASSESSMENT

In this chapter, first an overview of the indicators to be assessed is given, as extracted and restructured from the C2CPII standard. Second, the assessment framework developed in this research for analysing the scientific quality of the indicator-set is introduced. Third, the Transparency is assessed for the whole C2CPII standard. Fourth, the findings from the indicator assessment are summarised per cluster, including the assessment criteria Construct Validity, Reliability, Practicality and Generalisability. A more detailed assessment of each indicator can be found in appendices 2-4. Finally, a summary of all assessed criteria for all clusters is given.

4.1 Overview of the C2CPII Indicators

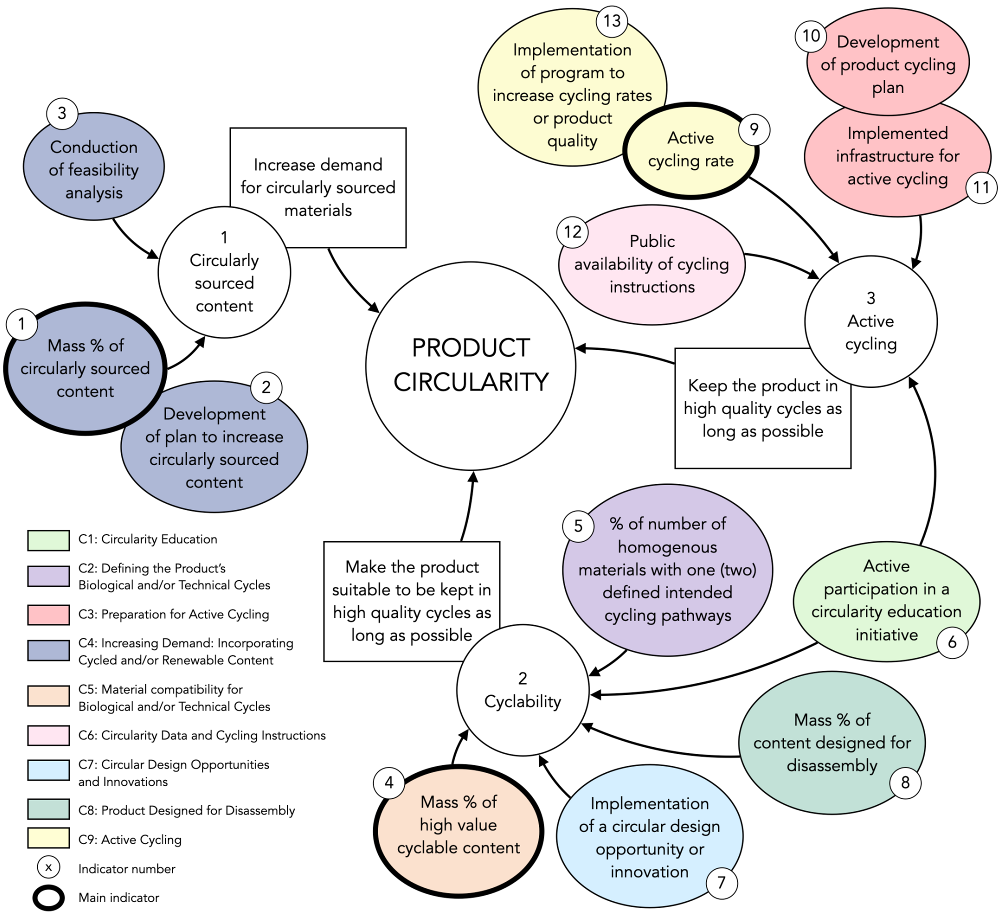

Figure 4: Overview of product circularity indicators in the C2CPII standard

From the C2CPII standard, 13 indicators were extracted, and each indicator was assigned to a certain cluster: (1) Circularly sourced content, (2) Cyclability and (3) Active cycling. Each of those clusters aims for a specific goal, which altogether form the construct of product circularity (see Figure 4). The colours in the figure refer to the sub-categories of product circularity in the C2CPII standard.

Within every cluster, each indicator was allocated either to the category of determination (determining the main indicator), support (supporting the determination), preparation (aiming for measures that are supposed to improve the outcome of the main indicator) or alternative (if the main indicator goal cannot be met). A list of all indicators can be found in Table 3, including information on the subcategory the indicators are derived from in the C2CPII standard, the cluster and the indicator category they were assigned to, and the scale level, output and unit they have.

Table 3: Overview of all assessed indicators

No	Indicator	Cat. St[1]	Cluster	Indicator category	Scale level	Output	Unit
1	Mass % of circularly sourced content	4	1 Circularly sourced content	Determination	Ratio	Number 0-100	%
2	Development of plan to increase cycled/renewable content	4	1 Circularly sourced content	Alternative	Nominal	Yes/no	No unit
3	Conduction of feasibility analysis	4	1 Circularly sourced content	Alternative	Nominal	Yes/no	No unit
4	Mass % of high value cyclable content	5	2 Cyclability	Determination	Ratio	Number 0-100	%
5	% of number of homogenous materials with one (two) defined intended cycling pathways	2	2 Cyclability	Preparation	Ratio	Number 0-100	%
6	Active participation in a circularity education initiative	1	2 Cyclability 3 Active cycling	Support	Nominal	Yes/no	No unit
7	Implementation of a circular design opportunity or innovation	7	2 Cyclability	Support	Nominal	Yes/no	No unit
8	Mass % of content designed for disassembly	8	2 Cyclability	Support	Ratio	Number 0-100	%
9	Active cycling rate	9	3 Active cycling	Determination	Ratio	Number 0-100	%
10	Development of product cycling plan	3	3 Active cycling	Support	Nominal	Yes/no	No unit
11	Implemented infrastructure for active cycling	3	3 Active cycling	Support	Nominal	Yes/no	No unit
12	Public availability of cycling instructions	6	3 Active cycling	Support	Nominal	Yes/no	No unit
13	Implementation of program to increase cycling rates or product quality	9	3 Active cycling	Alternative	Nominal	Yes/no	No unit

[1]Category in the C2CPII standard

4.2 Introduction of the Indicator Assessment Framework

For assessing those 13 indicators, an assessment framework was developed, based on the assessment criteria Construct Validity (Effectivity, Efficiency), Reliability (Test-Retest Reliability, Objectivity), Practicality (Time of Determination, Ease of Determination, Clearness of Language), Generalisability and Transparency.

To increase the transparency and structure of the assessment, a simple score from 1 (barely fulfilled) to 3 (fully fulfilled) was assigned to each criterion, based on a logical evaluation. Further information on the criteria, scores and the factors influencing the assessment can be found in appendix 1.

Those 13 indicators, together with the five assessment criteria, their seven sub-criteria and the scoring system from 1-3 build the base of the assessment framework. Additionally, it was accounted for the assumption that not all (sub-) criteria are equally important, and neither are all indicators. Therefore, a specific weighting scheme was added to the framework. The weighting factors assumed for the (sub-) criteria in this research can be derived from Table 4.

Table 4: Weighting factors for CV, R, P and their sub-criteria (left) and CV, R, P, G and T altogether (right)

Criterion	Weighting factor	Sub-Criterion	Weighting factor within criterion
CV	0,40	CVV	0,33
		CVC	0,67
R	0,40	TRR	0,33
		OR	0,67
P	0,20	TP	0,33
		EP	0,33
		CP	0,33
∑	1,00		

Criterion	Weighting factor
CV	0,3
R	0,3
P	0,15
G	0,05
T	0,2
∑	1,00

CV = construct validity, CVV = effectivity, CVC = efficiency, R = reliability, TRR = test-retest reliability, OR = objectivity, P = practicality, TP = time of determination, EP = ease of determination, CP = clearness of language

The weighting factors assumed for the indicators can be derived from Table 5. They were calculated once for the indicators for each cluster and once for the whole indicator-set, to enable further calculations at a later point. It is noted though that both the weighting factors for the criteria and for the indicators are only assumptions and require further research to be determined thoroughly.

Table 5: Weighting factors for the indicators

Indicator	Weighting	Weighting factor within the cluster	Weighting factor total
Mass % of circularly sourced content	x2	0,50	0,13
Development of plan to increase cycled/renewable content	x1	0,25	0,06
Conduction of feasibility analysis	x1	0,25	0,06
Mass % of high value cyclable content	x2	0,33	0,13
% of number of homogenous materials with one (two) defined intended cycling pathways	x1	0,17	0,06
Active participation in a circularity education initiative	x1	0,17	0,06
Implementation of a circular design opportunity or innovation	x1	0,17	0,06
Mass % of content designed for disassembly	x1	0,17	0,06
Active cycling rate	x2	0,33	0,13
Development of product cycling plan	x1	0,17	0,06
Implemented infrastructure for active cycling	x1	0,17	0,06
Public availability of cycling instructions	x1	0,17	0,06
Implementation of program to increase cycling rates or product quality	x1	0,17	0,06
∑			1,00

The indicators, the (sub-) criteria, the scoring system and the weighting in sum make up the whole assessment framework. The criteria Construct validity, Reliability and Practicality were assessed for each indicator individually, the Generalisability per cluster and the Transparency for the whole C2CPII standard. Therefore, the framework is separated into two parts. The first part is a table evaluating the sub-criteria of Construct validity, Reliability and Practicality on a scale from 1-3 for each indicator (Table 6).

Table 6: Assessment framework, part I

No.	Indicator	CVV	CVC	∑CV	TRR	OR	∑R	TP	EP	CP	∑P	∑EWC[1]	∑SWC[2]
1	Mass % of circularly sourced content												
2	…												
∑ equally weighted indicators													
∑ specifically weighted indicators													

CV = construct validity, CVV = effectivity, CVC = efficiency, R = reliability, TRR = test-retest reliability, OR = objectivity, P = practicality, TP = time of determination, EP = ease of determination, CP = clearness of language, EWC = equally weighted criteria, SWC = specifically weighted criteria

The main criteria were calculated using the weighting scores described in Table 4. In the last two columns in Table 6, the end scores for each indicator are displayed, one time with equally weighted criteria assumed, one time with the applied weighting schemes from Table 4. In the last two rows, the end scores per criterion are shown, again one time under the assumption that all indicators are weighted equally, one time with the weighting applied as shown in Table 5.

Part two of the framework is a table that adds the missing two criteria Generalisability and Transparency to the end scores on a cluster level (Table 7). Those end scores were calculated with different variants of weighting: (1) Criteria and indicators equally weighted, (2) Specifically weighted criteria, (3) Specifically weighted indicators and (4) Both specifically weighted criteria and indicators.

Table 7: Assessment framework, part II

Cluster	CV	R	P	G	T	EWC + EWI	EWC + SWI	SWC + EWI	SWC + SWI
Circularly sourced content									
Cyclability									
Active cycling									

CV = construct validity, R = reliability, P = practicality, G = generalisability, T = transparency, EWC = equally weighted criteria, EWI = equally weighted indicators, SWI = specifically weighted indicators, SWC = specifically weighted criteria

A Microsoft Excel file with the specific calculations can be found in the supplementary material to this report. It enables the reader to adjust the weighting factors, as well as the scoring system if needed. In the following, this developed assessment framework is applied to each cluster.

4.3 Assessment of the Transparency

The standard and all relevant side documents are publicly available on the website of the C2CPII. Thus, the standard's transparency is high and assessed with a 3 for all indicators.

4.4 Assessment of Cluster 1: Circularly Sourced Content

The first cluster has the main goal of increasing the demand for circularly sourced material. The main concept that it aims to measure is circularly sourced content. The indicators belonging to this cluster and their interrelations can be found in Figure 5.

Indicator 1 is the Mass % of circularly sourced content. The intention of this main (determination) indicator is to increase the demand for circularly sourced materials. It has a ratio scale and gives a number between 0-100% as an output.

Indicator 2 is the Development of a plan to increase the circularly sourced content. The intention of this alternative indicator is to increase the cycled/renewable content of the product. It has a nominal scale and a binary output of either yes or no.

Indicator 3 is the Conduction of a feasibility analysis. The intention of this alternative indicator is to increase the amount of cycled/renewable content in the product in difficult product types. It has a nominal scale and a binary output of yes or no.

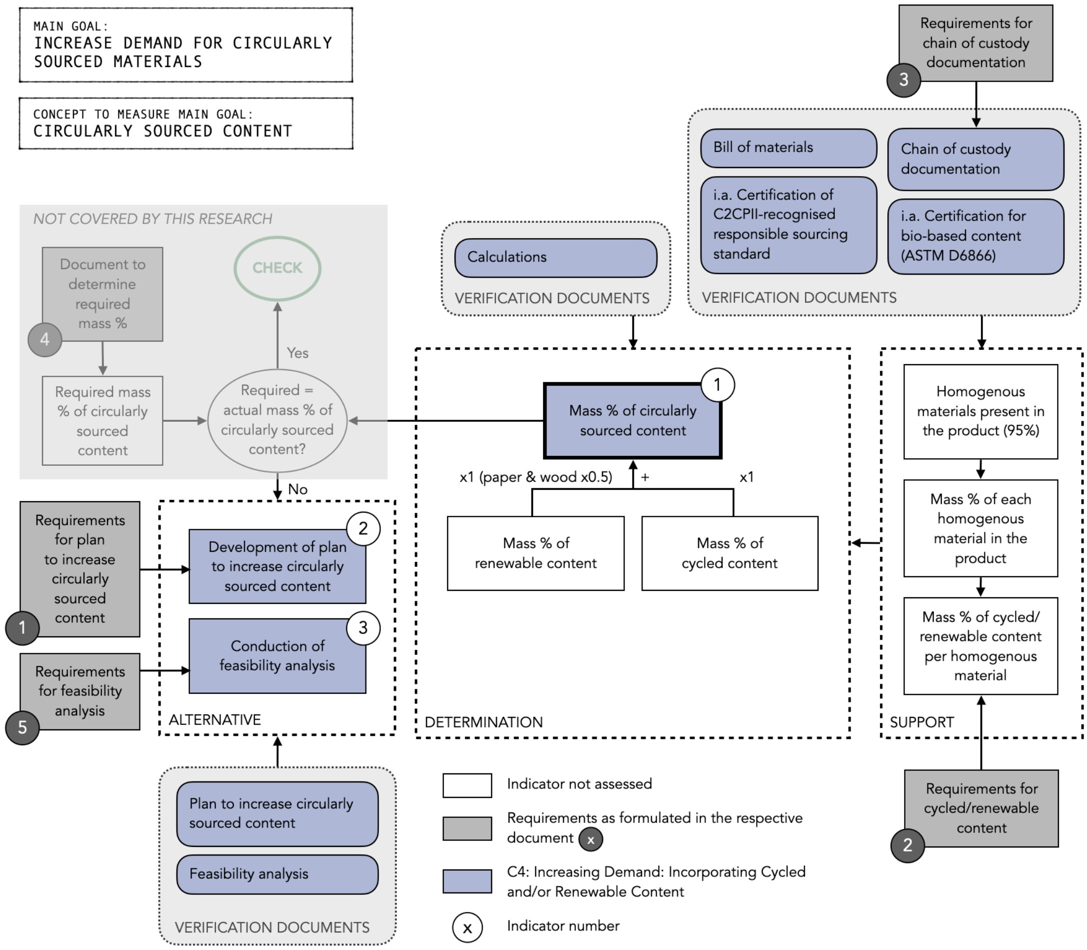

Figure 5: Current indicators and their interrelations in cluster 1

Construct Validity

The analysis showed that both indicators 1 and 2 have a high Effectivity, as their general idea is fitting for achieving the cluster's main goal/improving the main indicator. Indicator 3 seems to be of less importance in both regards.

All three indicators have weaknesses regarding the Efficiency of their set-up (it is pre-noted that all required standard tests for this indicator are assumed to be valid and not assessed in this research):

For indicator 1, it is not that clear whether it is also allowed to incorporate content that is derived from a higher quality product (which has been downcycled then). It is also not clear from up to which tier level the cycled/renewable content may be added, and there is no clear indication whether also cycled content from other r-strategies than recycling (reuse, remanufacture, refurbish) is allowed. Furthermore, there are only vague instructions on how to perform the chain of custody documentation. There is an ISO norm available (ISO 22095), but the C2CPII does not request its use. Renewable content must be renewable within ten years, but there is no justification of this time frame. It is also questionable to count renewable content equally as cycled content in the formula (with few exemptions). It could be argued to set a higher weighting on cycled content because it does not lead to land use conflicts (Barteková & Kemp, 2016; Colombia Climate School, 2017).

Indicators 2 and 3 are missing what the respective other indicator offers. For both indicators, normative requirements and stricter boundaries would strengthen the relation of the indicator and the main goal, telling what a good plan/feasibility analysis would entail (what is a good timeline, what is a good strategy etc.). For indicator 2, a list of suppliers who could potentially (or actually) supply the required demand of cyclable/renewable content is missing.

The addressed points lead to a weighted end score of 2.3 for the Construct Validity of this cluster.

Reliability

For indicator 1, the amount and interlacement of the input information and the complexity of the calculation could eventually lead to the administrator making a mistake in the indicator determination. The lack of clarity regarding the requirements and the boundaries (i.e., unclarity about definition of cycled content; difficulty of finding information on after how many years content counts as renewable) also diminishes the Objectivity of this indicator as different administrators could possibly interpret the boundaries differently.

For indicators 2 and 3, missing normative requirements (e.g., what is a good method in the plan to increase the cycled/renewable content, or what is a good strategy in the feasibility analysis) give room for opportunistic behaviour, and also decrease the Objectivity. Even in good will, different administrators might have different perspectives on how to interpret the requirements and thus come to different results.

In summary, this evaluation leads towards a weighted end score of 1.2 for the Reliability of this cluster.

Practicality

Based on the assumed processes of determination, all indicators in this cluster are assumed to be determinable in less than one day, while (especially for indicator 1) specific knowledge and skills are required for doing so. The language used to describe the indicators and their determination in the C2CPII standard is mostly confusing for all indicators. This is especially true for the structure and order in which the information is given, and for the description of how the indicator is exactly determined, which is often missing. Thus, the weighted overall score of the Practicality of this cluster is 1.8.

Generalisability

There are no specifically stated exemptions in the C2CPII standard for which the requirements do not apply. Thus, the Generalisability of this cluster is assumed to be high, and the criterion is assessed with a 3.

Summary for cluster 1

Summing it up, the scientific quality of the indicators in this cluster is medium, with an overall weighted end score of 2.0. While the indicators have a medium to good baseline regarding their Construct Validity (score 2.3) and Generalisability (score 3.0) and mostly only need minor improvements in this regard, the Practicality (score 1.8) and most of all Reliability (score 1.2) of this cluster are significantly lacking. This is especially true for the Objectivity, as no indicator scored higher than a 1 here. The single scores per indicator per criterion can be derived from Table 8 at the end of this chapter.

4.5 Assessment of Cluster 2: Cyclability

The second cluster has the main goal of making the product suitable to be kept in high quality cycles as long as possible. The main concept that it aims to measure is cyclability. The indicators in this cluster and their interrelations can be found in Figure 6.

Indicator 4 is the Mass % of high value cyclable content. The intention of this main (determination) indicator is to make the product suitable to be kept in high quality cycles as long as possible. It has a ratio scale and a number between 0-100% as an output.

Indicator 5 is the % of number of homogenous materials with one (two) defined intended cycling pathways. The intention of this preparation indicator is to prepare the product to become suitable to be kept in high quality cycles as long as possible. It has a ratio scale and gives a number between 0-100% as an output.

Indicator 6 is the Active participation in a circularity education initiative. The intention of this support indicator is to ensure that the applicant has understood the possibilities for circularity in their product and found ways to apply them. It has a nominal scale and gives a binary output of yes or no.

Indicator 7 is the Implementation of a circular design opportunity or innovation. The intention of this support indicator is to increase the product's cyclability through designing more end-of-use cycling opportunities. It has a nominal scale and gives a binary output of yes or no.

Indicator 8 is the Mass % of content designed for disassembly. The intention of this support indicator is to increase the likelihood that a large percentage of the materials in the product will be cycled. It has a ratio scale and gives a number between 0-100% as an output.

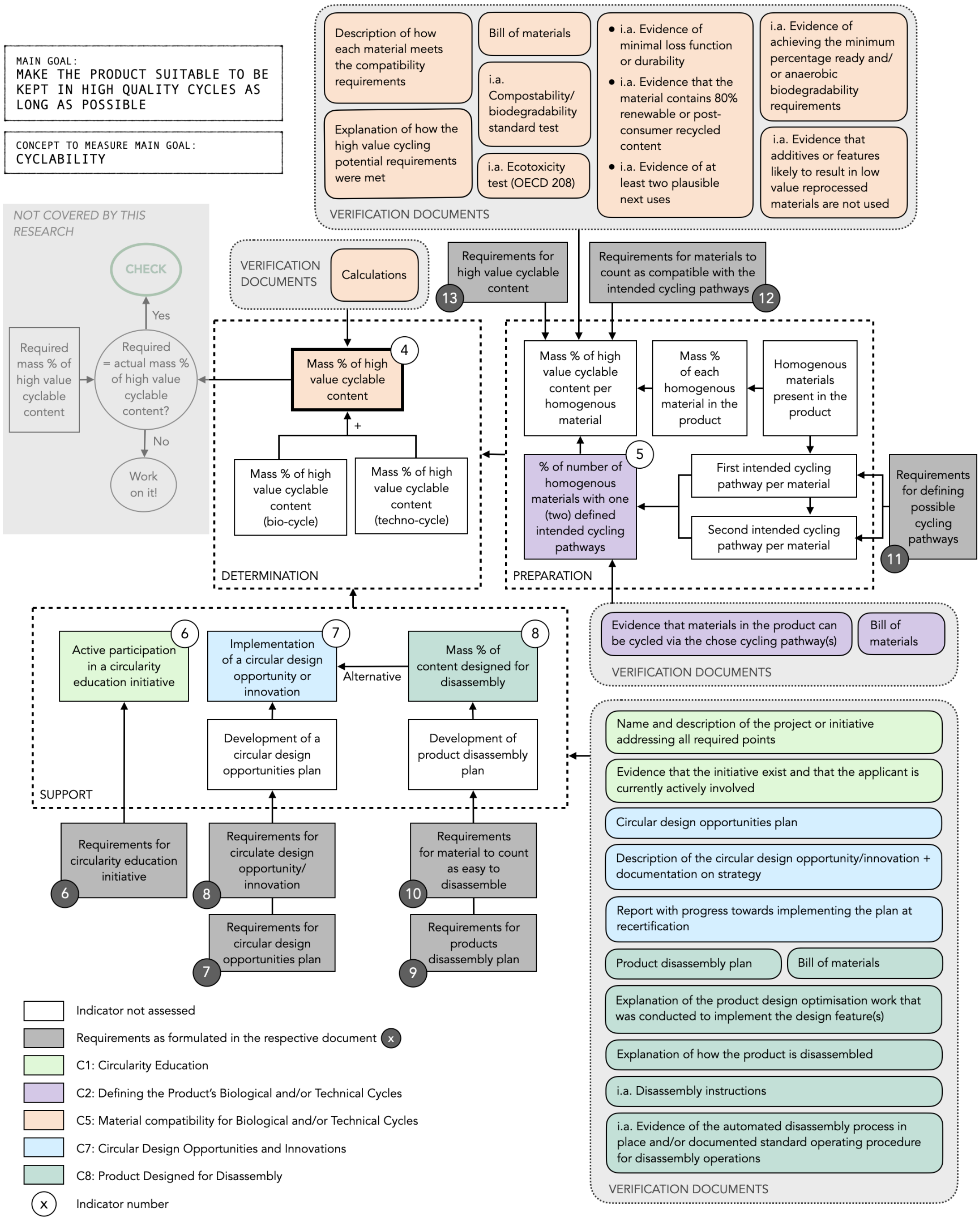

Figure 6: Current indicators and their interrelations in cluster 2

Construct Validity

The Effectivity of the indicators 4, 5, 7 and 8 is evaluated as high. That means that indicator 4 strongly helps in achieving the goal of making the product suitable to be kept in high quality cycles as long as possible, and that the indicators 5, 7 and 8 strongly help increasing the main indicator 4. Only indicator 6 is assessed with a medium Effectivity, as it is not perceived as that crucial for improving the main indicator.

The Efficiency of all indicators is only assessed as medium, as their set-up entails minor to major weaknesses:

For indicator 4, the following points can be criticised (It is pre-noted that all required standard tests for this indicator are assumed to be valid and not assessed in this research): For solid materials in the biological and all materials in the technical cycle, the applicant has to choose between one of the following to make a material count as high-value cyclable: (1) The material must substitute for virgin material without quality loss, (2) the material must incorporate at least 80% circularly sourced content or (3) the product must have at least two plausible next uses. For the biological cycle, (1) does not seem logical. For the technical cycle, there is a major drawback: Considering the options altogether, it would be possible for an applicant to produce a product that is only recyclable on a very low quality level, as long as it is either made of 80% cycled/renewable content or has two plausible next uses (and entails no additives that result in low quality recycling, as defined in a further requirement). This is not in line with what the C2C philosophy claims to strive for, that is cycling materials on a high quality level. Furthermore, the focus of this indicator is strongly on recycling, even though the other r-strategies (reuse, remanufacture, refurbish) are implicitly also allowed. But recycling should only be the last r-option, as there is a lot of potential for keeping the product in high quality cycles and maintain the product's value in the other r-strategies (Achterberg et al., 2016). Another point to criticise is that for the materials in the biological cycle, there is no indication about which nutrients should be the result of the biological cycling pathways. Many of the most common biodegradable plastics, such as Polylacticacid, Polyhydroxyalkanoate, Polybutylene adipate terephthalate, and Polybutylensuccinat (Grand View Research, 2020), do not add valuable nutrients to their environment during their biodegradation. And even if they did, those nutrients might not suit the environment and add elements that even do harm to the ecosystem and lead to eutrophication (Beier, 2009; Bundesgütergemeinschaft Kompost e.V., 2018).

For indicator 5, there is no weighting or normative evaluation of the quality of the intended cycling pathways (e.g., is reuse better than recycling?), neither of their suitability, nor whether the pathway is likely to happen. Furthermore, it can be misleading to offer anaerobic biodegradation as a pathway as it may lead to CH_4 emissions, which means that the C is lost in the atmosphere and the cycle is not closed anymore (Mitchell & Gu, 2009).

For indicator 6, there is no benchmark for what formulations like “supports learnings toward implementing the company’s circularity strategies” or “progress within an industry” exactly mean in the requirements. So it can be that this circularity education initiative really contributes to improving the main indicator, if taken seriously by an intrinsically motivated company, or that the connection is rather weak if the company is only doing the bare minimum.

Indicator 7 gives a list of different strategies for implementing a circular design opportunity. A point to criticise is that strategies 2a (minimise product weight) and 2b (enlarge lifetime) can also be counterproductive and not make the product eco-effective. Strategy 2c (design for product as a service) should be handled with care and only come together with a circular product design and reasonable manners of exchanging the product. Otherwise, products could break or not be handled with care by the customers as they do not feel responsible. This would not contribute to the goals of a circular economy. In all strategies, normative requirements and hard boundaries are missing.

For indicator 8, the following can be criticised. Requirement 1 (include at least one design feature that improves the ease of disassembly) is only very soft. Only one design feature needs to be implemented, and it needs to ease the disassembly only compared to other products. The usefulness of requirement 3 (make comprehensive disassembly instructions publicly available) depends on how pleasantly the instructions are designed and presented and where they are published. For requirement 4 (Components must be separable using common tools with minimal technical experience and instruction), it is unclear what “common tools” or “minimal technical experience” mean.

Summing it up, the weighted end score of the Construct Validity of this cluster is 2.2.

Reliability

For indicator 4, it is likely that the administrator makes a mistake in the indicator determination as for the confusing structure of the information on when something counts as (high value) cyclable in the C2CPII standard. Also, the requirements for products of the technical cycle are not that strict as there are no standard tests required (except for wet-applied products), so the required verification documents are more open for interpretation. This makes both opportunistic behaviour and a varying interpretation of different administrators more likely. Furthermore, it is likely that an administrator includes mistakes and/or misinterpretations in the calculations, which again increases the chance of assigning the indicator a wrong value.

Indicator 5 is evaluated with a high Test-Retest Reliability and Objectivity.

For indicator 6, administrators are likely to include mistakes in determining the indicator value as for a lack of strict boundaries and normative dimensions in the requirements, which gives large room for opportunistic behaviour. Requirements 2-5 ('The initiative must support learnings toward implementing the company's circularity strategies and cycling infrastructure', 'The initiative must aim to drive progress within an industry or across multiple industries', 'The initiative must ensure that it allows for adequate voice for all participants', 'The applicant must have actively participated within the last two years prior to certification or recertification') are evaluated as quite subjective as formulations like "supports learning", "drives progress" and "allows for adequate voice" are not clearly defined.

The requirements for indicator 7 for implementing a circular design strategy lack an indication on how to measure whether a strategy has been used or a goal has been met, and there is quite some text to read through in the C2CPII standard. Also, there are no normative boundaries defined.

For indicator 8, the main requirement ('include at least one design feature that improves the ease of disassembly') leaves a lot of room for interpretation without the administrator having to justify their choices, there are no normative requirements either. Requirement 4 ('Components must be separable using common tools with minimal technical experience and instruction') is quite subjective, assuming that everybody has a different definition of the terms "common tools" and "minimal technical experience".

In summary, the weighted end score for the Reliability of this cluster is 1.6.

Practicality

Based on the assumed process of determination, indicator 4 is assumed to require one hour to one day to be determined, all other indicators are likely to be determinable within less than an hour. Most of the indicators are quite hard to determine, as they require specific skills and knowledge from the administrator. The language used in the C2CPII standard is not that clear for the description of most of the indicators. Especially the part for the first indicator is very confusing and unclear. This evaluation leads to a weighted end score of 2.1 for the Practicality of this cluster.

Generalisability

Most of the assessed indicators in this cluster do not state any exemptions. Just indicator 5 names intermediate and wet-applied products as exemptions, and indicator 8 liquid products, intermediate products or products that do not require separation for the intended cycling pathway. Thus, the Generalisability of cluster 2 is evaluated as medium with a score of 2.

Summary of cluster 2

Summing it up, the scientific quality of the indicators in this cluster is medium, with an overall weighted end score of 2.1. The Construct Validity (score 2.2), Practicality (score 2.1), Generalisability (score 2.0) and transparency (score 3.0) seem at least medium sound and mostly only require minor improvements. The Reliability of this cluster on the contrary is lacking again (score 1.6). This is especially true for the Objectivity, as three out of five indicators only score a 1 here. The single scores per indicator per criterion can be derived from Table 8 at the end of this chapter.

4.6 Assessment of Cluster 3: Active Cycling

The third cluster has the main goal of keeping the product in high quality cycles as long as possible. The main concept that it aims to measure is active cycling. The indicators belonging to this cluster, and how they relate to each other, can be found in Figure 7.

Indicator 9 is the Active cycling rate. The intention of this main (determination) indicator is to keep the product in high quality cycles as long as possible. It has a ratio scale and gives a number between 0-100% as an output.

Indicator 10 is the Development of a product cycling plan. The intention of this support indicator is to ensure that the applicant is aware of all barriers to enable a cycling according to the intended cycling pathways. It has a nominal scale and gives a binary output of yes or no.

Indicator 11 is the Implemented infrastructure for active cycling. The intention of this support indicator is to ensure that the applicant has implemented an infrastructure to enable the active cycling of their product. It has a nominal scale and gives a binary output of yes or no.

Indicator 12 is the Public availability of cycling instructions. The intention of this support indicator is to ensure that entities other than the applicant are able to actively cycle the product, so the active cycling rate is increased. It has a nominal scale and gives a binary output of yes or no.

Indicator 13 is the Implementation of a program to increase the cycling rates or product quality. The intention of this alternative indicator is to increase the active cycling rate and improve the cycling quality. It has a nominal scale and gives a binary output of yes or no.

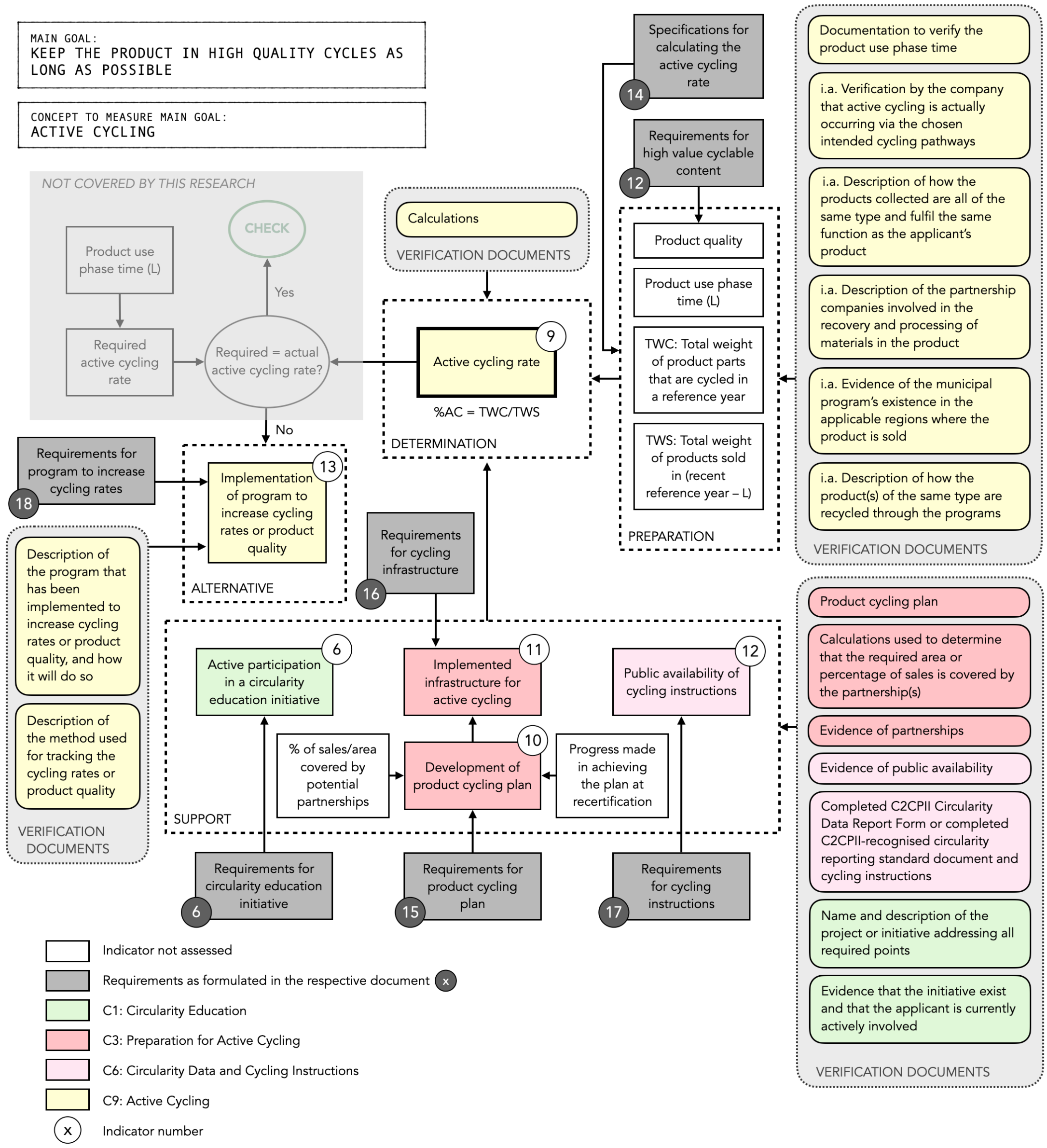

Figure 7: Current indicators and their interrelations in cluster 3

Construct Validity

The Effectivity of all indicators in this cluster is assumed to be high. For indicator 9, that means that the general idea behind the indicator is strongly fitting for achieving the main goal of keeping the product in healthy, high-quality cycles as long as possible. For indicators 10-13, that means that their general idea is strongly fitting for improving the main indicator, thus the active cycling rate.

The Efficiency includes some weaknesses for all indicators:

For indicator 9, it is not clear what the documents in requirement 3 (documentation on how the product is actively cycled) should include. Normative requirements are missing here. But the most crucial weakness of this indicator is the lack of a formulation that downcycling is forbidden. In the previous cluster, it has been (less or more) secured that the product is high value cyclable in theory, but there is no formulation saying that the product must still not be downcycled in practice.

For indicator 10, in the first three requirements normative implications are missing. What is also missing is the formulation of potential challenges in cycling the product and how to overcome those.

For indicator 11, in requirement 3 ('initiate partnerships for product recovery') there are no normative requirements for the quality of the partners (which partners count, which do not?). Also, there is information missing on which parts of the product have to be covered by the stewardship program/municipal cycling systems/implemented partnerships. The hypothetical example might occur that one part can be cycled by the municipality/a partner (a screw e.g.), but the rest is not compatible.

The only thing to criticise for indicator 12 is that it is not accounted for how and where the cyclability instructions are made available. If they are just on the website of the C2CPII as it looks like, it takes some effort to look them up. Also, the document (a Microsoft Excel file) is not that easy to read for a person who is not familiar with the topic. An improved set-up of the displayed information and a place where it is easily assessable would make the instructions more useful.

For indicator 13, the named examples of recognised programs are likely to help achieve the goal of this cluster, but only if applied in an effective way. For example, an applicant could have an incentivised take-back program that is not very much known. That would result in only few effects, even though the criterion would count as fulfilled for the C2CPII. Also, the requirements are just named examples. In theory, the applicant could come up with a totally different program and it is hard to determine whether this will be accredited or not, so whether this program is valid. Furthermore, it seems questionable to exclude products of a use-phase time of >1 year from the requirements.

In summary, the weighted end score for the Construct Validity of this cluster is 2.1.

Reliability

For indicator 9, the structuring of the chapter and the amount of input information is likely to result in some confusion for the administrator and makes it likely that they make a mistake. Requirements 3 and 4 (documents required to prove that active cycling is happening) give some room for interpretation, which makes them more subjective and open to opportunistic behaviour.

For indicator 10, the requirements offer room for interpretation, too, as there are no strict boundaries and normative dimensions.

Indicator 11 offers many possibilities for opportunistic behaviour and is subjective in its determination as in requirement 3 ('initiate partnerships for product recovery'), normative indications are missing (what is a good partner? when do they count?).

Indicator 12 is evaluated with a high Test-Retest Reliability and Objectivity.

For indicator 13, there is no boundary defined about how much the program needs to increase the active cycling rate/product quality. In requirement 1 ('The program must lead to a measurable improvement in the indicator "active cycling rate" or in the cycling quality'), it is not clear what "measurable improvement" means, so there is quite some room for interpretation. For requirements 2-4 ('The applicant must invest in a system that facilitates tracking of product cycling ', 'The applicant must incentivise the user to cycle the product', 'Examples of other programs'), the boundary is unclear between a yes and a no. Also, there is no indication about which criteria other programs have to follow that are not in the example list. Requirement 6 ('Track and monitor influence on active cycling rate and product quality over time') leaves a lot of room for interpretation, too, as there is no tool explained or information given on how to measure the product quality.

Summing it up, this cluster has a weighted end score of 1.9 for the Reliability.

Practicality

Based on the assumed process of determination, indicator 9 is assumed to need one hour to one day to be determined, all other indicators in this cluster can be determined within less than one hour. The indicator 9 is the hardest to determine (as it is a main indicator), all other indicators do not require that many skills and knowledge and are thus assumed to be easier determinable. The language for all indicators in this cluster is somewhat clear. This evaluation leads to a weighted end score of 2.2 for the Practicality of this cluster.

Generalisability

Exempted products are intermediate and liquid products for indicators 9, 11 and 13 and products for the biological cycle and for which no intervention is needed to ensure active cycling for indicator 12. Thus, the Generalisability of this cluster is evaluated with a 2.

Summary of cluster 3

Summing it up, the scientific quality of the indicators in this cluster is medium, with a weighted end score of 2.1. The Construct Validity (score 2.1), Practicality (score 2.2) and Generalisability (score 2.0) seem at least medium sound and mostly only require minor improvements. The Reliability of this cluster is barely exceeding the score for an acceptable level (score 1.9). Only three out of five indicators score higher than a 1 in Objectivity. The respective single scores per indicator can be derived from Table 8.

4.7 Summary

Table 8 shows the summary scores per indicator for the criteria Construct Validity, Reliability and Practicality and their respective sub-criteria.

Table 8: Summary scores of the indicator assessment

No.	Indicator	CVV	CVC	∑CV	TRR	OR	∑R	TP	EP	CP	∑P	∑EWC	∑SWC
1	Mass % of circularly sourced content	3	2	2.3	1	1	1.0	2	1	1	1.3	1.6	1.6
2	Development of plan to increase cycled/renewable content	3	2	2.3	2	1	1.3	3	2	2	2.3	2.1	1.9
3	Conduction of feasibility analysis	2	2	2.0	2	1	1.3	3	2	2	2.3	2.0	1.8
4	Mass % of high value cyclable content	3	1.5	2.0	1	1	1.0	2	1	1	1.3	1.5	1.5
5	% of number of homogenous materials with one (two) defined intended cycling pathways	3	2	2.3	3	3	3.0	3	3	2	2.7	2.7	2.7
6	Active participation in a circularity education initiative	2	2	2.0	2	1	1.3	3	2	2	2.3	2.0	1.8
7	Implementation of a circular design opportunity or innovation	3	2	2.3	2	2	2.0	3	2	2	2.3	2.3	2.2
8	Mass % of content designed for disassembly	3	2	2.3	2	1	1.3	3	2	2	2.3	2.1	1.9
9	Active cycling rate	3	1	1.7	2	2	2.0	2	1	2	1.7	1.9	1.8
10	Development of product cycling plan	3	2	2.3	2	1	1.3	3	2	2	2.3	2.1	1.9
11	Implemented infrastructure for active cycling	3	2	2.3	2	2	2.0	3	2	2	2.3	2.3	2.2
12	Public availability of cycling instructions	3	2	2.3	3	3	3.0	3	3	3	3.0	2.9	2.7
13	Implementation of program to increase cycling rates or product quality	3	2	2.3	2	1	1.3	3	2	2	2.3	2.1	1.9
∑ equally weighted indicators		2.8	2.9	2.2	2.1	1.6	1.8	2.8	2.0	2.0	2.3	2.2	2.0
∑ specifically weighted indicators		2.9	1.8	2.2	1.9	1.5	1.6	2.6	1.8	1.8	2.1	2.0	1.9

CV = construct validity, CVV = effectivity, CVC = efficiency, R = reliability, TRR = test-retest reliability, OR = objectivity, P = practicality, TP = time of determination, EP = ease of determination, CP = clearness of language, EWC = equally weighted criteria, SWC = specifically weighted criteria

Table 9 shows the weighted scores per criterion per cluster and the total end scores per cluster, in different variants of weighting: (1) Criteria and indicators equally weighted, (2) Specifically weighted criteria, (3) Specifically weighted indicators and (4) Both specifically weighted criteria and indicators. This weighting is applied to show the sensitivity of the scores to different weighting factors.

Table 9: Overall indicator scores per cluster, including CV, R, P, G and T

Concept	CV	R	P	G[1]	T[2]	EWC + EWI	EWC + SWI	SWC + EWI	SWC + SWI
Circularly sourced content	2.3	1.2	1.8	3.0	3.0	2.6	2.6	2.1	2.1
Cyclability	2.2	1.6	2.1	2.0	3.0	2.4	2.3	2.2	2.1
Active cycling	2.1	1.9	2.2	2.0	3.0	2.4	2.4	2.3	2.3

CV = construct validity, R = reliability, P = practicality, G = generalisability, T = transparency, EWC = equally weighted criteria, EWI = equally weighted indicators, SWI = specifically weighted indicators, SWC = specifically weighted criteria
[1]Assessed for the whole cluster, not for single indicators. Thus, no calculation is required.
[2]Assessed for the whole C2CPII standard, not for single indicators/clusters. Thus, no calculation is required

It gets evident that applying both versions of weighting decrease the end score. Equally weighted end scores are highest (cluster 1 = 2.6, cluster 2 = 2.4, cluster 3 = 2.4), while applying either a higher weighting of the main indicators or a higher weighting of the Construct Validity and Reliability both lower the end scores for all clusters. Applying both a higher weighting of the main inductors and of the Construct Validity and Reliability leads to the lowest end scores per cluster (cluster 1 = 2.1, cluster 2 = 2.1, cluster 3 = 2.3). Cluster 3 has the overall highest value, clusters 1 and 2 are similar. All clusters are quite close to each other in their weighted end scores, they just differ by 0.2 at maximum. Adding the scores of the criteria Generalisability and Transparency to the single indicator scores raises all scores a little. The Reliability is lowest for all indicators, which is mainly because of the sub-criterion Objectivity. The Effectivity and Time of Determination both score high, which indicates that the general idea of almost all indicators is valid, and that most of the indicators are determinable in less than one hour. Two out of the three main indicators score insufficiently regarding their average scores in Construct validity, Reliability and Practicality, where the Reliability and Practicality are most contributing to this. Indicators 5 and 12 are the only indicators that scored sufficiently and almost do not need improvement.

5 OTHER INDICATOR-SETS

For finding possible improvements for the C2C indicators, comparable circularity indicator sets were identified and used as a reference. The classification parameters from chapter 2.3 provided the base for this search, setting the attributes in a way to fit the indicators from the C2CPII standard (Table 10).

Table 10: Classification parameters for circularity indicators for this research

No.	Parameter	Set attributes
1	Application level	Nano (products)
2	Sustainability dimensions	Environmental + combinations
3	Life cycle stages	Full life cycle
4	Kind of assessment	Indicator, indicator group
5	R-loops	All (reduce, reuse, recycle, recover, remanufacture, redesign)
6	Performance	All (intrinsically, impacts)
7	Perspective	All (actual, potential)
8	Usages	All (decision-making, communication, learning)
9	Transversality	Generic
10	Units	All (qualitative, quantitative)
11	Format	All (web based tool, Microsoft Excel sheet, formula)
12	Sources	All (scholars, companies, organisations)

To find indicators fitting those attributes, the review from De Oliveira et al. (2021) was the first subject of analysis, as this one was the most recent review and comprised a supplementary Microsoft Excel file with a filter function. This led to 16 indicator-sets to be researched further, one of them being the indicators from the C2CPII. Additional twelve indicator-sets fitting the criteria were found in the studies by Corona et al. (2019), De Pascale et al. (2021), Kalmykovaa et al. (2018) and Saidani et al. (2019). An overview of those in total 28 indicators can be found in Table 11.

After thoroughly studying the original sources of the indicators, seven indicator-sets were found especially interesting for finding improvements for the C2C indicators (marked in blue in the table). They all are similar enough in their set-up to be comparable while at the same time comprising enough different aspects for taking inspiration from them. In the following, those seven indicators are roughly explained to better understand the inspiration they can bring to the subsequent chapter.

Table 11: Indicator-sets comparable to the C2C indicators (derived from literature)

No	Indicator (set)	Source
1	Global Resource Indicator	(Adibi et al., 2017)
2	C2C Indicators	(C2CPII, 2021a)
3	Circularity Check	(Ecopreneur, 2022)
4	Circulytics	(Ellen MacArthur Foundation, 2020)
5	Material Circularity Indicator	(Ellen MacArthur Foundation & Granta, 2015)
6	Circular Economy Toolkit	(Evans & Bocken, 2013)
7	Economic-environmental Indicators	(Fregonara et al., 2017)
8	Closed Loop Calculator	(Kingfisher, 2014)
9	Input-Output Balance Sheet	(Marco Capellini, 2017)
10	Product Circularity Data Sheet	(Ministry of the Economy of Luxembourg, 2020)
11	Systems Indicators for Circular Economy Dashboard	(Pauliuk, 2018)
12	PRP Circular e-Procurement Tool	(Rendement, 2016)
13	Material Input Per Service Delivered	(Ritthoff et al., 2002)
14	Circular Business Model Set of Indicators	(Rossi et al., 2020)
15	Circularity Potential Indicator	(Saidani et al., 2017)
16	Eco-efficiency index	(Laso et al., 2018)
17	Disassembly Effort Index	(Das et al., 2000)
18	Recyclability Benefit Rate	(Huysman et al., 2015)
19	Circularity Design Guidelines	(Bovea & Pérez-Belis, 2018)
20	Effective Disassembly Time	(Marconi et al., 2019)
21	End-of-use Product Value Recovery	(Cong et al., 2019)
22	Circularity Calculator	(Ideal & Co, 2016)
23	Remanufacturing Product Profiles	(Zwolinski et al., 2006)
24	Eco-efficient Value Creation	(Wever & Vogtländer, 2013)
25	Decision Tool for Remanufacturing	(van Loon & Van Wassenhove, 2018)
26	Typology for Quality Properties	(Iacovidou et al., 2019)
27	Eco-efficiency index	(Laso et al., 2018)
28	Circular Transition Indicators	(WBCSD & Circular IQ, 2022)

Global Resource Indicator (Adibi et al., 2017)

This indicator is determined by dividing the scarcity of a resource by its recyclability times its geopolitical availability. It assumes that the scarcer a resource and the lower the recyclability and geopolitical availability, the higher the indicator result and with the more caution the resource should be handled. Especially interesting for this research is the aspect of scarcity, as this is not yet fully present in the C2C indicator set. For abiotic resources, it is measured by the Abiotic Depletion Potential, which is composed of (1) the annual extraction rates of a resource and (2) its remaining reserve. For biotic resources, the Regeneration Rate is used, which is calculated by dividing 1 by the required time of a resource to be regenerated.

Circulytics (Ellen MacArthur Foundation, 2020)

This is a set of indicators for companies to assess their overall business circularity, including the circularity of manufactured products (theme 6). This theme includes the indicators shown in Table 12. Indicators offering novelty to the C2C set are marked blue.

Table 12: Product circularity indicators extracted from Ellen MacArthur Foundation (2020)

No	Product circularity indicator
1	Mass % of non-virgin material input
2	Mass % of material input sourced from by-products/waste streams
3	Mass % of virgin but renewable and regeneratively produced material input
4	Mass % of virgin but renewable and sustainably produced material input
5	Mass % of waste going to landfill or incineration
6	Mass % of physical products designed along circular economy principles during use (longevity, reusability, repairability, regeneratively grown materials of biological origin)
7	Mass % of physical products designed along circular economy principles in the end of their functional life (designed for disassembly, designed for remanufacturing/ refurbishment, designed for recycling, designed for nutrient recirculation)
8	Mass % of physical products designed along circular economy principles in other ways (designed to prevent waste and pollution by customers, designed to increase the longevity of other products further down in the value chain, designed to increase recycling yield of products further down in the value chain, designed to enable safe return of nutrients to the bioeconomy, designed to increase the use of renewable energy)
9	Mass % of practically reused/redistributed material output
10	Mass % of practically refurbished/ remanufactured material output
11	Mass % of practically recycled material output
12	Mass % of material output, of which practically the nutrients are recirculated
13	Average product uses before end of functional life for reused products

Material Circularity Indicator (Ellen MacArthur Foundation & Granta, 2015)

This indicator is focused on material flows. It is composed of seven different sub-indicators (which again have sub-indicators), which are displayed in Table 13. Indicators offering novelty to the C2C set are marked blue.

Table 13: Product circularity indicators extracted from Ellen MacArthur Foundation & Granta (2015)

No	Product circularity indicator
1	Virgin feedstock
2	Recycled feedstock
3	Reused components
4	Components collected for reuse

5	Material collected for recycling
6	Material going to landfill/energy recovery
7	Waste from recycling process

Product Circularity Data Sheet (Ministry of the Economy of Luxembourg, 2020)

This Microsoft Excel spreadsheet has been developed by the government of Luxemburg and contains, next to indicators for different topics, the product circularity indicators displayed in Table 14. Indicators offering novelty to the C2C set are marked blue.

Table 14: Product circularity indicators extracted from the Ministry of the Economy of Luxembourg (2020)

No	Product circularity indicator
1	Mass % of pre-consumer recycled content
2	Mass % of post-consumer recycled content
3	Mass % of renewable and sustainably sourced content
4	Design for maintenance and repair
5	Design for actively positive impacts
6	Design for demounting
7	Mass % of product designed for disassembly
8	Mass % of product designed for dismantling
9	Design for reuse
10	Design for refurbishment,
11	Design for remanufacturing
12	Mass % of the product designed for high quality recycling
13	Collection system in place
14	Portion of materials leaked during use and designed for the release environment
15	Design for industrial cascading in the biosphere
16	Design for composting in an industrial facility
17	Design for composting in a home composter
18	Design for biodigestion
19	Design for pyrolysis

Circular Business Model Set of Indicators (Rossi et al., 2020)

Rossi et al. aimed to "develop a set of indicators linking Circular Economy principles, Circular Business Model and the pillars of Sustainability". They came up with a set of 24 indicators, of which the ones regarding product circularity can be found in Table 15. Indicators offering novelty to the C2C set are marked blue.

Table 15: Product circularity indicators extracted from Rossi et al. (2020)

No	Product circularity indicator
1	Quantity of raw materials reduced in manufacturing
2	Quantity of raw materials reduced in the product
3	% of raw material from renewable sources in relation to all the materials used in a product
4	% of recycled materials in the composition of the product
5	% of the product that may be recycled after use
6	Quantity of material reused in the supply chain
7	Quantity of reused material in the product
8	Quantity of remanufactured products
9	Quantity of the total recovery or parts (components) of the product
10	Quantity of time added in the lifespan of the product

Circular Transition Indicators (WBCSD & Circular IQ, 2022)

The circular transition indicators assess material flows throughout the company at three key intervention points: Inflows, Outflows (potential recovery) and Outflows (actual recovery). For the assessment, four different modules containing different sets of indicators need to be analysed (Figure 8).

Indicators matching topic and scope of this research are marked in green. The % material circularity is composed of (1) % of circular (renewable/recycled) inflows, (2) % of potentially recoverable outflow and (3) % of actually recovered outflow. The (4) % critical material is defined as the critical mass of inflow divided by the total mass of linear inflow. This indicator especially offers novelty to the indicator set by the C2CPII. The (5) % recovery type just adds an indication to the calculated % of actually recovered outflow on the specific way of recovery (reused, repaired, refurbished, remanufactured, recycled). The (6) Actual lifetime is calculated by dividing the product actual lifetime by the average product actual lifetime. This indicator can also potentially be a valuable addition to the C2CPII indicators.

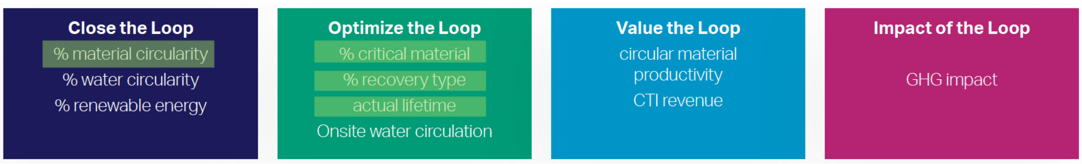

Figure 8: Modules to analyse in the Circular Transition Indicators Tool

Circularity Calculator (Ideal & Co, 2016)

This calculator was developed for businesses to assess their products' circularity in an intuitive, visual way (Figure 9). It uses 15 different sub-indicators (marked in green) to calculate the mass, percentage and value in € of material streams in 15 main indicators (the coloured boxes) in the five different life cycle stages component production, product assembly, product sale, product use and product waste. From that, four overall performance indices are calculated (cycles on the right): Circularity, Value Capture, Recycled Content and Reuse-Index. Especially interesting are the indicators on the different r-strategies (bottom of the figure), the indicator on collection, as well as the number of lease periods and the differentiation between closed-loop and open-loop recycling. Furthermore, the visualisation of how the indicators are interconnected is helpful for understanding material flows in a circular product in different life cycle stages.

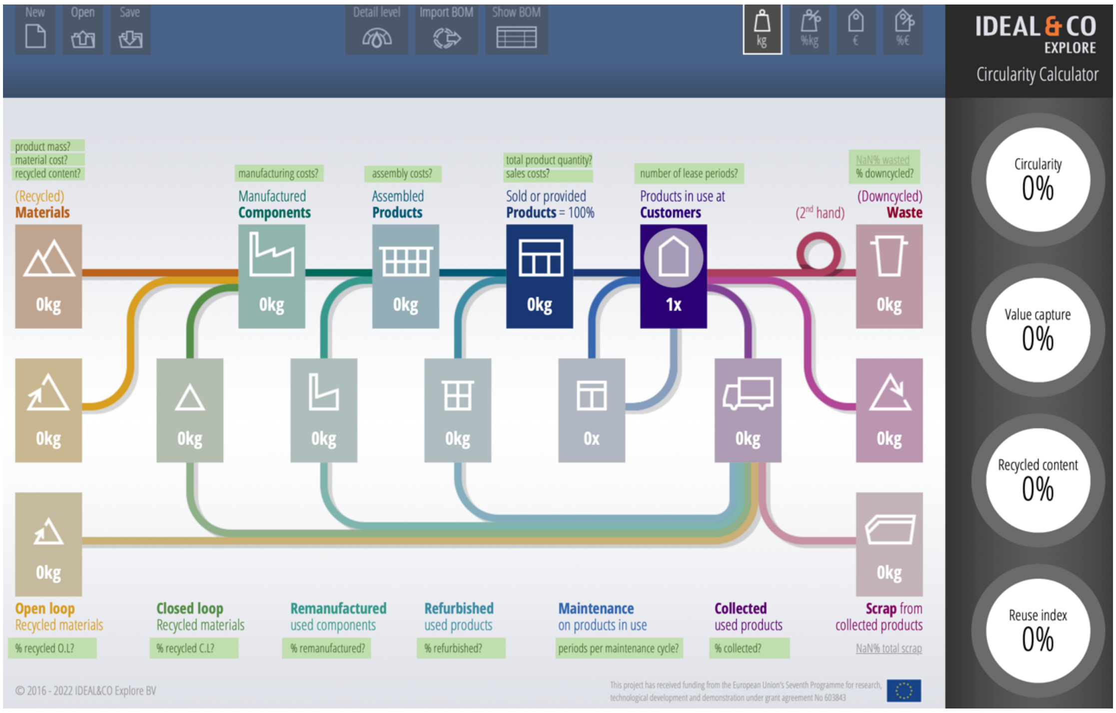

Figure 9: Circularity Calculator (Ideal & Co, 2016)

6 PROPOSED IMPROVEMENTS

In this chapter, improvements for each cluster are suggested. Based on the conclusions of chapter 4, it can be stated that the first priority is to improve the Objectivity of almost all indicators, the second priority are the Efficiency, the Test-Retest Reliability, the Clearness of Language and the Ease of Determination. The Effectivity and the Time of Determination barely need to be improved. The first two main indicators (Mass % of circularly sourced content and Mass % of high value cyclable content) should especially be in the focus for improvements. Indicators 5 and 12 can almost be kept as they are.

6.1 Improvements for Cluster 1

Indicator 1 is in need for improvement in all criteria except for the Effectivity. The lowest scores (assessed with a 1) were assigned in the Reliability (Test-Retest Reliability, Objectivity) and Practicality (Ease of Determination and Clearness of Language), thus those are the areas to focus on in this chapter. But also measures for improving the Efficiency (score = 2) are given. As indicator 1 is a main indicator, it is not perceived as that important to improve the Time of Determination, as this could probably go to the costs of the Construct Validity or Reliability. Built upon the analysis in chapter 4, the following improvements are suggested:

1. To increase the Objectivity and the Clearness of Language of indicator 1, clarification is needed on (1) whether it is also allowed to incorporate content that is derived from a higher quality product (which has been downcycled then) and (2) from up to which tier level the cycled/renewable content may be added.
2. More focus should be put on cycled content from other r-strategies than from recycling, creating separate sub-indicators (remanufactured and refurbished content). Those measures would increase the Objectivity.
3. Better instructions on how to perform the chain of custody documentation are necessary to increase both the Objectivity, the Test-Retest Reliability, the Clearness of Language and the Ease of Determination. The obligatory use of the ISO 22095 norm (ISO, 2020) seems an easy solution for that.
4. Some factors influencing the renewable content should be added, namely land use (the amount of land used for producing the virgin material), resource regeneration rate (as seen in Adibi et al., 2017) and the amount of resources that

are *actually* regenerated after harvest, not only whether they are renewable in theory). All of those would increase the Efficiency of this indicator.

5. For the cycled content, the use of virgin critical materials should be considered, as they are in special danger and economic importance in the future. (European Commission, 2014). Thus, the use of critical materials from virgin sources should be penalised, or the incorporation of cycled critical materials should specifically be rewarded (as seen in Adibi et al., 2017; WBCSD & Circular IQ, 2022).

6. A weighting should be applied to the renewable and cycled content. Cycled content should be weighted more than renewable content, as the use of renewable content leads to land use conflicts.

7. The language used in the C2CPII standard should be clarified in a way that the indicator and its determination are clearly described and underpinned by a comprehensive, user-friendly list of the requirements (such as given in appendix 2 of this report). This should be accompanied by a Microsoft Excel spread sheet where the necessary formulas are already filled in. Those measures would both increase the Test-Retest Reliability, the Objectivity, the Ease of Determination and the Clearness of Language of this indicator.

Indicators 2 and 3 mainly lack quality regarding their Objectivity (score = 1). But also their Efficiency, Test-Retest Reliability, Ease of Determination and Clearness of Language could be improved (score = 2). It is suggested to merge indicators 2 and 3 into a single indicator, and to add normative requirements and stricter boundaries to it. The goal would be to make it clearer what the demanded timeline, method and strategy must entail to count as approved. Furthermore, a list of suppliers who could potentially (or actually) supply the required demand of cyclable/renewable content could be added. All those measures would especially increase the Efficiency and the Objectivity of those two indicators. Apart from the already existing indicators, the following improvements are suggested for the whole cluster:

8. Currently, the main goal of the cluster is to increase the demand for circularly sourced content. In a side sentence, the C2CPII standard also mentions the goal of decreasing the impacts of virgin material use. These findings imply that it is, according to the standard, still okay to keep using virgin materials. This is a doubtable position as virgin material use can imply land use conflicts and probably now and in the future (Barteková & Kemp, 2016; Colombia Climate School, 2017). Therefore, the goal of decreasing virgin material use should be added as a second main goal to this cluster (as seen in Ellen MacArthur Foundation & Granta, 2015; Rossi et al., 2020).

9. Suggestion 8 leads to other indicators that can be added to the cluster as they also decrease virgin material use. Those are product lifetime and product weight

(Kuzmanovi, 2010; Rivera & Lallmahomed, 2016), as seen in Ellen MacArthur Foundation (2020), Rossi et al. (2020) and WBCSD & Circular IQ (2022).

10. One factor increasing the amount of non-virgin circular material in a product is the incorporation of by-products (as seen in Ellen MacArthur Foundation, 2020). Per definition in the C2CPII standard, those would not count yet as cycled material as they are just the waste stream of other products and still virgin materials. Thus, so far the applicant does not get credits for using by-products, while this actually does contribute to decreasing the need for virgin materials. So, an indicator accounting for that should be added.

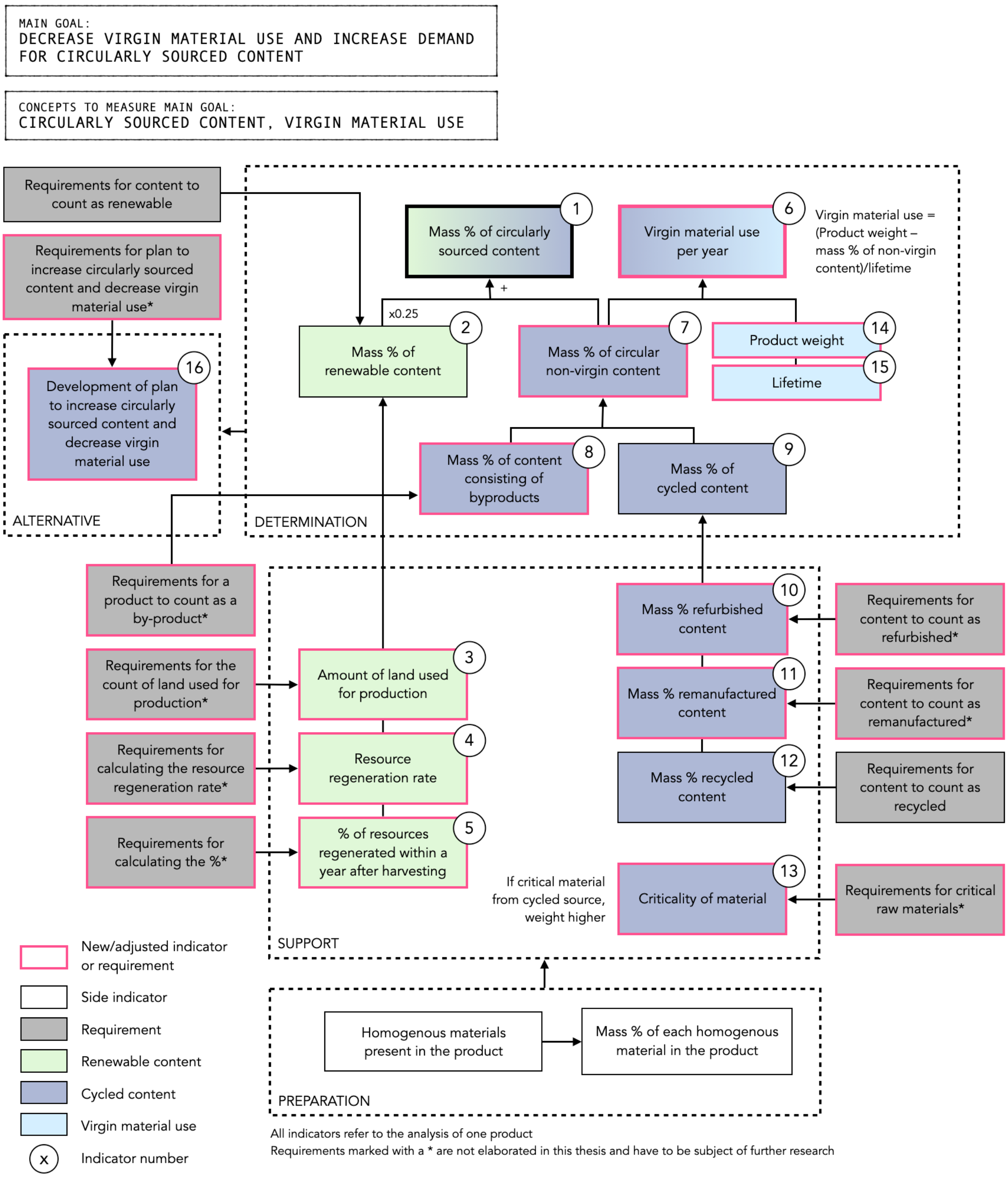

Figure 10: Suggestions for improvements of the indicators in cluster 1

A graphic summary of those suggestions for improvements can be found in Figure 10. It is noted that the displayed weighting score is exemplary and should be investigated by further research. Also, the respective required verification documents are not worked out and displayed in this graphic to enable a better overview and readability.

6.2 Improvements for Cluster 2

From chapter 4, it got clear that indicator 4 has the lowest overall score of all indicators and thus needs improvements in almost all criteria. Both the Efficiency, Test-Retest Reliability, Objectivity, Ease of Determination and Clearness of Language were assessed with a score lower than 2 and are thus the focus for finding improvements. The Time of Determination was assessed with a 2 but can be neglected as this indicator again is a main indicator, thus it is assumed that it is acceptable that it needs some more time to be determined. Only the Effectivity scored a 3 and does not need improvement. So, the following improvements are suggested for indicator 4:

1. The main requirement for this indicator, demanding that either (1) the material must substitute for virgin material without quality loss, or (2) the material must incorporate at least 80% circularly sourced content, or (3) the product must have at least two plausible next uses, needs to be adjusted. First, (1) should be deleted for the products/materials of the biological cycle, as it does not make sense. Second, for products/materials of the technical cycle, (1) needs to be made obligatory to prevent downcycling, while (2) and (3) could be made a bonus requirement. It should be noted that those named adjustments only apply if the goal is to stick close to the structure of the C2CPII standard, otherwise the following suggested improvements also tackle the issue.
2. In the technical cycle, other r-strategies than recycling (reuse, remanufacture, refurbish) should be brought into focus (as seen in Ideal & Co, 2016; Ministry of the Economy of Luxembourg, 2020; Rossi et al., 2020), as there are more ways to make a product suitable to be kept in high quality cycles. Thus, it is recommended to add the following new sub-indicators: (1) Longevity (enlarging the time of one product life cycle – measured by Product lifetime), (2) Reusability (measured by the Average number of use cycles before breakage), (3) Traceability (easing the collection at the end of life – measured by the % of products that can automatically be separated), (4) Repairability (measured by Repair time and Ease of repair), (5) Ability to get refurbished (measured by Disassembly time and Ease of disassembly) and (6) Ability to get remanufactured (also measured by Disassembly time and Ease of disassembly). It is noted that for all newly suggested indicators, it has been tried

to find an objective way to measure them. With all those named measures, the Objectivity, the Test-Retest Reliability and the Efficiency would be improved.

3. For the biological cycle, it is suggested to add some more differentiated sub-indicators, based on the different suggested biological cycling pathways in the C2CPII standard (as also seen in Ministry of the Economy of Luxembourg, 2020), which so far have been more implicitly covered in the requirements for the main indicator: (1) Mass % which is supposed and suitable to digest anaerobically, (2) Mass % which is supposed and suitable for nutrient extraction, (3) Mass % which is supposed and suitable to biodegrade and (4) Mass % which is supposed and suitable to compost. For all those indicators, requirements for a minimum nutrient quality should be defined to ensure that the material results in added value to the environment it disintegrates in (WBCSD & Circular IQ, 2022).
4. It is suggested to add an indicator determining the mass % of content cyclable in *both* the technical and in the biological cycle (only composting pathway), and to apply a high weighting factor to it. That would mean that a material is designed to be held in technical cycles as long as possible, but if it (by accident) ends up in a biological environment, would still not be disturbing for it and become compost (as for example described in OECD, 2006). This seems a desirable scenario.
5. The language used in the C2CPII standard should be clarified in a way that the indicator and its determination (and the determination of the sub-indicators) are clearly described and underpinned by a comprehensive, user-friendly list of the requirements, such as given in appendix 3 of this report. This should be accompanied by a Microsoft Excel spread sheet where the necessary formulas are already filled in. Those measures would both increase the Test-Retest Reliability, the Objectivity, the Ease of Determination and the Clearness of Language of this indicator.

Indicator 5 performs quite well in almost all criteria. Only the Efficiency and the Clearness of Language need slight adjustments, which is why the following improvements are suggested: First, it could be an option to apply a weighting or ranking to the requirements of the different intended cycling pathways. Second, it should be considered whether a suggested pathway is the best suitable pathway for a material (and not just the easiest) and also whether the pathway is likely to happen. Third, stricter requirements should be added to the anaerobic biodegradation pathway, to ensure that no CH_4 is emitted to the atmosphere.

Indicator 6 needs great improvements in the Objectivity and no improvements in the Time of Determination. All other criteria require only minor adjustments. It is recommended to completely delete this indicator from this cluster and account for its contents in another form (see discussion). If this indicator is to be kept in the C2CPII standard, it is suggested to clarify what the expressions "supports learnings toward implementing the company's circularity strategies" and "progress within an industry" exactly mean in the requirements.

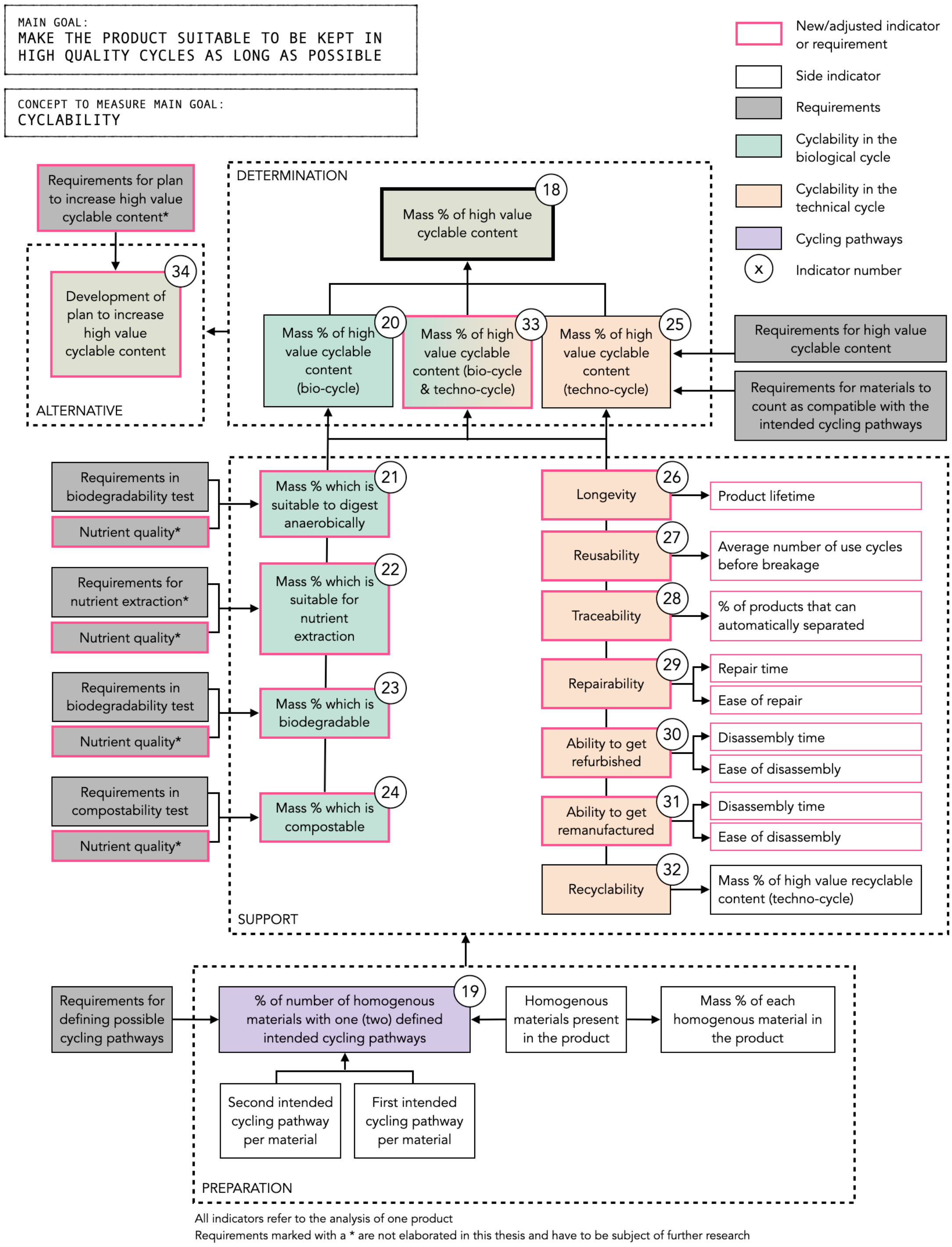

Figure 11: Suggestions for improvements of the indicators in cluster 2

Indicator 8 has major drawbacks in the Objectivity and performs well in the Efficiency and Time of Determination. All other criteria need slight improvements. But the actual recommendation is to completely delete this indicator as it is covered by the newly created sub-indicators 'Ability to get refurbished' and 'Ability to get remanufactured' at indicator 4. If this indicator is to be kept in the C2CPII standard, requirement 1 ('Include at least one design feature that improves the ease of disassembly') needs to be formulated stricter. For requirement 3 ('Make comprehensive disassembly instructions publicly available'), a formulation should be added that the instructions must be designed and presented in an easy and useful way to ensure a higher Efficiency. For requirement 4 ('Components must be separable using common tools with minimal technical experience and instruction'), the definition of "common tools" or "minimal technical experience" should be clarified. Furthermore, normative requirements should be added, in the best case even an alternative way of measuring the ease of disassembly to ensure a higher Objectivity. All those measures are expected to especially increase the Efficiency, Objectivity and Clearness of Language of this indicator.

A graphic summary of those suggestions for improvements can be found in Figure 11. It is noted that the respective required verification documents are not worked out and displayed in this graphic to enable a better overview and readability.

6.3 Improvements for Cluster 3

Indicator 9 scored lowest in the Efficiency and Ease of Determination, so those are the areas to focus on for improvements. The Effectivity scored sufficiently and does not need to be improved, all other criteria scored medium and need minor adjustments. Based on the findings of chapter 4, the following improvements are suggested for indicator 9:

1. Most importantly, a formulation needs to be added to the requirements that the product must be high value cycled and that so-called downcycling is forbidden. This would increase the Efficiency of this indicator a lot.
2. As requirement 3 (documentation on how the product is actively cycled) is crucial for this indicator, it should be clarified what the documents in requirement 3 should exactly include. This way, stricter and more normative boundaries could be set, which would increase the Efficiency, Objectivity and Clearness of Language of this indicator.
3. Currently, the Active cycling rate is calculated by dividing the Total weight of product parts that are cycled by the Total weight of products that are sold. It is suggested to again add a differentiation of the r-strategies (reuse, remanufacture, refurbish, recycle) to the first variable and to account for collection rates (as seen in Ellen MacArthur Foundation, 2020; Ellen MacArthur Foundation & Granta, 2015; Ideal & Co, 2016; Ministry of the Economy of Luxembourg, 2020; WBCSD

& Circular IQ, 2022), adding the following sub-indicators: (1) % of products collected after use, (2) % of reused products, (3) % of remanufactured products, (4) % of refurbished products, (5) % of recycled products (open loop) and (6) % of recycled products (closed loop). The recycling indicators also include recycling in biological cycling pathways.

4. It should be especially rewarded if critical materials are recovered during the recycling, as those are in special danger for meeting the future demand, and are also of high economic value (European Commission, 2014). Thus, an indicator should be created accounting for that.
5. The language used in the C2CPII standard should be clarified in a way that the indicator and its determination (also of the sub-indicators) are clearly described and underpinned by a comprehensive, user-friendly list of the requirements, such as given in appendix 4 of this report. This should be accompanied by a Microsoft Excel spread sheet where the necessary formulas are already filled in. Those measures would both increase the Test-Retest Reliability, the Objectivity, the Ease of Determination and the Clearness of Language of this indicator.

Indicator 10 has the biggest flaw in the Objectivity. The Effectivity does not need improvements, and all other criteria only need minor adjustments. Thus, the following is suggested: Normative requirements should be added to the first three requirements, and they should be made stricter. Also, a requirement could be added demanding the mandatory formulation of potential challenges in cycling the product and how to overcome those.

Indicator 11 has no major drawbacks and only needs slight adjustments in the Efficiency, Test-Retest Reliability, Objectivity, Ease of Determination and Clearness of Language. Thus, it is recommended to add normative requirements to requirement 3 ('initiate partnerships for product recovery' – which partners count, which do not?), as well as information on which parts of the product have to be covered by the stewardship program/municipal cycling systems/implemented partnerships.

Indicator 12 performs outstandingly in almost all criteria and is assessed with the best overall end score. Only the Efficiency could be slightly improved, which can be achieved through an additional requirement defining a mandatory set-up of the displayed information, and the place(s) where it must be published to make it easily accessible.

The last indicator, number 13, lacks most in the Objectivity and performs well enough in the Effectivity and Time of Determination. All other criteria need slight adjustments. Thus, the following is suggested: First, stricter boundaries should be added of when and how a program for increasing the cycling rates or product quality counts. This way, a set-up would be implemented that ensures a higher Efficiency (for example, preventing that an applicant has an incentivised take-back program no one knows about). Second, a boundary needs to be defined about how much the program needs to increase the active cycling rate/product quality. Third, it should be reconsidered to also include products of a use-phase time of more than one year. Fourth, the boundaries and definitions in requirements 2-4 ('The applicant must invest in a system that facilitates tracking of product cycling ', 'The applicant must incentivise the user to cycle the product', 'Examples of other programs') should be clarified. And last, requirement 5 on how to measure the product quality should be elaborated further, given a (range of) certain methods for doing so. All those measures mainly aim for increasing the Efficiency, Objectivity and Clearness of Language of indicator 13.

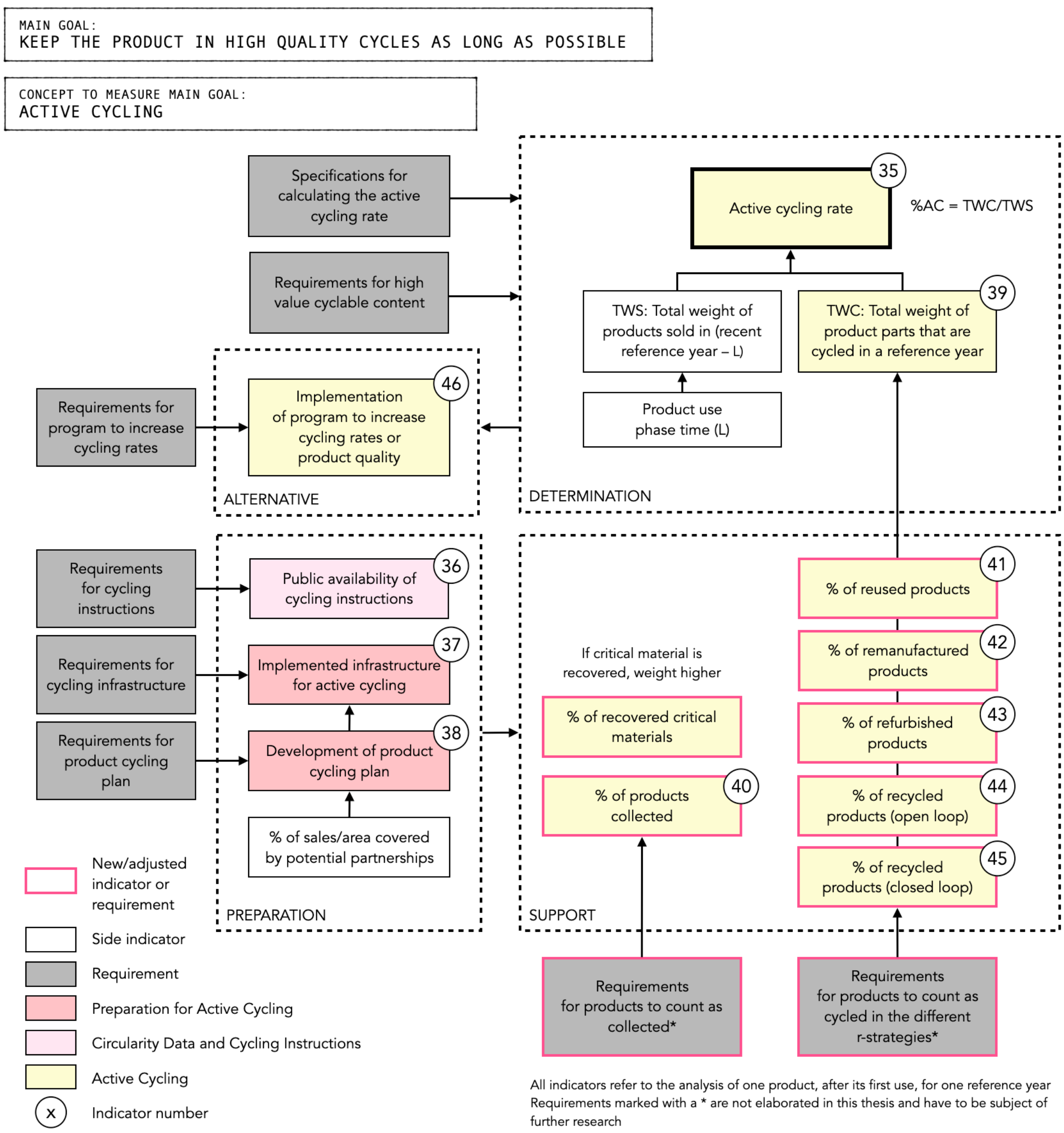

Figure 12: Suggestions for improvements of the indicators in cluster 3

Furthermore, it is (again) recommended to delete indicator 6 from this cluster and account for its contents in another form (see discussion). A graphic summary of all suggestions for improvements can be found in Figure 12. It is noted that the respective required verification documents are not worked out and displayed in this graphic to enable a better overview and readability.

6.4 Summary

The summarised main suggestions for clusters 1-3 are as follows:

For all clusters, (1) it should be differentiated more between the r-strategies (reuse, remanufacture, refurbish, recycle), and (2) more objective ways to measure the indicators should be found. Also, it is suggested to (3) improve the language and structuring of requirements, and to (4) add normative requirements and stricter boundaries to the majority of the indicators.

For cluster 1, it is recommended to (5) add more influencing factors for the renewable content, (6) account for by-product use, (7) add a new additional main goal and corresponding sub-indicators, (8) add an indicator accounting for criticality, (9) add weighting factors to the renewable and cycled content, (10) merge the plan for increasing the circularly sourced content and the feasibility analysis, (11) redefine high value cycling and (12) make the use of the ISO 22095 norm obligatory for the chain of custody documentation.

For cluster 2, (13) more distinctions should be made between the biological cycling pathways, (14) an indicator accounting for the nutrient quality should be added, (15) an indicator accounting for the content that is cyclable in both the biological cycle and the technical cycle should be added, (16) it should be considered to apply weighting factors to content cyclable in the biological cycle, technical cycle, and both, and (17) it should be considered to eliminate the Circularity education, the Circular design opportunity and the Ease of disassembly indicator.

For cluster 3, (18) an indicator should be added accounting for the collection rates of the product, (19) a differentiation of the r-strategies (reuse, remanufacture, refurbish, recycle) should be integrated, (20) the Circularity education indicator should be eliminated and (21) a requirement should be added that prohibits downcycling.

7 DISCUSSION

In this research, the indicator-set of the C2CPII standard was assessed for its scientific quality. For doing so, a framework of five scientific quality criteria, each rated with a score from one to three, was developed. The assessment identified several shortcomings, for which subsequently improvements were suggested. In the following, a critical review of the results and methods is given, and the limitations of this research are addressed.

7.1 Discussion of Methods & Results

The results of this research are (1) an assessment framework, consisting of individual scores for the Construct validity, Reliability and Practicality per indicator, Generalisability per cluster and Transparency for the whole C2CPII standard, and (2) suggestions for improvements to the identified shortcomings.

A first point that should be reflected on is the way the indicators were extracted from the C2CPII standard. The standard is the base of a certification system, targeting applicants who want to validate and share their achievements (Circle Economy, 2020). Therefore, the standard does not consist of a list of single indicators, but rather criteria formulated as a checklist to evaluate whether the certificate can be granted or not. This checklist is building up on underlying indicators, but those are not mentioned explicitly and had to be extracted from the standard. This entails subjectivity as the extracted indicators are only an interpretation of what the author thought the C2CPII means with their formulations. To still enable scientifically sound research, this subjectivity was intended to be diminished by transparently describing the indicator extraction process.

Second, there is subjectivity in the choice and definition of the scientific quality criteria. Literature was intensively used as a base for the criteria, but those criteria have been adjusted to better fit the purpose of this research. Again, a transparent documentation of the process was used to tackle this issue and increase the reliability of this research.

Third, it was attempted to extract the requirements and the process of determination from the standard. The goal was to understand this given information and show it in a more comprehensive way, so it could be used as a base for the further assessment. But the partly unclear and unstructured formulations in the standard could have contributed to the drawback that some parts might have been misinterpreted in this regard. Especially the process of determination was only assumed on a logical base, as the author never conducted an actual product assessment herself. This problem could partly be solved with some unofficial talks with an assessor from EPEA who already did a lot of product assessments with the standard. Still, it is likely that some interpretations are not entirely true, which diminished the reliability of this research.

Fourth, the scores given to each indicator are highly subjective and have only an ordinal scale level. They have not been measured but assigned by the author based on the indicator description in the standard. Neither the scale from 1-3 nor the boundary between the different values does have a real meaning. For the end scores, the (weighted) average was used, but there are also other approaches to determining the end value per indicator/cluster, as for example, letting the end score equal the lowest/highest score of the single indicator (Pavan & Todeschini, 2008). Thus, the used assessment framework should rather be interpreted as an attempt to bring more transparency and structure into the process of assessing the indicators. The goals were to make the findings from the assessment more tangible, to find priority areas for improvements, to spot trends and to give a ranking to the different indicators, and these goals could be fulfilled that way. In no case, those values should be interpreted as meaningful interval or ratio scales that display reliable numbers from the real world.

Fifth, the weighting of the criteria and indicators in the assessment framework is based on subjective decisions as well, which lack a scientific backup. But the goal was to come up with a logic idea for weighting factors, and to show the sensitivity of the outcomes to this specific weighting (compared to equal weighting). By providing an adjustable Microsoft Excel file, the reader can experiment with different weighting scores and explore the effects on the outcome. Thus, the reliability of the scores in the assessment framework is diminished again by the subjective choice of weighting factors, but the provision of a transparent Excel file and an explanation of the reasons for the specific weighting factors tries to mitigate this issue.

Last, it could be criticised that the only method in this research was literature research, and this literature research was mostly focused on one single document. This could be argued to diminish the validity of this research. Due to the scope of this research, it was decided to not include other social science methods such as expert interviews or group discussions. And as for the limited amount of literature: This research was dedicated to analysing one single set of indicators, and the standard from the C2CPII is the only document that gives information about this indicator set. So, the nature of this research itself centred the attention on this document, and the results of this research are thus assumed to be valid.

7.2 Limitations & Recommendations for Further Research

This research has several limitations. First, the scope of this report was to assess the product circularity category in the C2CPII standard, thus an assessment of the other categories accounting for material health and the production processes with their impacts was not included. It would be interesting for future research to apply the assessment framework developed in this research to the other categories as well and to find more improvements that way, or even to other indicator-sets.

Second, the subject of assessment was purely the standard itself, not its surrounding procedures. It might be that the reliability of the assessment is higher than assessed in this report, as there are control mechanisms such as independent checks in place. But this was out of the research scope as those exact processes are not described in a public place and are thus accessible (and assessable) by the public.

Third, suggested improvements were often only given about what and roughly how something should be improved, but there was no formulation of the exact improvement itself. For example, a lot of new sets of requirements still need to be formulated. Also, it was suggested to weight some of the sub-indictors for calculating the main indicator. Further research needs to be done on what the best suiting weighting factors would be, and how to calculate with them. Furthermore, it is suggested to further analyse the indicator on nutrient quality. It would be an interesting and important research topic to find an indicator properly accounting for nutrients released by materials from the biological cycle, which would be valuable to its release environment.

Fourth, financial indicators were completely excluded from the suggested improvements, which are indeed used in some other product circularity indicator systems (for example, Ideal & Co, 2016; Fregonara et al., 2017; Pauliuk, 2018; Rossi et al., 2020; WBCSD & Circular IQ, 2022; Zwolinski et al., 2006). This has been done for scope reasons, but it would be interesting to investigate how they relate to the other indicators and whether it would add value to include them in the C2CPII standard, too.

Fifth, no improvements were suggested regarding the calculation of the Active Cycling Rate. Further research could try to analyse existing approaches, such as suggested by van Schaik & Reuter (2004), to find a more differentiated way of calculation.

Sixth, a special recommendation is proposed for the development of a new fourth cluster. For the establishment of a globally functional circular economy, collaboration and a common infrastructure are essential (Circle Economy, 2021). The C2C indicator Active participation in a circular economy education initiative slightly touches upon this topic, but there is much room for improvement. Thus, the author wants to propose some ideas on how to potentially develop this cluster, which are summarised in Figure 13.

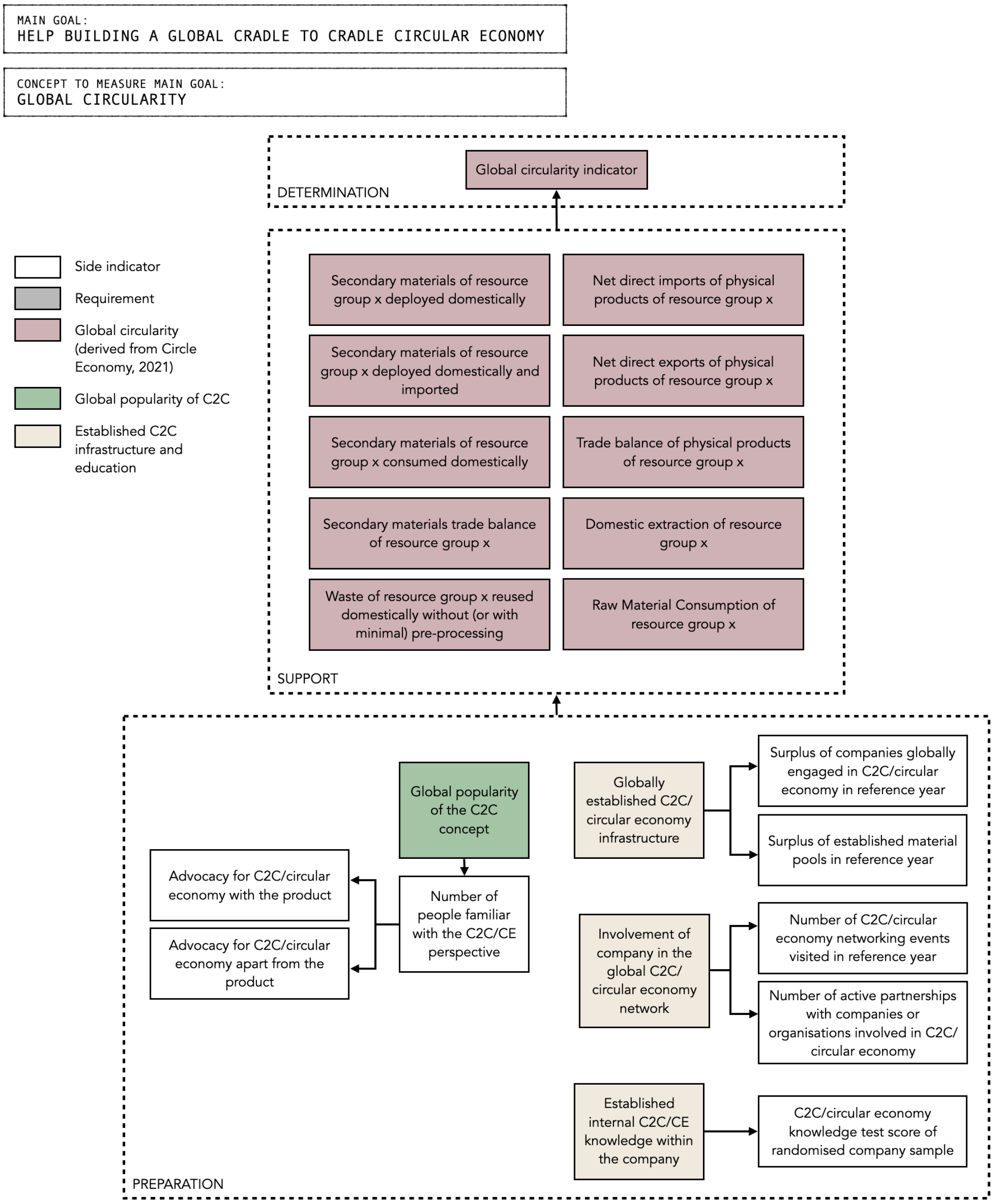

Figure 13: Suggestions for the establishment of a cluster 4

The general idea was to find a main indicator that measures circularity on a global level, such as the Global Circularity Indicator proposed by Circle Economy (2021). It has several support indicators, which are all variables of the main indicator. The author's preliminary assumption was that those global support indicators are potentially influenced by different preparation indicators, belonging to the topic of C2C/circular economy advocacy (green box in the figure) and circular economy infrastructure building (beige boxes in the figure). It is out of the scope of this report to do further research on that, but the author proposes to use Figure 13 a base for a more thorough investigation.

Seventh, the Generalisability of the clusters was only assessed based on the exemptions stated in the C2CPII standard. The author lacks practical knowledge about potential other exemptions that are not mentioned in the standard. So, this criterion should be re-assessed by an expert. The same holds true for a more comprehensive assessment of the required standard tests used for determining cyclability in the biological cycle, or the amount of renewable content. The author does not have enough chemical or biological knowledge for assessing this matter and would have gone out of scope of this research with an attempt to still do so. A further investigation of the required official chemical and biological tests would enhance the reliability of this research.

Last, it would be interesting to think about how to combine the values of the three main indicators (Mass % of circularly sourced content, Mass % of cyclable content, Active cycling rate) into a single index. This has not been investigated further so far, but there are examples from literature that could be used as an orientation (see, Ellen MacArthur Foundation, 2020; Ellen MacArthur Foundation & Granta, 2015; Ideal & Co, 2016; WBCSD & Circular IQ, 2022).

8 CONCLUSIONS

This report has been researching the question: *How far do the indicators for product circularity in the C2CPII standard comply with scientific quality criteria, and how can their scientific quality be improved?*

For answering this question, first 13 indicators used for measuring product circularity were extracted from the most recent C2CPII standard. Those indicators were visually put into relation to each other, and three indicator clusters were identified, which together build the basis for assessing product circularity: (1) Circularly sourced content, (2) Cyclability and (3) Active cycling.

Consequently, five different scientific quality criteria were defined: Construct validity, Reliability, Practicality, Generalisability and Transparency. Based on that, an assessment framework was developed where each of the 13 indicators was assessed on a scale from 1 (low quality) to 3 (high quality) for each criterion. For calculating the end scores per indicator and cluster, a weighting was applied, which gives a higher weight to both the three main indicators and the criteria Construct Validity and Reliability. Those end scores can be derived from Table 16.

Table 16: Overall indicator scores per cluster

Cluster	**CV**	**R**	**P**	**G**[1]	**T**[2]	**Weighted end score**
Circularly sourced content	2.3	1.2	1.8	3.0	3.0	2.1
Cyclability	2.2	1.6	2.1	2.0	3.0	2.1
Active cycling	2.1	1.9	2.2	2.0	3.0	2.3

CV = construct validity, R = reliability, P = practicality, G = generalisability, T = transparency,
[1]Assessed for the whole cluster, not for single indicators. Thus, no calculation is required.
[2]Assessed for the whole C2CPII standard, not for single indicators/clusters. Thus, no calculation is required

It got evident that the weighted end scores of all clusters are medium and close to each other, but that the active cycling cluster performs best (end score 2.3). The Reliability is lowest for all clusters, which is mainly because of the sub-criterion Objectivity, while the Effectivity (belonging to the Construct validity) and Time of determination (belonging to the Practicality) both scored high. Also the Transparency and Generalisability were both assessed with high values for all clusters. Two out of the three main indicators scored insufficiently regarding their average scores in Construct validity, Reliability and Practicality, where the Reliability and Practicality were most contributing to this. Indicators 5 and 12 were the only indicators that overall scored sufficiently and almost do not need improvement.

Next, indicators used in other circularity assessment approaches were researched to find indicators comparable to the ones by the C2CPII standard. 13 indicator-sets could be identified to serve as a basis for formulating improvements to the C2CPII indicators.

Last, based on the indicator assessment and the researched indicator-sets, improvements were suggested to increase the scientific quality of the C2CPII product circularity indicators. It was recommended to (1) differentiate more between the r-strategies (reuse, remanufacture, refurbish, recycle) in all clusters and to (2) find more objective ways to measure them. Furthermore, it was suggested to (3) improve the language and structuring of requirements in the C2CPII standard in all clusters, and to (4) add normative requirements and stricter boundaries to most indicators. Also, different additional indicators were suggested to increase the Reliability and Construct Validity of the cluster, such as (5) influencing factors for the renewable content, (6) by-product use, (7) virgin material use, (8) criticality, (9) differentiated sub-indicators for the biological cycling pathways, (10) accounting for the nutrient quality, and (11) collection rates. Additional major suggested improvements were (12) a redefinition of high value cycling for the cyclability and (13) an addition ensuring that downcycling is prohibited for the active cycling rate, as well as (14) the mandatory use of the ISO 22095 norm for the chain of custody documentation and (15) the application of weighting for the calculation of the main indicators (for example, weighting renewable content less than cycled content).

In summary, this research shows that the standard used by the C2CPII has a valid general idea but can be improved in many ways to enhance its scientific quality. The author hopes that this report will be useful to relevant actors in the field and can help to increase the credibility of C2C products. This report could be seen as a starting point for a discussion in the scientific community for C2C.

9 RECOMMENDATIONS

The first group of recommendations are proposed to associates of the C2CPII. The most important recommendation is to transfer the standard from a pure wording-based checklist format to a (more) objective indicator-based format with defined numerical thresholds for passing a check for the certification. The cluster structure as explained in this research could be adopted, and thresholds could be defined for each main indicator of the cluster for each certification level (bronze, silver, gold, platinum). The graphs, or adjusted versions of it, could be used for a better overview at the beginning of each cluster, and the requirements and process of determination could be displayed per indicator in a similar format as in this research. It is assumed that this would make an assessment easier and quicker for potential administrators and decrease misevaluations and -interpretations. All in all, the scientific quality of the standard would be improved and certified C2C products would be even more credible.

The second target group for recommendations are associates from EPEA. The visual overview of the indicators in general and the overviews of the indicators per cluster can help in understanding and applying the standard in the daily work. Also, it might be helpful to use those visuals as communication elements for clients, to make them understand better what the administrators are doing. Additionally, the provided tables with requirements (having an if… then… format), together with the visuals (partly resembling decision trees), could be seen as a preparation for an interactive web tool for undertaking an assessment. This could make an assessment form easier and more pleasant to look at, be available at any time and place for both the administrator and the applicant and ease the process of sharing the required documents with the administrator (as those can be directly uploaded where required). Furthermore, the author suggests that EPEA could also engage in a discussion with the C2CPII about the findings and how they could be implemented in a next version of the standard.

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Appendix 1: Explanations on the assessment framework

The criteria assessed in this research are:

1. Construct Validity (Effectivity, Efficiency)
2. Reliability (Test-Retest Reliability, Objectivity)
3. Practicality (Time & Ease of Determination, Clearness of Language)
4. Generalisability
5. Transparency

The first three criteria are assessed for each indicator individually. The Reliability and Practicality are hereby assessed independently of the main goal of the cluster, whereas the Construct Validity refers to the 'big picture'. The Generalisability is assessed for the whole cluster, the Transparency for the whole indicator-set.

Each criterion is evaluated on a logical (not empirical) base. To be as concise as possible, it is only mentioned what can be criticised on each indicator, not what is done well. So, everything that is not mentioned as criticism is assumed to be in line with the scientific quality criterion. To increase the transparency and structure of the assessment, a number from one to three is assigned to each criterion. In the following, further explanations on the basic information given per indicator, each assessed criterion and the assessment scales are given.

General information

General information is given about the indicator's intention, scale level, output and about what kind of an indicator it is (determination, support, preparation, alternative).

Requirements

The requirements for assigning an indicator value are listed, as extracted from the C2CPII standard. Those can be one or several sets.

Process of determination

The (assumed) process of determining the indicator is described. It is assumed that each indicator follows the same scheme:

1. Gather from the applicant the verification documents
2. Read through the requirements for the documents
3. Apply requirements to documents
4. Determine indicator value

Construct Validity

To assess the Construct Validity, slightly different approaches are taken for the different types of indicators. For main indicators, it is analysed how far improving the indicator contributes to achieving the main goal of the cluster, for all other indicator types (preparation/support/alternative) how far the indicator helps improving the main indicator. For a more differentiate analysis, the Construct Validity is split into the sub-criteria Effectivity (CVV) and Efficiency (CVC), which are assumed to be influenced by different factors (see Table 17).

Table 17: Sub-criteria and factors used for the assessment of the construct validity

Criterion	Factors	Explanation
CVV	General causal relation of the concepts	Is the general idea behind the indicator fitting for achieving the main goal?
CVC	Clearness of boundaries	How clearly defined are the boundaries for assigning the indicator value?
	Strictness of boundaries	How strictly defined are the boundaries for assigning the indicator value?
	Inclusion of normative requirements	How far do the requirements define what a good or a bad fulfilment of the requirements means?
	Completeness of requirements	Which requirements are missing?
	Wrong or misleading requirements	Are there requirements that are not supporting the goal of the cluster?
	Internal interrelation of sub-concepts	How sound is the determination of the indicator?

1) Effectivity (CVV)

For main indicators, it is assessed whether there is a general relation between the indicator and the main goal of the cluster, for other indicators whether there is a general relation between the indicator and the main indicator. Assessment scores mean the following:

1- The general idea behind the indicator is barely fitting for achieving the main goal/improving the main indicator.
2- The general idea behind the indicator is somewhat fitting for achieving the main goal/improving the main indicator.
3- The general idea behind the indicator is strongly fitting for achieving the main goal/improving the main indicator.

2) Efficiency (CVC)

For main indicators, it is assessed how far the set-up of the indicator supports the main goal of the cluster, for other indicators how far the set-up of the indicator helps improving the main indicator. Assessment scores hereby mean the following:

1- The set-up of the indicator does only establish a weak connection between the indicator and the main goal/indicator.
2- The set-up of the indicator establishes a connection between the indicator and the main goal/indicator but could be improved to strengthen the effect.
3- The set-up of the indicator establishes a strong connection between the indicator and the main goal/indicator.

Reliability

Indicators are assessed regarding the consistency of their output under changing conditions. The requirements in the C2CPII standard and the assumed process of determination serve hereby as the main subjects of analysis. For a more differentiate analysis, the Reliability is split into the sub-criteria Test-Retest Reliability (TRR) and Objectivity (OR), which are assumed to be influenced by different factors (see Table 18).

Table 18: Sub-criteria and factors used for the assessment of the reliability

Criterion	Factors	Explanation
TRR	Likelihood of accidentally assigning the indicator an incorrect value due to internal (personal) circumstances	Influenced by scale level, clarity of boundaries, and all the factors related to EP and CP
	Likelihood of opportunistically assigning the indicator an incorrect value	How far can someone willingly assign the indicator an incorrect value following their own personal interests?
OR	Scale level	How many potential outcomes are defined by the scale level?
	Clearness of boundaries	How clearly defined are the boundaries for assigning the indicator value?
	Room of interpretation due to strictness of boundaries	How much constraints does an administrator have in assigning the indicator value?
	Room of interpretation due to missing normative requirements	How much guidance does an administrator have in assigning an indicator value?
	Room of interpretation in the indicator determination	How strictly defined is the way an indicator is determined?

1) Test-Retest Reliability (TRR)

Here, it is assessed how consistent the indicator results are if the same administrator determined the indicator several times, given the same information. It is assumed that the existence of normative requirements does not play a role as it seems logical that every administrator consistently sticks to their own norms and interpretations. Furthermore, it is assumed that external (environmental) circumstances do not play a role either because all indicator values are not measured by an instrument but assigned by a human being. Assessment scores mean the following:

1- If determined several times by the same administrator, given the same information, the indicator is very likely to show a different result.
2- If determined several times by the same administrator, given the same information, the indicator is somewhat likely to show a different result.
3- If determined several times by the same administrator, given the same information, the indicator is likely to show the same result.

2) Objectivity (OR)

The assessment determines how consistent the indicator results are if two different administrators got the same information and determined the indicator at the same time. It is assumed that the factors from the Test-Retest Reliability do not play a role and every administrator acts without mistakes and at their best will. So mainly, this sub-criterion is determined by the amount of room for interpretation the administrators have. Assessment scores mean the following:

1- If two different administrators got the same input information and determined the indicator at the same time, the indicator is likely to show a different result.
2- If two different administrators got the same input information and determined the indicator at the same time, the indicator is somewhat likely to show a different result.
3- If two different administrators got the same input information and determined the indicator at the same time, the indicator is likely to show the same result.

Practicality

This criterion assesses how practical it is for the administrator to determine the indicator. This is determined by analysing the assumed process of determination and the descriptions in the C2CPII standard. For a more differentiate analysis, the Practicality is split into the sub-criteria Time of Determination (TP), Ease of Determination (EP) and Clearness of Language (CP), which are assumed to be influenced by different factors (see Table 19). It is assumed that the administrator is somewhat familiar with the C2CPII standard and has used it for assessment before.

Table 19: Sub-criteria and factors used for the assessment of the practicality

Criterion	Factors	Explanation
TP	Sum of time each step takes in the process of determination	Assumption
EP	Required knowledge	Assumption
	Required skills	
	Amount of required concentration and logical thinking	

CP	Clearness of language used to describe the indicator's intention	As elaborated in the standard 4.0
	Clearness of language used to describe the requirements	As elaborated in the standard 4.0
	Clearness of language used to describe the process of determination	As elaborated in the standard 4.0

1) Time of Determination (TP)

This is assessed by summing up the assumed time frames every step takes. The step of gathering the documents from the applicant is always excluded from the count, as the time this takes is not in the hands of the administrator and would thus bias the outcome. Assessment scores mean the following:

1- Takes much time (>1d)
2- Takes medium time (1h-1d)
3- Takes few time (<1h)

2) Ease of Determination (EP)

This is assessed by estimating the knowledge and skills required for determining the indicator, as well as the amount of concentration and logical thinking. Assessment scores mean the following:

1- Very hard to determine. Requires a lot of skills and/or specific knowledge, concentration and logical thinking.
2- Medium hard to determine. Requires some skills and/or some specific knowledge, concentration and logical thinking.
3- Easy to determine. Requires almost no skills or specific knowledge and just very few concentration and logical thinking.

2) Clearness of Language (CP)

Assessed is the Clearness of Language in the C2CPII standard regarding the indicator's intention, the requirements and the description of how the indicator is to be determined. Assessment scores mean the following:

1- The language used to describe the indicator's intention, requirements and determination is very confusing and unclear.
2- The language used to describe the indicator's intention, requirements and determination is somewhat clear but could be improved.
3- The language used to describe the indicator's intention, requirements and determination is very clear and easy to understand.

Generalisability (G)

For this criterion, it is analysed how far the indicator can be interpreted independently of the industry and technology. The only factor considered in this research for assessing this criterion is the amount of officially stated exempted products in the C2CPII standard. It is noted that there might be products for which an indicator cannot be determined that are not stated as exemptions in the C2CPII standard. But due to the limited scope of this research, those are neglected. Assessment scores mean the following:

1- The indicator is very product-specific and cannot be interpreted independently of the industry and technology.
2- The indicator is somewhat product-specific and can only partly be interpreted independently of the industry and technology.
3- The indicator is not product-specific and can be interpreted independently of the industry and technology.

Transparency (T)

This criterion evaluates how far the indicator and how it is determined is assessable to all readers, thus where the C2CPII standard is published, and how far this place is accessible to the public. Assessment scores mean the following:

1- Information on the indicator and how it is determined is not publicly available.
2- Only parts of the information on the indicator and how it is determined is publicly available.
3- Information on the indicator and how it is determined is publicly available.

Appendix 2: In depth indicator assessment of cluster 1

Indicator 1: Mass % of circularly sourced content

The intention of this main (determination) indicator is to increase the demand for circularly sourced materials and to decrease the impacts related to virgin material use. It has a ratio scale and gives a number between 0-100% as an output.

Requirements

Table 20: Requirements for circularly sourced content

No.	Condition	Requirement
1	If content intended to count as cycled	- At least some of the recycled content must be post-consumer (required % see C2CPII standard) - Verify cycled content by chain of custody documentation or cycled content verification certification certificate (exemption: steel and aluminium)
2	If content intended to count as renewable	- Certification of the material to a C2CPII-recognised responsible sourcing standard (FSC or RSPO), or an alternative equivalent - Verify renewable content by either established standards that quantify bio-based content using radiocarbon dating (ASTM D6866) or by chain of custody documentation - Commonly recycled renewable content (cellulose-based paper, corrugated fibreboard, paperboard (and similar), wood sawdust) only counts half, except for biological fibres used in apparel

Table 21: Requirements for chain of custody documentation

No.	Required purport
1	A description of how each cycled/renewable material meets the definition of pre- or post-consumer cycled content or renewable content
2	A diagram and/or a description of the manufacturing process showing how cycled or renewable materials are tracked and chain of custody is maintained
3	Records that demonstrate the applicant has an active business relationship with each supplier of the cycled/renewable material. If the applicant does not purchase the cycled/renewable content directly, this documentation must also be collected from supplier(s).

Process of determination

1. Gather from the applicant:
    a. A bill of materials, including:

i. ≥95% of all homogenous materials present in the product.
ii. Mass concentration per homogenous material.
iii. Mass % of cycled/renewable content per homogenous material.

b. Verification documents:

i. For cycled content: Chain of custody documentation (exemption steel and aluminium) or a cycled content verification certificate. Verification that least some of the recycled content is post-consumer.

ii. For renewable content: Certification of responsible sourcing standard certificate (FSC or RSPO, or an alternative equivalent), plus a chain of custody documentation or a test for biobased content (ASTM D6866 or equivalent).

2. Read through the requirements for cycled/renewable content.
3. Check the mass % of cycled content per homogenous material with the requirements.
4. Check the mass % of renewable content per homogenous material with the requirements.
5. Determine the whole mass % of cycled content in the product by multiplying for each material the mass % of cycled content with the respective total material concentration in the product, and finally adding up those numbers.
6. Determine the whole mass % of renewable content in the product by multiplying for each material the mass % of renewable content with the respective total material concentration in the product, and finally adding up those numbers.
7. Add up those two numbers for determining the end value, the mass % of circularly sourced content. Note that commonly recycled renewable content (cellulose-based paper, corrugated fibreboard, paperboard (and similar) and wood sawdust) only counts half. The only exemption are biological fibres used in apparel. They count as a whole.

Construct validity

Overall question: *How far does increasing the mass % of cycled and renewable content in a product increase the demand for circularly sourced materials?*

1) Effectivity

How far is there a general relation between the mass % of cycled and renewable content in a product and the demand for circularly sourced materials?

The main question to be clarified here is: Does circularly sourced mean cycled and renewable?

If following the definition in the C2CPII standard: Yes, it is defined like that. So, if a higher mass % of circularly sourced content (thus cycled/renewable content) is required, it is logical to assume a generally higher demand for circularly sourced content.

Applying a broader scope to the definition in the C2CPII standard, the question occurs: Can circularly sourced content at all be defined as cycled/renewable? Is that sufficient? Or even misleading? The answer depends on the given definitions of the terms cycled and renewable: Cycled material is defined in the C2CPII standard as "material or parts that have been reclaimed, recycled, salvaged, or otherwise captured from a pre-consumer or post-use phase of a previous cycle" (C2CPII, 2021b, p. 263), whereas renewable material is "derived from a natural resource (agriculture or animal-derived) that has a maximum 10-year regeneration cycle" (C2CPII, 2021b, p. 266). Both definitions are assumed to fit the general purposes of circularly sourced content claimed in the C2CPII standard:

1. Helping to close the loop
2. Advancing the circular economy (see definition in the introduction)
3. Minimising negative impacts of virgin material use

It is out of the scope of this research, but still the following question can be asked: Are those three defined purposes of circularly sourced content valid? The first two are assumed to be answerable with yes, even though the term "close the loop" is quite vague (Which loop? How? Within which time frame?). As for the third one: Should the goal really be to minimise negative impacts of virgin material use, or rather to decrease virgin material use? Thus, is it possible to have virgin material use without negative impact?

Still, within the scope of this research, this sub-criterion is still evaluated with a 3 – The general idea behind the indicator is strongly fitting for achieving the main goal.

2) Efficiency

How far does the set-up of the indicator support the goal of increasing the demand for circularly sourced materials?

The cycled and the renewable content are assessed separately.

Referring to the definition and the requirements for cycled content as named above, the following points remain unclear or are misleading:

1. Cycled content from different r-strategies is allowed, but those are not strictly defined. Especially for recycled content, some implications are missing: The C2CPII standard further defines recycled content as the "proportion of pre-consumer or post-consumer materials, by mass, of recycled material in a product or packaging" (p.266 UG). This raises the question whether it is allowed to incorporate content that is derived from a higher quality product (that has been downcycled then).
2. It is not that clear that the reused, remanufactured or refurbished components also count.
3. Implications are missing on up to which tier level the cycled content can be added.
4. Depending on whether the cycled content is post-consumer or pre-consumer, it is assumed to be increasing the demand for circularly sourced materials or not. If it is post-consumer, yes. If pre-consumer, not so much, at least not if the manufacturing company is reprocessing their own wastes. But the use of both pre- and post-consumer cycled content can lead to a decrease of the impacts of virgin material use.
5. It is required to verify the cycled content with chain of custody documentation or a cycled content verification certification certificate. The requirements for this chain of custody documentation are quite vague and do not specify standards, or what exact content has to be included. There is an ISO norm (ISO 22095 – see ISO, 2020) that does that, but the C2CPII does not seem to require its use.

Referring to the definition and the requirements for renewable content as named above, the following points remain unclear or are misleading:

1. The time span in which the resource is seen as renewable is set to ten years. There is no justification of this number, and further investigation would be necessary to back it up scientifically. An interesting approach could be to assess different land use scenarios. Even assuming that there are no direct impacts of growing the renewable resource (which is doubtable), it is always competing with other land uses such as agriculture, living space or natural habitat (Barteková & Kemp, 2016; Colombia Climate School, 2017).
2. At the moment, there are just two C2CPII recognised sourcing standards (FSC and RSPO). One is for wood, one is for palm oil. Additional programs can be recognised following the criteria of the C2CPII which are publicly available, but apparently this has not happened yet (otherwise they would appear in the list of recognised sourcing standards). Does that mean that, so far, all certified

renewable materials have been made of wood or palm oil? In any case, it leaves some confusion.

3. For the chain of custody documentation, the same arguments apply as explained for the cycled content.
4. It is questionable whether it is valid to count renewable content equally towards the indicator end-result as cycled content. The argument named in point 1 is does not apply for cycled material. So, using cycled material would in any case prevent land use conflicts and leave space to other, maybe more essential land uses. Thus, it might be worth considering counting renewable material only with half, a third or even a fourth towards the indicator end-result to set a higher incentive on using cycled material in a product.

It is noted that all the required standard tests are assumed to be valid, as their assessment is out of the scope of this research. Summing it up, this sub-criterion is evaluated with a 2 – The set-up of the indicator establishes a connection between the indicator and the main goal but could be improved to strengthen the effect. Adding up the scores of the Effectivity (weighting 1/3) and Efficiency (weighting 2/3), the overall Construct Validity score of this indicator is 2.3.

Reliability

1) Test-Retest Reliability

The following points are assumed to diminish the Test-Retest Reliability:

1. Given the complexity and the amount of the given information on which the cycled/renewable amount shall be determined (bills of materials, chain of custody documentation, requirements), it is possible that the administrator might accidentally count too many/few materials as cycled/renewable and thus come to a wrong result. Additionally, assuming that no user-friendly Microsoft Excel file is provided with the formulas already filled in, it is quite likely that an administrator will make mistakes in the calculations (for example in the multiplication with the weight) and thus will get different results in different repetitions of the calculations.
2. Opportunistic behaviour is possible, but not likely. Every material that is counted towards the percentage of renewable content needs to be backed up by standardised evidence. For the cycled content, the required evidence is not that standardised and open for manipulation though. Opportunistic behaviour might be possible due to the lack of overview and transparency one might have about what the administrator is thinking and reporting.

Summing it up, this sub-criterion is evaluated with a 1 – If determined several times by the same administrator, given the same information, the indicator is very likely to show a different result.

2) Objectivity

The following points are assumed to diminish the Objectivity:

1. The scale level offers a wide range of possible results (numbers 1-100), which generally increases the likelihood of different results per administrator.
2. For cycled content, it is not clear how far one can go up the supply chain to call a material cycled. There are requirements for a chain of custody documentation, but they do not include this definition either. For renewable content, it is not easy to find information on how quick the resource should regrow.
3. The calculations per se are objective, but as argued above they are likely to include mistakes, depending on the concentration, Microsoft Excel and mathematical skills of the administrator.

Summing it up, this sub-criterion is evaluated with a 1 – If two different administrators got the same input information and determined the indicator at the same time, the indicator is very likely to show a different result. Adding up the scores of the Test-Retest Reliability (weighting 1/3) and Objectivity (weighting 2/3), the overall Reliability score of this indicator is 1.

Practicality

1) Time of Determination

The time step 1 takes in the process of determination is excluded from the count. Step 2 is assumed to take >10 min, step 3 and 4 around 1h and step 5-7 >10 min. Summing it up, this sub-criterion is evaluated with a 2 – Takes medium time (1h-1d).

2) Ease of Determination (EP)

It is necessary to know and understand the requirements for when a material counts as cycled/renewable to determine this indicator, and also to understand the respective tests required to verify it. Skills in thorough, concentrated reading and Microsoft Excel (or another calculation program) are required for finding the input for and doing the calculations. Summing it up, this sub-criterion is evaluated with a 1 – Very hard to determine. Requires a lot of skills and/or specific knowledge, concentration and logical thinking.

3) Clearness of language (CP)

The language describing the indicator's intention is clear. The description of the required elements is lacking structure and overview though and is full of complicated formulations. The process of determination is very confusing and unclear in the C2CPII standard. The definition of the terms cycled and renewable is not clear enough, and there is no description/aid describing how the indicator is exactly calculated. Summing it up, this sub-criterion is evaluated with a 1 – The language used to describe the indicator's intention, requirements and determination is very confusing and unclear. Adding up the scores of the Time of Determination, Ease of Determination and Clearness of Language (all weighted equally), the overall Practicality score of this indicator is 1.

Indicator 2: Development of plan to increase cycled/renewable content

The intention of this alternative indicator is to increase the cycled/renewable content of the product. It has a nominal scale and a binary output of either yes or no.

Requirements

Table 22: Required purport of the plan to increase cycled/renewable content

No.	Required purport
1	Type and source of content intended to be included or increased in the product
2	Timeline with targets for increasing the content
3	Method for achieving these increases

Process of determination

1. Gather from the applicant the plan to increase cycled/renewable content.
2. Read through the requirements.
3. Check whether the plan meets the requirements.
4. Assign the indicator yes/no.

Construct validity

Overall question: *How far does the development of a plan to increase the cycled/renewable content of a product lead to an increase in the mass % of circularly sourced content?*

Note: Officially, the plan always needs to be made, but it actually only makes sense when the mass % of circularly sourced content in a product is not equal yet to the maximum technically feasible amount of circularly sourced content.

1) Effectivity

How far is there a general relation between the development of a plan to increase the cycled/renewable content of a product and the mass % of circularly sourced content?

It is assumed that generally, a plan for increasing cycled/renewable content helps increasing the mass % of cycled/renewable content in a product. Thus, this sub-criterion is evaluated with a 3 – The general idea behind the indicator is strongly fitting for improving the main indicator.

2) Efficiency

How far does the set-up of the indicator help increase the mass % of circularly sourced content in a product?

This depends on the content of the plan (see requirements). The following things can be criticised about it:

1. There is no description required of possible challenges and how to overcome them. This is partly done in the feasibility analysis (next indicator), but it would make more sense to couple it directly to the plan.
2. A list of actual or potential suppliers which are supplying/could supply the required demand would make the plan more valuable. And a strategy on how to approach them and strengthen the relationship.
3. There is no formulation of normative requirements (what is a good method, timeline etc.).

Thus, this sub-criterion is evaluated with a 2 – The set-up of the indicator establishes a connection between the indicator and the main indicator but could be improved to strengthen the effect. Adding up the scores of the Effectivity (weighting 1/3) and Efficiency (weighting 2/3), the overall Construct Validity score of this indicator is 2.3.

Reliability

1) Test-Retest Reliability

The outcome of this indicator is a simple yes or no and the requirements are clearly formulated, so it is unlikely that the administrator will assign the indicator a different value by accident. The opportunity for opportunistic behaviour is big though because there is no report required on the normative judgements the administrator makes for doing so. Thus, this sub-criterion is evaluated with a 2 – If determined several times by the same administrator, given the same information, the indicator is somewhat likely to show a different result.

2) Objectivity

Even though it is a binary indicator and there are clear requirements formulated for the assessment of the plan, it is quite likely that different administrators will interpret those requirements (or rather the boundary when a no becomes a yes) differently. This might depend on their personal background, such as department, education, level of knowledge etc. Thus, this sub-criterion is evaluated with a 1 – If two different administrators got the same input information and determined the indicator at the same time, the indicator is very likely to show a different result. Adding up the scores of the Test-Retest Reliability (weighting 1/3) and Objectivity (weighting 2/3), the overall Reliability score of this indicator is 1.3

Practicality

1) Time of Determination

The time step 1 takes in the process of determination is excluded from the count. Step 2 is assumed to take less than 10 min, step 3 around 30 min and step 4 less than 5 min. Summing it up, this sub-criterion is evaluated with a 3 – Takes few time (<1h).

2) Ease of Determination

Knowledge is required about what is a good plan. It might be hard for the administrator to determine the border between a yes and a no. It is also necessary to be able to study documents carefully und fully concentrated. Thus, this sub-criterion is evaluated with a 2 – Medium hard to determine. Requires some effort and/or some specific knowledge, concentration and logical thinking.

3) Clearness of language

The indicator's intention is clearly formulated. The requirements are quite clearly formulated, too, but still open for interpretation (of the border between yes/no), there is no information at all on the indicator determination. Thus, this sub-criterion is evaluated with a 2 – The language used to describe the indicator's intention, requirements and determination is somewhat clear but could be improved. Adding up the scores of the Time of Determination, Ease of Determination and Clearness of Language (all weighted equally), the overall Practicality score of this indicator is 2.3.

Indicator 3: Conduction of feasibility analysis

Th intention of this alternative indicator is to increase the amount of cycled/renewable content in the product in difficult product types. It has a nominal scale and a binary output of yes or no.

Requirements

Table 23: Minimum required purport of the feasibility analysis

No.	Minimum required purport
1	An explanation of limitation(s) preventing the incorporation of the target amount of cycled/renewable content and how the current amount represents the maximum that is currently feasible (report publicly) → For single-use plastics and plastic packaging products, only two limitations count: a. Legal obligations for products in food contact b. Product performance specifications
2	A strategy for addressing the identified limitation(s) and increasing the amount of cycled and/or renewable content over time, including discrete objectives and an associated timeline
3	For recertification: Description of progress toward achieving the objectives (report publicly)

Process of determination

1. Gather from the applicant the feasibility analysis.
2. Read through the requirements.
3. Check whether the analysis meets the requirements.
4. Assign the indicator yes/no.

Construct validity

Overall question: *How far does the conduction of a feasibility analysis help increase the mass % of circularly sourced content?*

Note: The indicator only comes into play if the main indicator (mass % of circularly sourced content) has an insufficiently low value.

1) Effectivity

Is there a general relation between the conduction of a feasibility analysis and the mass % of circularly sourced content in a product?

It is assumed that a feasibility analysis generally can help increasing the mass % of circularly sourced content in a product, but that it just plays a minor role. Thus, this sub-criterion is evaluated with a 2 – The general idea behind the indicator is somewhat fitting for improving the main indicator.

2) Efficiency

How far does the set-up of the indicator help increase the mass % of circularly sourced content in a product?

In the C2CPII standard, they formulate the feasibility analysis and the development of a plan to increase the circularly sourced content as two separate requirements that come into play under different conditions. The plan needs to be developed in any case, whereas the feasibility analysis is mentioned as an alternative if the required mass % cannot be met. It would make much more sense to have the feasibility analysis included as a sub-part in the plan, and to develop both just in the case that there is still room for improvement (=actual mass % is below maximum technically feasible mass % of circularly sourced content).

Analysing the requirements of the indicator itself, the set-up could also be improved: Clearer and stricter boundaries, inclusion of normative requirements and, as mentioned above, make it a subpart of the plan to increase the cycled/renewable content. Summing it up, this sub-criterion is evaluated with a 2 – The set-up of the indicator establishes a connection between the indicator and the main indicator but could be improved to strengthen the effect. Adding up the scores of the Effectivity (weighting 1/3) and Efficiency (weighting 2/3), the overall Construct Validity score of this indicator is 2.

Reliability

1) Test-Retest Reliability

As the outcome of this indicator is a simple yes or no, and the requirements are clearly formulated, it is unlikely that the administrator will assign the indicator a wrong value by accident. Due to the missing normative dimensions of the indicator, there is lots of room for opportunistically assigning the indicator an incorrect value though. Thus, this sub-criterion is evaluated with a 2 – If determined several times by the same administrator, given the same information, the indicator is somewhat likely to show a different result.

2) Objectivity

Even though it is a binary indicator and there are clear requirements formulated for the assessment of the feasibility analysis, it is quite likely that different administrators will interpret those requirements (or rather the boundary when a no becomes a yes) differently. This depends on their personal background, such as department, education, level of knowledge etc. Thus, this sub-criterion is evaluated with a 1 – If two different administrators got the same input information and determined the indicator at the same time, the indicator is very likely to show a different result. Adding up the scores of the Test-Retest Reliability (weighting 1/3) and Objectivity (weighting 2/3), the overall Reliability score of this indicator is 1.3

Practicality

1) Time of Determination

The time step 1 takes in the process of determination is excluded from the count. Step 2 is assumed to take less than 10 min, step 3 around 30 min and step 4 less than 5 min. Thus, this sub-criterion is evaluated with a 3 – Takes few time (<1h).

2) Ease of Determination

Knowledge is required about what is a good/useful feasibility analysis, i.e., knowledge about the product (system), industry and recycling technologies. Furthermore, it is necessary to be able to study documents carefully. Thus, this sub-criterion is evaluated with a 2 – Medium hard to determine. Requires some effort and/or some specific knowledge, concentration and logical thinking.

3) Clearness of Language

The description of the indicator's intention is clear. The requirements are quite clearly formulated, too, but still open for interpretation (of the border between yes/no), there is no information about the indicator determination. Thus, this sub-criterion is evaluated with a 2 – The language used to describe the indicator's intention, requirements and determination is somewhat clear but could be improved. Adding up the scores of the Time of Determination, Ease of Determination and Clearness of Language (all weighted equally), the overall Practicality score of this indicator is 2.3.

Appendix 3: In depth indicator assessment of cluster 2

Indicator 4: Mass % of high value cyclable content

The intention of this main (determination) indicator is to make the product suitable to be kept in high quality cycles as long as possible. It has a ratio scale and a number between 0-100% as an output.

Requirements

Table 24: Requirements for a material to count as compatible with the biological cycle

No.	Condition	Requirement
1	If solid material or wet-applied product	The material must be biodegradable in the intended cycling pathway(s) (conditions specified in biodegradability test)
2	If product is a liquid formulation (excluding wet-applied products)	a. If organic: The material must be biodegradable in the intended cycling pathway(s) (conditions specified in biodegradability test) and i.a. be (readily) aerobically/anaerobically biodegradable b. If inorganic: Include benign minerals as compatible c. Exclude water weight from the calculation
3	If composting is one intended cycling pathway	The material must be environmentally safe (conditions specified in ecotoxicity test)
4	If material has unavoidable release to the environment during product use	The fraction of material released to the environment over its lifetime must be biodegradable in the release environment
5	If a homogeneous material needs to be separated	The material must be separable with given instructions and no additional special knowledge
6	If product is installed prior to use	It must be possible to extract the product from the installed location

Table 25: Requirements for a material to count as compatible with the technical cycle

No	Condition	Requirement
1	If wet-applied product	The product must comply to the INGEDE Method 11 (de-inkability) OR INGEDE Method 12 (adhesive separation) OR it must be proven that the product does not adversely affect the reprocessing value of the material to which it has been applied
2	If product/material is intended for technical municipal cycling	The product/material must be compatible for municipal cycling systems
3	If a homogeneous material needs to be separated	The material must be separable with given instructions and no additional special knowledge

4	If product is installed prior to use	It must be possible to extract the product from the installed location

Table 26: Requirements for a material to count as high-value cyclable in the biological cycle

No	Condition	Requirement
1	If solid material	a. The material must not contain additives that are likely to result in low-quality reprocessed material (see list in C2CPII standard) b. The material must fulfil at least one of the following: i. Substitute for virgin material without loss of essential product function or material durability (different requirements for different materials) ii. Contain at least 80% renewable or post-consumer recycled content iii. Have at least two plausible next uses = at least 1 existing example of the next use occurring for that material in one or more similar products. Must also be part of the Active Cycling plan and implementation c. The product must be certified by a C2CPII-recognised compostability program (see list in the C2CPII standard)
2	If select liquid formulation	The product must meet the minimum % of ready biodegradability and/or anaerobic biodegradability requirements per C2CPII-recognised standards
3	If plastic beverage container	Plastic caps and lids must remain attached to the container during the product's intended use

Table 27: Requirements for a material to count as high-value cyclable in the technical cycle

No	Condition	Requirement
1	Always	a. The material must not contain additives that are likely to result in low-quality reprocessed material (see list in C2CPII standard) b. The material must be able to fulfil at least one of the following: i. Substitute for virgin material without loss of essential product function or material durability (different requirements for different materials) ii. Contain at least 80% renewable or post-consumer recycled content iii. Have at least two plausible next uses = at least 1 existing example of the next use occurring for that material in one or more similar products. Must also be part of the Active Cycling plan and implementation
2	If plastic beverage container	Plastic caps and lids must remain attached to the container during the product's intended use

Process of determination

1. Gather from the applicant:
    a. A bill of materials, including
        i. All homogenous materials present in the product.

    ii. The mass concentrations of each material.
    iii. The intended cycling pathway per material.
    iv. The mass % of high value cyclable content per homogenous material intended for the biological cycle/technical cycle.

b. Verification documents for verifying cyclability in the biological cycle:

    i. All products:

        1. Description of how each material meets the compatibility requirements.
        2. Explanation of how the high value cycling potential requirements are met.

    ii. Solid materials:

        1. Biodegradability/compostability standard test.
        2. Ecotoxicity test if composting is one intended cycling pathway.
        3. Confirmation and documentation that additives or features likely to result in low-value reprocessed material are not used.
        4. Either evidence of minimal loss of function or durability OR evidence that the material contains 80% renewable or post-consumer recycled content OR evidence of at least two plausible next uses.

    iii. Wet-applied products:

        1. Biodegradability standard test.
        2. Ecotoxicity test if composting is one intended cycling pathway.

    iv. Liquid formulations:

        1. Biodegradability standard test.
        2. i.a. Evidence of achieving the minimum percent ready biodegradability and/or anaerobic biodegradability requirements.

c. Verification documents for verifying cyclability in the technical cycle:

    i. All products:

        1. Description of how each material meets the compatibility requirements.
        2. Explanation of how the high value cycling potential requirements are met.
        3. Confirmation and documentation that additives or features likely to result in low-value reprocessed material are not used.

4. Either evidence of minimal loss of function or durability OR evidence that the material contains 80% renewable or post-consumer recycled content OR evidence of at least two plausible next uses.

ii. Wet-applied products: i.a. INGEDE method 11 + 12.

2. Read through the requirements for materials to count as compatible with the intended cycling pathway(s).
3. Read through the requirements for high value cyclable content.
4. Check the mass % of high value cyclable content per homogenous material intended for the biological cycle with the requirements.
5. Check the mass % of high value cyclable content per homogenous material intended for the technical cycle with the requirements.
6. Determine the whole mass % of high value cyclable content intended for the biological cycle in the product by multiplying for each material the mass % of high value cyclable content (biological cycle) with the respective total material concentration in the product, and finally adding up those numbers.
7. Determine the whole mass % of high value cyclable content intended for the technical cycle in the product by multiplying for each material the mass % of high value cyclable content (technical cycle) with the respective total material concentration in the product, and finally adding up those numbers.
8. Add up those two numbers for determining the end value, the mass % of high value cyclable content in the whole product.

Construct validity

Overall question: *How far does increasing the mass % of high value cyclable content in the product help make the product suitable to be kept in high quality cycles as long as possible?*

1) Effectivity

Is there a general relation between the mass % of high value cyclable content and the goal to make the product suitable to be kept in high quality cycles as long as possible?

This depends on the definition of cyclability. In the C2CPII standard, cycling is defined as

"the processing of material, parts, or whole products toward a new use cycle via a technical or biological cycling pathway that includes at least one of the following: reuse, remanufacturing, refurbishing, recycling, nutrient extraction/anaerobic digestion, composting, or biodegradation" (C2CPII, 2021b, p. 63).

The term cyclability thus logically refers to the ability of a product to be cycled in the intended cycling pathways as described above. Additionally, this cycling has to happen under the condition of maintaining a product's quality, requiring the high value cyclability of a product. The definition of high value is given in the requirements that are evaluated under the next sub-criterion Efficiency. The described cycling pathways are evaluated in the next indicator and are thus taken as valid here to avoid double accounting.

Merging all the given explanations, it is assumed that the amount of high value cyclable content in a product directly refers to the ability of a product to be kept in high quality cycles as long as possible, as it has been defined like this. Thus, the sub-criterion is evaluated with a 3 – The general idea behind the indicator is strongly fitting for achieving the main goal.

2) Efficiency

How far does the set-up of the indicator support the goal of making the product suitable to be kept in high quality cycles as long as possible?

The answer to this question depends on how the terms cyclable and high value are defined.

The definition of the term cyclable does, as explained above, refer to the compatibility of the materials or components with their intended cycling pathways. The pathways themselves are evaluated in the next indicator, but here it is evaluated how valid the definition of the term compatibility is. This definition can be found in the requirements for a material to count as compatible with the biological/technical cycle (Table 24 and Table 25). The definition of the term high value is given in the requirements for a material to count as high-value cyclable in the biological/technical cycle (Table 26 and Table 27). Both sets of requirements are assessed separately for the biological and the technical cycle.

For the biological cycle, there is not much to criticise in the requirements for materials to count as compatible with intended cycling pathways. In the requirements for materials to count as high value cyclable, all requirements seem fine except for the crucial requirement 1b. The following points can be criticised here:

1. 1bi aims for endless cycling in the described intended cycling pathways. Taking a closer look, this does not make much sense for the biological cycling pathways though. It is hard to imagine how a product intended to undergo the process of nutrient extraction/anaerobic digestion, composting, or biodegradation would after the process be able to substitute for virgin materials. The result of those

processes will be either fertiliser, energy, CO_2 or water, or a mix of them (Beier, 2009). Thus, it is assumed that the amount of saved virgin materials in biological cycling pathways would be rather small compared to the total product weight, and that the essential product function or material durability would be lost in any case. So, it is assumed that this requirement is not valid for products of the biological cycle.

2. 1bii aims for a large share of circularly sourced content in the product. This is per se a valid requirement but kind of double with the indicator 'mass % of circularly sourced content'.

3. 1biii aims for another r-strategy, reuse. This seems to set a good incentive, even though the question occurs why only reuse is allowed, and no other r-strategy. The most likely assumption to answer this is because reuse is the most value retaining r-strategy.

4. Taking all those three requirements together (of which only one needs to be fulfilled), high value cycling for products in the biological cycle is (among others) practically defined through either incorporating a large share of circularly sourced content or through making the product reusable, before the it finally digests/degrades/composts into (nutrients), CO_2 and water again. But it is doubtable whether this is enough to make a material count to be as high value cyclable.

5. The philosophy of C2C aims to make products and materials nutrients again after the use phase. For the materials in the biological cycle, the requirements named above give no indication about which nutrients that exactly should be though. Many of the most common biodegradable plastics, such as PLA, PHA, PBAT, and PBS (Grand View Research, 2020), do not add valuable nutrients to their environment during their biodegradation. And even if they do, those nutrients might not suit the environment and add elements that even do harm to the ecosystem and lead to eutrophication (Beier, 2009; Bundesgüter-gemeinschaft Kompost e.V., 2018).

For the technical cycle, the following criticism can be addressed in the requirements for materials to count as compatible with intended cycling pathways:

1. No specific formulation of requirements for solid products exists. It is assumed that the C2CPII just wants them to be compatible with the intended cycling pathways, without further requirements, and that they do not mention them specifically for that reason. But it would be clearer to have it formulated like that.

2. The same applies for liquid products.

In the requirements for materials to count as high value cyclable in the technical cycle, the following criticism can be addressed:

1. Requirement 1b looks like the crucial one (again – it is the same as for the biological cycle):

   - 1bi aims for endless cycling in the described intended cycling pathways and makes perfect sense for the technical cycle.

   - 1bii aims for a large share of circularly sourced content in the product. This is per se a valid requirement but not for this indicator. It means that, as long as a product is made of enough cycled/renewable content, the applicant does not need to make the product cyclable on a high level (even taking into account requirements 1a, 1c and 2). Thus, it would be also allowed to downcycle the product, which is totally not what the C2CPII standard claims to want (keep the product in high value cycles)

   - 1biii aims for another r-strategy (reuse). This seems to set a good incentive, even though the question occurs why only reuse is allowed, and no other r-strategy. The most likely assumption to answer this is because reuse is the most value retaining r-strategy. Still, it could mean that an applicant has a product that is not suitable to be high value recycled on a material level but can in theory be used two more times after its first use, to then be downcycled.

2. Taking all the arguments together, it would be easy for an applicant to produce a product that is only recyclable on a very low quality level, as long as it is either made of 80% cycled/renewable content or has two plausible next uses. To give an example: A company could produce a single use coffee-cup made from a composite of paper and 80% biobased polystyrene. Under the condition that they do not add any additives that are likely to result in low quality reprocessed material, their product would count as high value cyclable, according to the C2CPII, even though the cup's material can only be burned after use because it is a composite.

3. So, it can be noted that the C2CPII tries to also account for especially one other r-strategy (reuse) and implicitly also allows all other r-strategies (remanufacture and refurbish) but focusses a lot on the recycling in the requirements. But recycling should only be the last r-option, as there is a lot of potential for keeping the product in high quality cycles and maintain the product's value in the other r-strategies (Achterberg et al., 2016).

It is noted that all the required standard tests are assumed to be valid, as their assessment is out of the scope of this research. Summing it up, this sub-criterion is evaluated with a 2 for the biological cycle (The set-up of the indicator establishes a connection between the indicator and the main goal but could be improved to strengthen the effect) and a 1 for the technical cycle (The set-up of the indicator does only establish a weak connection between the indicator and the main goal), which makes an average of 1.5 for the Efficiency of this indicator. Adding up the scores of the Effectivity (weighting 1/3) and Efficiency (weighting 2/3), the overall Construct Validity score of this indicator is 2.

Reliability

1) Test-Retest Reliability

The following points are assumed to diminish the Test-Retest Reliability:

1. The information on when something counts as cyclable (=compatible with intended cycling pathways) or high value cyclable is not that neatly presented in the C2CPII standard as it is presented in this report. So, it is quite likely that an administrator evaluating the same product several times will come to different conclusions and accidentally assign a wrong value. Just because he might have overread something, lost track or got confused by what he did himself.
2. The requirements for products of the technical cycle are not that strict as there are no standard tests required (except for wet-applied products), so the required verification documents are more open for interpretation and opportunistic behaviour is more likely.
3. The calculations for determining the indicator are clearly described in this report, but not clearly defined in the C2CPII standard. Assuming that no user-friendly Microsoft Excel file is provided with the formulas already filled in, it is quite likely that an administrator will make mistakes in the calculations (e.g. multiplication with the weight) and thus will get different results in different repetitions of the calculations.

Summing it up, this sub-criterion is evaluated with a 1 – If determined several times by the same administrator, given the same information, the indicator is very likely to show a different result.

3) Objectivity

The following points are assumed to diminish the Objectivity:

1. Checking whether the stated cyclable content of a product is actually cyclable under the defined conditions might be difficult because of the confusing formulations in the C2CPII standard and partly missing clearness and strictness of boundaries, especially for the cyclable content.
2. The calculations are per se objective but still likely to include mistakes, depending on the concentration, Microsoft Excel and mathematical skills of the administrator.

Summing it up, this sub-criterion is evaluated with a 1 – If two different administrators got the same input information and determined the indicator at the same time, the indicator is very likely to show a different result. Adding up the scores of the Test-Retest Reliability (weighting 1/3) and Objectivity (weighting 2/3), the overall Reliability score of this indicator is 1.

Practicality

1) Time of Determination

The time step 1 takes in the process of determination is excluded from the count. Steps 2 and 3 are assumed to take around 30 min, step 4 and 5 less than 2h and step 6-8 around 30 min. Thus, this sub-criterion is evaluated with a 2 –Takes medium time (1h-1d).

2) Ease of Determination

For determining this indicator, very specific knowledge (and deep understanding) is required about the requirements, thus what it means to be a cyclable material in both cycles. This includes the assessment of the biodegradability and eco-toxicity tests, also chemical knowledge to deal with exemptions and specific cases. Additionally, knowledge about the product (system) and the industry, recyclers and consumers is needed. The calculations require skills in Microsoft Excel and quite some concentration and logical thinking. Thus, this sub-criterion is evaluated with a 1 – Very hard to determine. Requires a lot of effort and/or specific knowledge, concentration and logical thinking.

3) Clearness of Language

The intention of this indicator is clear. The formulation of the requirements is very confusing and badly structured, spread over different pages, and entails complicated formulations. The indicator determination is very confusing and unclear. Thus, this sub-criterion is evaluated with a 1 – The language used to describe the indicator's intention, requirements and determination is very confusing and unclear. Adding up the scores of the Time of Determination, Ease of Determination and Clearness of Language (all weighted equally), the overall Practicality score of this indicator is 1.

Indicator 5: % of number of homogenous materials with one (two) defined intended cycling pathways

The intention of this preparation indicator is to prepare the product to become suitable to be kept in high quality cycles as long as possible. It has a ration scale and gives a number between 0-100% as an output.

Note: Depending on the level of certification, one or two intended cycling pathways have to be determined. But the same requirements and calculations take place, so this indicator is taken as one.

Requirements

Table 28: Requirements for assigning a material its intended cycling pathway

No	Condition	Requirement
1	Always	Chosen pathway(s) must be possible at least at pilot scale
2	Always	Specify the entity intended to carry out the process
3	If technical cycling pathway	Choose one or more of the following pathways: a. Reuse/Recontextualising b. Repair c. Refurbish d. Remanufacture e. Recycling Recycling always has to be one pathway
4	If biological cycling pathway	Choose one or more of the following pathways: a. Nutrient extraction b. Anaerobic digestion c. Composting (Home) d. Composting (Industrial) e. Biodegradation (Soil) f. Biodegradation (Water) g. Biodegradation (Anaerobic)
5	If: a. Material designed to be released directly to the biosphere (e.g., liquid cleaning products) b. Biological or biologically derived material commonly released to the biosphere c. Coating, finish, or liquid applied to materials intended for biological cycles	Material must be designated for the biological cycle

Process of determination

1. Gather from the applicant a bill of materials, including:

   a. All homogenous materials present in the product.
   b. Their respective cycling pathways.

2. Read through the requirements for defining possible cycling pathways.
3. Count the number of homogenous materials present in the product.
4. Count the number of materials with one (or two) defined intended cycling pathways, checking with the requirements.
5. Divide 2 by 3 to assign the indicator value.

Construct validity

Overall question: *How far does defining an intended cycling pathway for every homogenous material in the product help increase the mass % of high value cyclable content in a product?*

1) Effectivity

Is there a general relation between the % of number of homogenous materials with one (two) defined intended cycling pathways and the mass % of high value cyclable content in a product?

It is essential to calculate this indicator to be able to calculate the main indicator. If there are no intended cycling pathways defined for all materials, it cannot be assessed whether the materials are compatible to the intended cycling pathways.

So in general: Yes, defining an intended cycling pathway for every homogenous material in the product (as defined in the requirements) totally makes the product more suitable to be kept in high quality cycles as long as possible. Thus, this sub-criterion is evaluated with a 3 – The general idea behind the indicator is strongly fitting for improving the main indicator.

2) Efficiency

How far does the set-up of the indicator help increase the mass % of high value cyclable content in a product?

Analysing the requirements, the following points can be criticised:

1. There is no weighting/normative evaluation of the quality of the pathways (e.g., is reuse better than recycling?).

2. There is no normative evaluation of the suitability of the intended cycling pathway, neither whether the pathway is likely to happen.

3. It can be misleading to offer anaerobic biodegradation as a pathway as it leads to CH_4 emissions, which might mean that the C is lost in the atmosphere and the cycle is not closed anymore (Mitchell & Gu, 2009).

Thus, this sub-criterion is evaluated with a 2 – The set-up of the indicator establishes a connection between the indicator and the main indicator but could be improved to strengthen the effect. Adding up the scores of the Effectivity (weighting 1/3) and Efficiency (weighting 2/3), the overall Construct Validity score of this indicator is 2.3.

Reliability

1) Test-Retest Reliability

It is unlikely that an administrator accidentally assigns the indicator an incorrect value, as it is quite easy to check whether the stated pathway meets the requirements. The calculation (as assumed) is quite simple, too.

The possibilities for opportunistic behaviour are not very big either, as the requirements are quite clear and easy to check. The same applies for the calculation. Thus, this sub-criterion is evaluated with a 3 – If determined several times by the same administrator, given the same information, the indicator is likely to show the same result.

2) Objectivity

The indicator has a ratio scale with theoretically an infinite number of possible values (numbers between 0-100). But the requirements are clear and strict, and so is the calculation. Normative requirements are missing though (whether a pathway is realistic for example and thus can be counted). But this fact can be neglected as the feasibility of a pathway just gets important during the determination of the main indicator. Thus, this sub-criterion is evaluated with a 3 – If two different administrators got the same input information and determined the indicator at the same time, the indicator is likely to show the same result. Adding up the scores of the Test-Retest Reliability (weighting 1/3) and Objectivity (weighting 2/3), the overall Reliability score of this indicator is 3.

Practicality

1) Time of Determination

The time step 1 takes in the process of determination is excluded from the count. Steps 2 and 3 are assumed to take around 20 min each, and step 4 not more than 5 min. Thus, this sub-criterion is evaluated with a 3 –Takes few time (<1h).

2) Ease of Determination

There is not much knowledge required for determining this indicator. Reading through the requirements is almost enough, plus possibly understanding when a product needs to be cycled in the biological or in the technical cycle. Thus, this sub-criterion is evaluated with a 3 – Easy to determine. Requires almost no effort or specific knowledge and just very few concentration and logical thinking.

3) Clearness of Language

The indicator's intention is clear, and so are the requirements. What is not clear is the indicator determination though. The underlying indicator and how it is determined is not mentioned in the C2CPII standard, which decreases the clearness of what is measured. Thus, this sub-criterion is evaluated with a 2 – The language used to describe the indicator's intention, requirements and determination is somewhat clear but could be improved. Adding up the scores of the Time of Determination, Ease of Determination and Clearness of Language (all weighted equally), the overall Practicality score of this indicator is 2.7.

Indicator 6: Active participation in a circularity education initiative

The intention of this support indicator is to ensure that the applicant has understood the possibilities for circularity in their product and found ways to apply them. It has a nominal scale and gives a binary output of yes or no.

Requirements

Table 29: Requirements for the circularity initiative

No	Requirements
1	The initiative must be led by another company/organisation than the applicant OR it is led by the applicant, and is a collaborative platform that involves other companies/organisations
2	The initiative must support learnings toward implementing the company's circularity strategies and cycling infrastructure
3	The initiative must aim to drive progress within an industry or across multiple industries
4	The initiative must ensure that it allows for adequate voice for all participants
5	The applicant must have actively participated within the last two years prior to certification or recertification

Process of determination

1. Gather from the applicant:
    a. Name and description of the initiative addressing all required points.
    b. Evidence that the initiative exists, and that the applicant is currently actively involved.

2. Read through the requirements.
3. Check whether the initiative meets the requirements.
4. Assign the indicator yes/no.

Construct validity

Overall question: *How far does the active participation in a circularity initiative help increase the mass % of high value cyclable content in a product?*

1) Effectivity

Is there a general relation between the active participation in a circularity education initiative and the mass % of high value cyclable content in a product?

The goal of the initiative is to ensure that the applicant has understood the possibilities for circularity in their product and found ways to apply them. This is assumed to help increasing the product cyclability, though it is not the main influencing factor. Thus, this sub-criterion is evaluated with a 2 – The general idea behind the indicator is somewhat fitting for improving the main indicator.

2) Efficiency

How far does the set-up of the indicator help increase the mass % of high value cyclable content in a product?

This depends on the content of the initiative (see requirements). While the requirements 1, 4 and 5 determine the surrounding conditions and seem adequate, requirements 2 and 3 determine the quality of the content of the initiative. The direction they are aiming for looks right, but the formulation is very vague. There is no benchmark for what "supports learnings toward implementing the company's circularity strategies" or "progress within an industry" exactly means. So it can be that this initiative really contributes to improving the main indicator, if taken seriously by an intrinsically motivated company, or that the connection is rather weak if the company is only doing the bare minimum.

Thus, this sub-criterion is evaluated with a 2 – The set-up of the indicator establishes a connection between the indicator and the main indicator but could be improved to strengthen the effect. Adding up the scores of the Effectivity (weighting 1/3) and Efficiency (weighting 2/3), the overall Construct Validity score of this indicator is 2.

Reliability

1) Test-Retest Reliability

The likelihood of accidentally assigning the indicator an incorrect value due to personal circumstances is estimated as very low. The indicator has only two answer possibilities and there is just small number of requirements and required verification documents. The possibilities for opportunistically assigning the indicator an incorrect value are assumed to be big though, as the requirements for the initiative are clear indeed, but lack strict boundaries and normative dimensions. Thus, this sub-criterion is evaluated with a 2 – If determined several times by the same administrator, given the same information, the indicator is somewhat likely to show a different result.

2) Objectivity

Requirement 1 is assumed to be assessable quite objectively, as it requires a yes/no answer that can be checked easily. Requirements 2-4 are assumed to be subject of great subjectivity as formulations like "supports learning", "drives progress" and "allows for adequate voice" are not clearly defined. Their interpretation differs from person to person. Requirement 5 is also quite subjective. To check the timeliness ("within two years") is assumed to be easy and objective, but the term "active participation" is not clearly defined. Thus, this sub-criterion is evaluated with a 1 – If two different administrators got the same input information and determined the indicator at the same time, the indicator is very likely to show a different result. Adding up the scores of the Test-Retest Reliability (weighting 1/3) and Objectivity (weighting 2/3), the overall Reliability score of this indicator is 1.3.

Practicality

1) Time of Determination

The time step 1 takes in the process of determination is excluded from the count. Step 1 is assumed to take around 30 min, step 2 and 3 less than 10 min each and step 4 not more than 5 min. Thus, this sub-criterion is evaluated with a 3 – Takes few time (<1h).

2) Ease of Determination

For determining this indicator, the administrator needs knowledge about the applicant, the applicant's products and the surrounding industry (players). Almost no special skills are required, just reading through documents thoroughly. Thus, this sub-criterion is evaluated with a 2 – Medium hard to determine. Requires some effort and/or some specific knowledge, concentration and logical thinking.

3) Clearness of Language

The indicator's intention is described clearly. The requirements are also somewhat clear, but it would be easier to formulate them as a checklist, and not like three different criteria sets on different hierarchical levels. The underlying indicator and how it is determined are not mentioned in the C2CPII standard, which decreases the clearness of what is measured. Thus, this sub-criterion is evaluated with a 2 – The language used to describe the indicator's intention, requirements and determination is somewhat clear but could be improved. Adding up the scores of the Time of Determination, Ease of Determination and Clearness of Language (all weighted equally), the overall Practicality score of this indicator is 2.3.

Indicator 7: Implementation of a circular design opportunity or innovation

The intention of this support indicator is to increase the product's cyclability through designing more end-of-use cycling opportunities. It has a nominal scale and gives a binary output of yes or no.

Requirements

Table 30: Requirements purport of the circularity design opportunities plan

No.	Required purport
1	Opportunities/innovations receive credit if they contribute to at least one of the following outcomes: a. Increased end-of-use cycling b. Greater engagement with users for end-of-use cycling c. Prolonged use of the product d. Decreased need to extract and produce virgin materials
2	Opportunities/innovations must follow at least one of the following strategies: a. Designed to minimise Material Weight: At least a 10% decrease in material weight or 10% less material than the average product of the same type b. Design Strategy for Prolonging the Use Phase of the Product: Extend the use of the product beyond the most common use phase time for the product type c. Designed for Product as a Service: Designed to be rented or shared among customers of the product d. Designed for Modularity/Upgradability: Product parts are replaceable, and replacement of these parts can be used toward the maintenance, upgrade, or expansion of the product e. Designed for Maintenance, Repair, or Refurbishment Services f. Designed for Manufacturer Recovery and Reuse: Designed for a company take-back program or another company-based recovery initiative

g. Designed for Product Compatibility: Designed for standardisation or compatibility with other parts or products, enabling extension of the use phase of the product)
h. Designed for Remanufacturing: The product's components can be re-used for other applications
i. Designed for Industrial Symbiosis: Designed to utilise waste material from a local manufacturing process (within 160 km or 100 miles)
j. Designed for Extending Resource Value: Designed to incorporate the residual value of otherwise "wasted" materials or resources
k. Designed for Other Innovation: Designed in a way that meaningfully increases circularity

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Process of determination

1. Gather from the applicant:
    a. A document with a description of the circular design opportunity/ innovation.
    b. Documentation on the strategy.
2. Read through the requirements.
3. Check whether the opportunity/innovation meets the requirements.
4. Assign the indicator yes/no.

Construct validity

Overall question: *How far does the implementation of a circular design opportunity or help increase the mass % of high value cyclable content in a product?*

Note: This indicator could also be placed in the first or third cluster as both decreased virgin material use (side effect of the first cluster) and increased end-of-use cycling (goal of the third cluster) are claimed to be one of the goals of this indicator. But as the means (strategies) all refer to adapting the design of the product (so cyclability), this indicator is evaluated in this cluster. This perfectly showcases how the clusters are intertwined: Cyclability is a preparation, almost a necessity for active cycling, and active cycling is producing cycled content for a consecutive product that can be cycled again, in the best case, and so on.

1) Effectivity

Is there a general relation between the implementation of a circular design opportunity or innovation and the mass % of high value cyclable content in a product?

As the term circular design innovation is relatively broad, this depends on its definition. This definition can be found in the requirements, which are assessed in the next sub-criterion. But in general, it is assumed that implementing an innovation in a product that aims for improving its cyclability will potentially increase the mass % of high value cyclable content. One could go even further and argue that a product that is not yet cyclable can only become cyclable through innovating the product. Thus, this sub-criterion is evaluated with a 3 – The general idea behind the indicator is strongly fitting for improving the main indicator.

2) Efficiency

How far does the set-up of the indicator help increase the mass % of high value cyclable content in a product?

For the reasons named above (interlacement of indicator goals with the other clusters), requirement 1 is ignored in this evaluation, the focus is on the strategies. So, the question to be answered needs to be reformulated slightly to *How far does implementing one of the named circular design strategies in a product help increase the mass % of high value cyclable content in a product?*

Analysing the requirements, the following points can be criticised:

1. Strategy 2a and b can also be counterproductive and rather make a product eco-efficient than eco-effective. The applicant could make the product lighter, using fewer virgin materials, or increase the use phase time by two years, without making the product necessarily more circular. Still, the requirement would count as fulfilled then.

2. Strategy 2c should be handled with care and only come together with a circular product design and reasonable manners of exchanging the product. Otherwise, products could get broken or not be handled with care by the customers as for a lack of feeling responsible and thus not contribute to the goals of a circular economy. For example, the applicant could just lease their bikes instead of selling them, without designing them for one of the r-strategies (remanufacture, refurbish, recycle). The engagement with the user for end-of-use cycling would be higher, as the applicant gets those bikes back when the user does not need them anymore. But the bikes are still not more cyclable than before and be potentially thrown away. It is assumed that the C2CPII just assumes an economic interest of the applicant to retain as much value of the bike as possible, and thus to engage in a more cyclable version without external pressure.

3. In all strategies, normative requirements are missing. So, the effect on the mass % of high value cyclable content in a product could be quite strong if for example all product parts are modular. But if only one part is modular and the rest is molten together, the effect is very small. But still the strategy would count as 'in place' so the indicator would be assessed with a yes.

Summing it up, this sub-criterion is evaluated with a 2 – The set-up of the indicator establishes a connection between the indicator and the main indicator but could be improved to strengthen the effect. Adding up the scores of the Effectivity (weighting

1/3) and Efficiency (weighting 2/3), the overall Construct Validity score of this indicator is 2.3.

Reliability

1) Test-Retest Reliability

The likelihood of accidentally assigning the indicator an incorrect value due to personal circumstances is assumed to be medium. The outcome of this indicator is a simple yes or no, but there is no indication on how to measure whether a strategy has been used or a goal has been met, and there is quite some text to read through in the C2CPII standard. So it could be that an administrator gets confused and one day assigns a different result than another. The possibilities for opportunistically assigning the indicator an incorrect value are assumed to be big, as there are no normative boundaries defined. Thus, this sub-criterion is evaluated with a 2 – If determined several times by the same administrator, given the same information, the indicator is somewhat likely to show a different result.

2) Objectivity

This indicator offers a great room for interpretation. Different administrators might assess strategies (and their contribution to the goal) slightly differently. This also depends on the document with the description that they get from the applicant. Thus, this sub-criterion is evaluated with a 2 – If two different administrators got the same input information and determined the indicator at the same time, the indicator is somewhat likely to show a different result. Adding up the scores of the Test-Retest Reliability (weighting 1/3) and Objectivity (weighting 2/3), the overall Reliability score of this indicator is 2.

Practicality

1) Time of Determination

The time step 1 takes in the process of determination is excluded from the count. Step 2 is assumed to take around 20 min, step 3 not more than 30 min and step 4 less than 5 min. Thus, this sub-criterion is evaluated with a 3 – Takes few time (<1h).

2) Ease of Determination

There is not much knowledge required for determining this indicator, just some knowledge about the product and surrounding sub-system, and about circular innovations to evaluate whether the requirements are fulfilled. As for the required skills:

It might be hard for the administrator to determine the border between a yes and a no, and documents need to be studied carefully. The connection needs to be made whether the strategy chosen as an innovation really contributes to one of the goals (even though not specified how this is determined). This takes some effort and requires some concentration and logical thinking. Thus, this sub-criterion is evaluated with a 2 – Medium hard to determine. Requires some effort and/or some specific knowledge, concentration and logical thinking.

3) Clearness of Language

The indicator's intention is clear. The requirements are also quite clearly formulated. But there is no clear definition for the determination of the indicator, the requirements are still open for interpretation (of the border between yes/no). Thus, this sub-criterion is evaluated with a 2 – The language used to describe the indicator's intention, requirements and determination is somewhat clear but could be improved. Adding up the scores of the Time of Determination, Ease of Determination and Clearness of Language (all weighted equally), the overall Practicality score of this indicator is 2.3.

Indicator 8: Mass % of content designed for disassembly

The intention of this support indicator is to increase the likelihood that a large percentage of the materials in the product will be cycled. It has a ratio scale and gives a number between 0-100% as an output.

Requirements

Table 31: Elements required for 90- 99%* of materials by weight to count as easy to disassemble

No.	Condition	Requirement
1	Always	The product includes at least one design feature that improves the ease of disassembly compared to a commonly or previously used alternative product, e.g.: a. Does not require any disassembly to be cycled under the intended cycling pathway b. Uses fewer fasteners c. Decreased number of disassembly operations d. Elimination of destructive processes e. Minimised the number of tools needed to disassemble the product f. Use of detachable/resolvable fasteners g. Full accessibility to critical parts h. Increased automation of disassembly and/or improved other mechanisms for material separation that minimise loss of material

2	Always	Processes that result in the loss of specific materials in the product to recover other materials (e.g., burning plastics to recover metals) must be avoided
3	If disassembly operations not conducted by the applicant	Make comprehensive disassembly instructions publicly available, including: a. A description of each step in the disassembly operation b. Identification of parts and components c. The type of connectors involved d. How to access components and parts e. Tools required for each step
4	If disassembly operations conducted by the general public	Components must be separable using common tools with minimal technical experience and instruction
5	If product contains ≥ 30 homogeneous materials and/or if disassembly is not performed by the consumer	The disassembly process: a. Must be at least semi-automated (e.g., for electronics), or b. Can occur in a reliably consistent manner with clear instructions
6	If: a. Liquid product b. Intermediate product c. Product that does not require separation for the intended cycling pathway	Exempted from all requirements

*Depending on certification level

Process of determination

1. Gather from the applicant:
    a. Bill of materials, including mass concentrations per material.
    b. Explanation of the product design optimisation work that was conducted to implement the design feature(s).
    c. Explanation of how the product is disassembled.
    d. i.a. Disassembly instructions.
    e. i.a. Evidence of the automated disassembly process in place and/or documented standard operating procedure for disassembly operations.
2. Read through the requirements for materials to count as easy to disassemble.
3. Check per material whether it meets the requirements to count as easy to disassemble.
4. Add up the mass concentrations of the materials that meet the requirements.

Construct validity

Overall question: *How far does increasing the mass % of content designed for disassembly in a product help increase the mass % of high value cyclable content?*

1) Effectivity

Is there a general relation between the mass % of content designed for disassembly in a product and the mass % of high value cyclable content?

It is assumed that having a product that is easy to disassemble makes it more cyclable. The easier and quicker components can be disassembled, the better they can be replaced and repaired, and the better homogenous materials can be separated as a preparation for recycling. Thus, this sub-criterion is evaluated with a 3 – The general idea behind the indicator is strongly fitting for improving the main indicator.

2) Efficiency

How far does the set-up of the indicator help increase the mass % of high value cyclable content?

Analysing the requirements, the following points can be criticised:

1. Requirement 1 is only a very soft requirement. Only one design feature needs to be implemented, and it needs to ease the disassembly only compared to other products.
2. Requirement 3 is strict and straight forward, but the usefulness depends on how pleasantly the instructions are designed and presented and where they are published, to give an estimation on whether anybody is going to read them.
3. In requirement 4, it is not clear what "common tools" or "minimal technical experience" mean.

Summing it up: If there is a high intrinsic motivation and the applicant fulfils every requirement to the fullest, the Construct Validity of this indicator can be high. But it is easy to make a material count as easy to disassemble, so low motivated applicants would just fulfil the bare minimum and then the Efficiency is not that high. Thus, this sub-criterion is evaluated with a 2 – The set-up of the indicator establishes a connection between the indicator and the main indicator but could be improved to strengthen the effect. Adding up the scores of the Effectivity (weighting 1/3) and Efficiency (weighting 2/3), the overall Construct Validity score of this indicator is 2.3.

Reliability

1) Test-Retest Reliability

The likelihood of accidentally assigning the indicator an incorrect value due to personal circumstances is assumed to be low, as all requirements are quite clear and presented in a structured way. The possibilities for opportunistically assigning the indicator an incorrect value are assumed to be big, as the main requirement (no. 1) leaves a lot of room for interpretation without the administrator having to justify it. Thus, this sub-criterion is evaluated with a 2 – If determined several times by the same administrator, given the same information, the indicator is somewhat likely to show a different result.

2) Objectivity

The scale level offers only two different outcomes (yes/no), which decreases the general likelihood that different administrators will come to different results. Requirement 1 is very subjective as it is not defined what counts as a design feature or not, the list are only examples. Requirement 4 is quite subjective, assuming that everybody has a different definition of the terms "common tools" and "minimal technical experience". Summing it up, this sub-criterion is evaluated with a 1 – If two different administrators got the same input information and determined the indicator at the same time, the indicator is very likely to show a different result. Adding up the scores of the Test-Retest Reliability (weighting 1/3) and Objectivity (weighting 2/3), the overall Reliability score of this indicator is 1.3.

Practicality

1) Time of Determination

The time step 1 takes in the process of determination is excluded from the count. Steps 2 and 3 are assumed to take around 20 min each, and step 4 around 10 min. Thus, this sub-criterion is evaluated with a 3 – Takes few time (<1h).

2) Ease of Determination

For determining this indicator, knowledge about the product and the industry is required, as well as some knowledge about physical/chemical material properties. Some concentration is necessary to add up the numbers. Thus, this sub-criterion is evaluated with a 2 – Medium hard to determine. Requires some effort and/or some specific knowledge, concentration and logical thinking.

3) Clearness of Language

The indicator's intention is clearly formulated. The requirements are quite clearly formulated, too, but sometimes still open for interpretation (requirements 1+4). The indicator and how it is determined is not mentioned like that in the C2CPII standard. Thus, this sub-criterion is evaluated with a 2 – The language used to describe the indicator's intention, requirements and determination is somewhat clear but could be improved. Adding up the scores of the Time of Determination, Ease of Determination and Clearness of Language (all weighted equally), the overall Practicality score of this indicator is 2.3.

Appendix 4: In depth indicator assessment of cluster 3

Indicator 9: Active cycling rate

The intention of this main (determination) indicator is to keep the product in high quality cycles as long as possible. It has a ratio scale and a number between 0-100% as an output.

Requirements

Table 32: Requirements and specifications when calculating the active cycling rate

No.	Condition	Requirement
1	Always	Formula to calculate the active cycling rate: %AC = TWC/TWS • TWC = Total weight of the product or its components and materials cycled pre-processing (after collecting and sorting, not the weight of recovered material) • TWS = Total weight of products sold in (recent reference year – L) • Recent reference year = The most recent full calendar or fiscal year for which data are available • L = the product's estimated average use phase time (e.g., based on warranties, public marketing claims, or quality tests)
2	When calculating the TWC and TWS	Obtain representative sales and recovery weights for every region where the product is sold (at a minimum representing 60% of sales)
3	If product cycled via a manufacturer or third-party take-back program	Active cycling if the following are provided: a. Document verifying that active cycling is actually occurring via the chosen intended cycling pathway(s) b. If not possible to differentiate between the applicant product and others that are collected through the program → Description of how the products collected are all of the same type and fulfil the same function as the applicant product c. Description of the partnership companies involved in the recovery and processing of materials in the product (provide a statement on a website or an active contract)
4	If product can be cycled via municipal systems	Active cycling if the following are provided: a. Evidence of the municipal program's existence in the applicable region(s) in which the product is sold b. Description of how product(s) of the same type are recycled through the program(s) Data on cycling rates for the product type in the sale regions can be used + product's sales weight in each region in which data are available
5	If intermediate product or liquid formulation	Exempted from all requirements

Process of determination

1. Gather from the applicant:

    a. Product use phase time (L).
    b. Total weight of products sold in (recent reference year — L) (TWS).
    c. Total weight of product parts that are cycled in a reference year (TWC).
    d. Information and verification of product use phase time.
    e. Verification by the company that active cycling is actually occurring via the chosen intended cycling pathway.
    f. i.a. Description of how the products collected are all of the same type and fulfil the same function as the applicant product.
    g. i.a. Description of the partnership companies involved in the recovery and processing of materials in the product.
    h. i.a. Evidence of the municipal program's existence in the applicable region(s) in which the product is sold.
    i. i.a. Description of how the product(s) of the same type are recycled through the program(s).
    j. Description of the method used for tracking the cycling rates or quality of the product.

2. Read through the requirements for calculating the active cycling rate.

3. Read through the high value cycling requirements.

4. Check whether materials claimed to be actively cycled do meet the requirements defined for calculating the active cycling rate and the high value cycling requirements.

5. Determine the active cycling rate: %AC =TWC/TWS.

6. Determine product quality.

Construct validity

Overall question: *How far does increasing the active cycling rate of the product help in keeping the product in healthy, high quality cycles as long as possible?*

1) Effectivity

Is there a general relation between the active cycling rate and the goal of keeping the product in high quality cycles as long as possible?

In general, it is assumed that there is a strong connection. Having active cycling can actually be defined as keeping the product in high quality cycles as long as possible. Thus, this sub-criterion is evaluated with a 3 – The general idea behind the indicator is strongly fitting for achieving the main goal.

2) Efficiency

How far does the set-up of the indicator support the main goal of keeping the product in healthy, high quality cycles as long as possible?

Analysing the requirements, the following point scan be addressed:

1. Requirement 3: What should this document include? Normative requirements are missing.
2. Most crucial: Where is written that downcycling is forbidden? Indeed, the product must be high value cyclable (in theory), but where is described that the product must still not be downcycled in practice?

Summing it up, this sub-criterion is evaluated with a 1 – The set-up of the indicator does only establish a weak connection between the indicator and the main goal. Adding up the scores of the Effectivity (weighting 1/3) and Efficiency (weighting 2/3), the overall Construct Validity score of this indicator is 1.7.

Reliability

1) Test-Retest Reliability

The likelihood of accidentally assigning the indicator an incorrect value due to personal circumstances is assumed to be medium. The requirements are clearly stated, but the structuring of the chapter and the amount of input information is likely to result in some confusion of the administrator. The possibilities for opportunistically assigning the indicator an incorrect value are also assumed to be medium, as the basis of this indicator is a mathematic formula that is clearly defined and described. Still, at requirements 3 and 4 there is some room for interpretation. Thus, this sub-criterion is evaluated with a 2 – If determined several times by the same administrator, given the same information, the indicator is somewhat likely to show a different result.

2) Objectivity

The scale level offers a wide range of possible outputs, so the general likelihood of different outcomes per administrator is increased. Requirements 3 and 4 are open for interpretation, so subjective. Thus, this sub-criterion is evaluated with a 2 – If two different administrators got the same input information and determined the indicator at the same time, the indicator is somewhat likely to show a different result. Adding up the scores of the Test-Retest Reliability (weighting 1/3) and Objectivity (weighting 2/3), the overall Reliability score of this indicator is 2.

Practicality

1) Time of Determination

The time step 1 takes in the process of determination is excluded from the count. Steps 2 and 3 are assumed to take around 10 min each, step 4 around 30 min and step 5 around 15 min. Thus, this sub-criterion is evaluated with a 2 – Takes medium time (1h-1d).

2) Ease of Determination

Knowledge is required about what active cycling in the intended cycling pathways means, about the industry and recycling technologies to assess the usefulness of potential cycling partners, and about municipal cycling technologies. Also, knowledge about what is a useful method for tracking product quality is needed. Skills in Microsoft Excel are necessary to do calculations, as well as the ability to read through documents thoroughly. Thus, this sub-criterion is evaluated with a 1 – Very hard to determine. Requires a lot of skills and/or specific knowledge, concentration and logical thinking.

3) Clearness of Language

The indicator's intention is clear. Requirements 1 and 2 are clearly defined, while requirements 3 and 4 are not that clearly structured and formulated. It is very clear how the indicator is determined. Thus, this sub-criterion is evaluated with a 2 – The language used to describe the indicator's intention, requirements and determination is somewhat clear but could be improved. Adding up the scores of the Time of Determination, Ease of Determination and Clearness of Language (all weighted equally), the overall Practicality score of this indicator is 1.7.

Indicator 10: Development of product cycling plan

The intention of this support indicator is to ensure that the applicant is aware of all barriers to enable a cycling according to the intended cycling pathways. It has a nominal scale and gives a binary output of yes or no.

Requirements

Table 33: Requirements for the product cycling plan

No.	Condition	Requirement
1	Always	Formulate discrete planned actions and an associated timeline
2	If NOT intermediate or wet-applied product AND IF product is NOT intended to be cycled via municipal systems/addressed by regional product stewardship laws	Identify potential partners or internal resources for product recovery and processing in accordance with the intended cycling pathway(s), covering a region accounting for 60% or more of product sales.
3	If intermediate or wet-applied product	Address challenges inhibiting development of the cycling infrastructure for at least one finished product/applied substrate example application
4	If product contains electronic components	Address the recovery and recycling of intentionally used scarce elements as defined in the European Commission Critical Raw Materials list

Process of determination

1. Gather from the applicant:
    a. Product cycling plan.
    b. Evidence of partnership(s).
    c. Calculations used to determine that the required area or percentage of sales is covered by the partnership(s).
2. Read through the requirements.
3. Check whether the provided documents meet the requirements.
4. Assign the indicator yes/no.

Construct validity

Overall question: *How far does the development of a product cycling plan help increase the active cycling rate?*

1) Effectivity

Is there a general relation between the development of product cycling plan and the active cycling rate?

The goal of the product cycling plan, according to the C2CPII standard, is to get aware of and remove all barriers for active cycling, and thus achieving a high active cycling rate. Thus, there is a high correlation between the two indicators and this sub-criterion is evaluated with a 3 – The general idea behind the indicator is strongly fitting for improving the main indicator.

2) Efficiency

How far does the set-up of the indicator help increase the active cycling rate?

This depends on the content of the plan (see requirements). The following things can be criticised about it:

1. For requirement 1-3, the normative implications are missing.
2. Requirement 4 does not explicitly contribute to the goal but doesn't hinder it either.
3. What is missing is an anticipation of challenges for all products, and how to overcome those.

Thus, this sub-criterion is evaluated with a 2 – The set-up of the indicator establishes a connection between the indicator and the main indicator but could be improved to strengthen the effect. Adding up the scores of the Effectivity (weighting 1/3) and Efficiency (weighting 2/3), the overall Construct Validity score of this indicator is 2.3.

Reliability

1) Test-Retest Reliability

The likelihood of accidentally assigning the indicator an incorrect value due to personal circumstances is assumed to be low, as the indicator has a binary output, and the requirements are quite clearly formulated. The possibilities for opportunistically assigning the indicator an incorrect value are assumed to be large. All requirements offer room for interpretation as there are no strict boundaries and normative dimensions. Thus, this sub-criterion is evaluated with a 2 – If determined several times by the same administrator, given the same information, the indicator is somewhat likely to show a different result.

2) Objectivity

Even though it is a binary indicator and there are clear requirements formulated for the assessment of the plan, it is likely that different administrators will interpret those requirements (or rather the normative implications, thus the boundary when a no becomes a yes) differently. Thus, this sub-criterion is evaluated with a 1 – If two different administrators got the same input information and determined the indicator at the same time, the indicator is very likely to show a different result. Adding up the scores of the Test-Retest Reliability (weighting 1/3) and Objectivity (weighting 2/3), the overall Reliability score of this indicator is 1.3.

Practicality

1) Time of Determination

The time step 1 takes in the process of determination is excluded from the count. Steps 2 and 3 are assumed to take around 20 min each, and step 4 around 5 min. Thus, this sub-criterion is evaluated with a 3 – Takes few time (<1h).

2) Ease of Determination

For determining this indicator, knowledge is required about which actions are useful for increasing the cycling rate, what is a realistic timeline, which are good potential partners, which are valid potential challenges and what are scarce elements. As skills, it is required to be able to read through documents thoroughly. Thus, this sub-criterion is evaluated with a 2 – Medium hard to determine. Requires some skills and/or some specific knowledge, concentration and logical thinking.

3) Clearness of Language

The indicator's intention is clearly formulated. The requirements are also clear, but the structure is quite confusing in this subcategory. There is no information about how the indicator is determined. Thus, this sub-criterion is evaluated with a 2 – The language used to describe the indicator's intention, requirements and determination is somewhat clear but could be improved. Adding up the scores of the Time of Determination, Ease of Determination and Clearness of Language (all weighted equally), the overall Practicality score of this indicator is 2.3.

Indicator 11: Implemented infrastructure for active cycling

The intention of this support indicator is to ensure that the applicant has implemented an infrastructure to enable the active cycling of their product. It has a nominal scale and gives a binary output of yes or no.

Requirements

Table 34: Requirements for the infrastructure for active cycling

No.	Condition	Requirement
1	If product stewardship law/program for product type in place	No further requirements. Assure that the program covers ≥60% of the product sales area
2	If municipal cycling is one intended cycling pathway	Assure compatibility with municipal cycling systems for ≥60% of product sales area

3	Else	Initiate partnership(s) or dedicate internal resources for product recovery and processing (proof with active contract) which cover ≥60% of product sales area

Process of determination

1. Gather form the applicant information about absolute sales of the product per region in a reference year.
2. Determine how much % of the product is sold in which region.
3. Check whether there is a product stewardship law/program in place for that product type:
   a. If not, check with indicator "% of number of homogenous materials with one (two) defined intended cycling pathways" whether municipal cycling is one intended cycling pathway
      i. If yes
         1. Gather from the applicant information about the exact intended municipal cycling system.
         2. Check whether the product is compatible with those municipal cycling system.
         3. Check in which of the regions the intended municipal cycling is implemented, add up those percentages and check whether this number is ≥60%.
      ii. If not
         1. Gather from the applicant a list with established partnerships (verified by contracts).
         2. Check which of the regions are covered by those partnerships, add up those percentages and check whether this number is ≥60%.
4. Assign the indicator yes/no.

Construct validity

Overall question: *How far does the implementation of an infrastructure for active cycling help increase the active cycling rate?*

1) Effectivity

Is there a general relation between the implemented infrastructure for active cycling and the active cycling rate?

The general idea of establishing an infrastructure for enabling active cycling is valid. Without a respective infrastructure and partners who are part of the value chain, active cycling is almost impossible. Thus, this sub-criterion is evaluated with a 3 – The general idea behind the indicator is strongly fitting for improving the main indicator.

2) Efficiency

How far does the set-up of the indicator help increase the active cycling rate?

The idea to differentiate between three different ways of doing so makes sense. The following can be criticised though:

1. For requirement 3, there are no normative requirements for the quality of the partners (which partners count, which do not?).
2. There is information missing on how far it is considered which parts of the product have to be covered by the stewardship program/municipal cycling systems/implemented partnerships. It might be that one part can be cycled by the municipality/a partner (a screw for example), but the rest is not compatible.

Thus, this sub-criterion is evaluated with a 2 – The set-up of the indicator establishes a connection between the indicator and the main indicator but could be improved to strengthen the effect. Adding up the scores of the Effectivity (weighting 1/3) and Efficiency (weighting 2/3), the overall Construct Validity score of this indicator is 2.3.

Reliability

1) Test-Retest Reliability

The likelihood of accidentally assigning the indicator an incorrect value due to personal circumstances is assumed to be low, as there is a binary output, and the input information is quite clear. The opportunity for opportunistically assigning the indicator an incorrect value is assumed to be high for requirement 3, as normative indications are missing (what is a good partner? when do they count?). Thus, this sub-criterion is evaluated with a 2 – If determined several times by the same administrator, given the same information, the indicator is somewhat likely to show a different result.

2) Objectivity

Requirement 3 lacks normative dimensions (when is a company a suitable partner and when not?) and thus is assumed to be highly subjective. Thus, this sub-criterion is evaluated with a 2 – If two different administrators got the same input information and determined the indicator at the same time, the indicator is somewhat likely to show a different result. Adding up the scores of the Test-Retest Reliability (weighting 1/3) and Objectivity (weighting 2/3), the overall Reliability score of this indicator is 2.

Practicality

1) Time of Determination

The time step 1 takes in the process of determination is excluded from the count. Step 2 is assumed to take around 10 min, step 3 around 5 min, step 3a around 5 min, too, step 3ai2 and 3ai3 are assumed to take 20 min, and step 4 not more than 5 min. Thus, this sub-criterion is evaluated with a 3 – Takes few time (<1h).

2) Ease of Determination

For determining this indicator, knowledge is required about the product and the industry (and recycling industry) to evaluate whether the chosen partners count. Basic calculation skills and some concentration are necessary for calculating whether the required area is covered. Thus, this sub-criterion is evaluated with a 2 – Medium hard to determine. Requires some skills and/or some specific knowledge, concentration and logical thinking.

3) Clearness of Language

The indicator's intention is clearly formulated. The structure of the requirements in the C2CPII standard is somewhat confusing, they are not listed in an order that is easy to understand. Also, just very few information is given at all. There is no information about the exact indicator determination. Thus, this sub-criterion is evaluated with a 2 – The language used to describe the indicator's intention, requirements and determination is somewhat clear but could be improved. Adding up the scores of the Time of Determination, Ease of Determination and Clearness of Language (all weighted equally), the overall Practicality score of this indicator is 2.3.

Indicator 12: Public availability of cycling instructions

The intention of this support indicator is to ensure that entities other than the applicant are able to actively cycle the product, so the active cycling rate is increased. It has a nominal scale and gives a binary output of yes or no.

Requirements

Table 35: Requirements for cycling instructions

No.	Requirement

1	Include information on how to identify the materials for cycling
2	Include information on any required product maintenance
3	Include information on how to recover, reprocess, or recycle the product
4	Report the instruction with the Cradle to Cradle Certified® Circularity Data Report or another C2CPII-recognised circularity reporting standard
5	Make the instructions publicly available
6	Products for the biological cycle and for which no intervention is needed to ensure active cycling are exempted from all requirements (e.g., soaps, personal care products, and cosmetics)

Process of determination

1. Check whether the product is entirely designated for the biological cycle and no active cycling is needed.
2. If not, gather form the applicant:
    a. Filled-in Cradle to Cradle Certified® Circularity Data Report.
    b. Evidence of public availability.
3. Read through the requirements.
4. Check whether all information is valid and whether the requirements have been fulfilled sufficiently.
5. Assign the indicator yes/no.

Construct validity

Overall question: *How far does making cycling instructions for the product publicly available help increase the active cycling rate?*

1) Effectivity

Is there a general relation between the public availability of cycling instructions and the active cycling rate?

It is assumed that the general idea is valid. Without knowing how, a product cannot be actively cycled. Thus, this sub-criterion is evaluated with a 3 – The general idea behind the indicator is strongly fitting for improving the main indicator.

2) Efficiency

How far does the set-up of the indicator help increase the active cycling rate?

The requirements and the referred document (there are currently no other C2C-recognised circularity data reporting standards) look very exhaustive and like a valid way of giving cycling instructions. There is no assessment of whether the cyclability is good or not though, just whether the cycling instructions are there or not. But assuming that the existence of cycling instructions is the only, main point of this indicator, this flaw can be neglected. The only thing to criticise that it is not accounted for how and where the instructions are made available. If they are just on the website of the C2CPII (as it looks like), then it takes some effort to look them up, download them and read them. Also, the document and Microsoft Excel file are not that easy to read for a common person. So, an improved set-up of the displayed information and a place where it is easily assessable would make the instructions more useful.

Thus, this sub-criterion is evaluated with a 2 – The set-up of the indicator establishes a connection between the indicator and the main indicator but could be improved to strengthen the effect. Adding up the scores of the Effectivity (weighting 1/3) and Efficiency (weighting 2/3), the overall Construct Validity score of this indicator is 2.3.

Reliability

1) Test-Retest Reliability

The likelihood of accidentally assigning the indicator an incorrect value due to personal circumstances is assumed to be low, as there is a binary output and the data form by the C2CPII gives quite clear, straight forward and hard boundary instructions on what to report. The opportunity for opportunistically assigning the indicator an incorrect value is also assumed to be low, as the assessment is just on whether the form has been filled out neatly, and this can be checked easily and transparently. Thus, this sub-criterion is evaluated with a 3 – If determined several times by the same administrator, given the same information, the indicator is likely to show the same result.

2) Objectivity

In this indicator, there is almost no room for interpretation. There is just an assessment of whether the form has been filled out neatly, but this can be checked objectively and without much room for variation. Thus, this sub-criterion is evaluated with a 3 – If two different administrators got the same input information and determined the indicator at the same time, the indicator is likely to show the same result. Adding up the scores of the Test-Retest Reliability (weighting 1/3) and Objectivity (weighting 2/3), the overall Reliability score of this indicator is 3.

Practicality

1) Time of Determination

It is assumed that step 1 takes less than 5 min. The time step 2 takes in the process of determination is excluded from the count. Step 3 is assumed to take around 5 min, step 4 not more than 20 min and step 5 around 5 min. Thus, this sub-criterion is evaluated with a 3 – Takes few time (<1h).

2) Ease of Determination

There is no specific knowledge required for determining this indicator. It just needs to be checked whether the form is filled in in a reasonable manner, thus the only required skill is being able to read thoroughly through documents. Thus, this sub-criterion is evaluated with a 3 – Easy to determine. Requires almost no skills or specific knowledge and just very few concentration and logical thinking.

3) Clearness of Language

Both the indicator's intention, the requirements and the indicator determination are clearly formulated. Thus, this sub-criterion is evaluated with a 3 – The language used to describe the indicator's intention, requirements and determination is very clear and easy to understand. Adding up the scores of the Time of Determination, Ease of Determination and Clearness of Language (all weighted equally), the overall Practicality score of this indicator is 3.

Indicator 13: Implementation of program to increase cycling rates or product quality

The intention of this alternative indicator is to increase the active cycling rate and improve the cycling quality. It has a nominal scale and gives a binary output of yes or no.

Requirements

Table 36: Requirements for the program to increase cycling rates

No.	Condition	Requirement
1	Always	The program must lead to a measurable improvement in the indicator "active cycling rate" or in the cycling quality, based on the requirements for high-value cycling (see above)

2	If circular accounting is the chosen strategy	The applicant must invest in a system that facilitates tracking of product cycling, e.g.: a. RFID tracking b. Targeting waste management inefficiencies in the recycling stream c. Implementing a system for tracking take-back rates of products in the company d. Implementing a leasing program where products are tracked by leasing ownership e. If product cycled through municipal systems → Determine the recycling/composting rates of product, based on state or regional statistics if available
3	If circular incentives are the chosen strategy	The applicant must incentivise the user to cycle the product, or must contribute to a program that increases the cycling activity, e.g.: a. Providing a monetary incentive to customers to cycle the product b. Developing a product-as-a-service program
4	Else	Examples of other programs that are recognised: - Increasing the scale of the cycling program (e.g., through TerraCycle) - Initiating an additional partnership for take-back - Increasing engagement with partners involved in cycling (e.g., expansion of take-back program to other communities)
5	If use-phase time is >1 year	Determining this indicator is optional
6	Always	Track and monitor influence on active cycling rate and product quality over time

Process of determination

1. Gather from the applicant:
    a. A description of the program that has been implemented to increase cycling rates or quality, and how it will do so.
    b. A description of the method used for tracking the cycling rates or quality of the product.
2. Read through the requirements.
3. Check whether the documents meet the requirements.
4. Assign the indicator a yes/no.

Construct validity

Overall question: *How far does implementing a program to increase the cycling rates and product quality help increase the active cycling rate?*

1) Effectivity

Is there a general relation between the implementation of a program to increase the cycling rates or product quality and the active cycling rate?

The only purpose of this program is to increase the cycling rates and the product quality, so yes, there is a strong connection between the two indicators. Thus, this sub-criterion is evaluated with a 3 – The general idea behind the indicator is strongly fitting for improving the main indicator.

2) Efficiency

How far does the set-up of the indicator help increase the active cycling rate?

This depends on the quality of the program (see requirements). The following things can be criticised about it:

1. The named examples of recognised programs are likely to help achieving the goal of this cluster, but only if applied in an effective way. For example, an applicant could have an incentivised take-back program no one knows about. That would result in no effect, even though the criterium would count as fulfilled for the C2CPII.

2. The requirements are just named examples. In theory, the applicant could come up with a totally different program and no one knows whether this will be accredited or not. So, no one knows whether this program is valid.

3. It seems questionable to exclude products of a use-phase time of >1 year from the requirements.

Thus, this sub-criterion is evaluated with a 2 – The set-up of the indicator establishes a connection between the indicator and the main indicator but could be improved to strengthen the effect. Adding up the scores of the Effectivity (weighting 1/3) and Efficiency (weighting 2/3), the overall Construct Validity score of this indicator is 2.3.

Reliability

1) Test-Retest Reliability

The likelihood of accidentally assigning the indicator an incorrect value due to personal circumstances is assumed to be medium. There is a binary output, but no boundary is defined how much the program needs to increase the active cycling rate/product quality (just increase it at all?). Requirement 5 is not directly required for calculating the indicator, it is more an add-on/follow up. But there is no indication of how the product quality should be tracked at all. The opportunity for opportunistically assigning the indicator an incorrect value is also assumed to be medium. The defined programs are clear, but what if there is a program that is not in the list? Maybe the administrator would count it one day when it is fitting and another not, when it is not fitting him anymore. Thus, this sub-criterion is evaluated with a 2 – If determined several times by the same administrator, given the same information, the indicator is somewhat likely to show a different result.

2) Objectivity

In requirement 1, it is not clear what “measurable improvement” means, so there is quite some room for interpretation. Requirements 2-4 are easy to check, but the boundary is unclear (from no to a yes). Also, there is no indication about which criteria other programs have to follow that are not in the example list. Requirement 6 leaves a lot of room for interpretation as there is no tool explained or information given on how to measure the product quality. Thus, this sub-criterion is evaluated with a 1 – If two different administrators got the same input information and determined the indicator at the same time, the indicator is very likely to show a different result. Adding up the scores of the Test-Retest Reliability (weighting 1/3) and Objectivity (weighting 2/3), the overall Reliability score of this indicator is 1.3.

Practicality

1) Time of Determination

The time step 1 takes in the process of determination is excluded from the count. Step 2 is assumed to take around 15 min, step 3 around 30 min and step 4 around 5 min. Thus, this sub-criterion is evaluated with a 3 – Takes few time (<1h).

2) Ease of Determination

For determining this indicator, knowledge is required about what the factors potentially increasing the product quality and cycling rate are, and what a good way of tracking product quality is. As a skill, it is required to be able to read documents thoroughly and check calculations. Thus, this sub-criterion is evaluated with a 2 – Medium hard to determine. Requires some skills and/or some specific knowledge, concentration and logical thinking.

3) Clearness of Language

The indicator’s intention is clearly formulated, the language used for the requirements is medium clear and on the determination of the indicator, there is just very few information. Thus, this sub-criterion is evaluated with a 2 – The language used to describe the indicator’s intention, requirements and determination is somewhat clear but could be improved. Adding up the scores of the Time of Determination, Ease of Determination and Clearness of Language (all weighted equally), the overall Practicality score of this indicator is 2.3.