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Development of a Product Circularity Indicator Suitable for the EPD-scheme of Construction Products

A Review of Product Circularity Indicators and their Potential Applicability in EPDs for the Construction Sector.

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Abstract

(English)

A change in resource consumption patterns is crucial to avoid climate change, reduce greenhouse gas (GHG) emissions and to increase climate resilience and consequently, the idea of a circular economy (CE) has gained widespread attention. The resource intense building and construction sector has become subject to both internal and external pressure to become more circular. Throughout the sector, the environmental product declaration (EPD) is often used to communicate environmental and sustainability information about products but currently, the EPD lacks the inclusion of specific circularity information. This thesis aims to identify a suitable indicator for measuring the product circularity of construction products that can be implemented into the existing EPD-scheme. The study is based on an extensive literature review, qualitative interviews with green building councils (GBCs) and expert discussions with the ECO Platform task group for CE. The identified product circularity indicators have been assessed against a certain set of subjects and criteria to evaluate their inclusion of circularity subjects as well as their suitability to the EPD. The assessment identified two indicators scoring the highest, the Material Circularity Indicator (MCI) and the New Circularity Index (NCI). These indicators were included in a short pilot study to further evaluate their usability and applicability. The study concludes that both indicators are suitable for inclusion in the EPD-scheme to some extent, but they both lack a full inclusion of the end of life (EoL) stage. These subjects must be covered to ensure inclusion of comprehensive circularity information but nevertheless, the MCI and the NCI remains the best options.

Keywords: *Circular Economy, Product Circularity, Indicator, EPD, Construction Products, Green Buildings*

Sammanfattning

(Swedish)

För att undvika klimatförändringar, minska utsläppen av växthusgaser och öka samhällets resiliens måste användandet av naturresurser förändras. I samband med en ny syn på resursanvändning har idén om en cirkulär ekonomi fått stor uppmärksamhet. Både interna och externa krav har ökat på den resursintensiva byggsektorn att bli mer cirkulär. I byggsektorn används ofta miljövarudeklarationer (EPD) för att kommunicera miljö- och hållbarhetsinformation om produkter. Idag saknar dock EPD-systemet specifik information om produkters cirkuläritetsprestanda. Detta examensarbete syftar därför till att identifiera en indikator som är lämplig för att mäta produktcirkuläritet hos byggprodukter och som kan implementeras i det befintliga EPD-systemet. Studien är baserad på en omfattande litteraturstudie och kvalitativa intervjuer med Green Building Councils (GBC) samt expertdiskussioner med ECO Platforms arbetsgrupp för cirkulär ekonomi. Ett antal identifierade indikatorer för produktcirkuläritet har utvärderats mot ett antal kriterier framtagna av arbetsgruppen. Målet var att utvärdera deras respektive inkludering av cirkuläritet samt deras lämplighet i förhållande till en EPD. De två indikatorer som fick högst poäng, Material Circularity Indicator (MCI) och New Circularity Index (NCI), inkluderades i en pilotstudie för att utvärdera deras användbarhet och tillämpbarhet i praktiken. Studien drar slutsatsen att båda indikatorerna är lämpliga för att inkluderas i EPD-systemet till en viss utsträckning. Dock saknar de båda en fullständig inkludering av cirkuläritetsperspektiv som täcker produktens slutskede i livscykeln. Dessa perspektiv är av stor vikt för att säkerställa framförandet av fullständig cirkuläritetsinformation. Trots detta visar studien att MCI och NCI är de indikatorer som utgör de bästa alternativen för att integreras i en EPD.



Nyckelord: *Cirkulär Ekonomi, Produktcirkuläritet, Indikator, EPD, Byggprodukter, Hållbara Byggnader*

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Abbreviations

CE – Circular Economy

EPD – Environmental Product Declaration

ISO – International Standardization Organization

LCA – Life Cycle Assessment

EU – European Union

US – United States

UN – United Nations

UNFCCC – United Nations Framework Convention on Climate Change

SDGs – Sustainable Development Goals

GBC – Green Building Council

BREEAM – Building Research Establishment Environmental Assessment Method

DGNB – The German Sustainable Building Council

LEED – Leadership in Environmental Design

USGBC – United States Green Building Council

CEAP – Circular Economy Action Plan

1. Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) secretariat (2022) is the parent treaty of the Paris Agreement. It argues that a change in resource consumption patterns is crucial to avoid a threatening climate change, reduce greenhouse gas (GHG) emissions and to increase climate resilience. The unsustainable consumption- and production patterns of our society are the culprits of the crisis that we are facing and changing them is essential to achieve a sustainable future and secure human well-being. (UN, 2022) The relationship between the extensive resource use and the waste production that they have resulted in constitutes an immense and complex challenge. Waste is a global problem that contributes significantly to climate change through its emissions and is rooted in an unsustainable system of consuming and producing products which requires a radical shift in resource management and use. (Singh et al, 2014)

The industry of material production is emission heavy and the second fastest growing sector. (Dhakal et al., 2022) Because of the extraction, growing, and processing of raw materials that are transformed into products and infrastructure, the sector is responsible for over 30 % of the global GHG emissions. (Thunberg, 2022) Due to economic growth, consumption, rapid increasing urban populations and infrastructure development, there has been a rising demand on materials such as cement, steel, aluminum, and plastics. (Dhakal et al., 2022) The production of these materials is highly carbon dioxide (CO₂) intense, drives climate change, pollutes water, and causes human health issues. As such, this urgently calls for a more regenerative and circular production system, with less consumption and a reliance on new ways to derive economic values. (Thunberg, 2022)

Consequently, the idea of a system built on circularity has gained more widespread attention. (IRP, 2017) The transition to a regenerative growth model such as the circular economy (CE) is seen as essential to minimize both waste and the dependance on virgin material sources and would pose as a central strategy to support a sustainable development. (European Commission, n.d.a.) The implementation of CE into policy making can be seen in various shapes around the world at the time being. One example is in the US, where the Environmental Protection Agency, has incorporated the CE approach into their overall strategy, also including goals striving towards an improved recycling system. (EPA, 2019) Another is the “New circular economy action plan 2020” in the European Union (EU) which considers a wide range of aspects based in a CE and, as such, targets a variety of areas of improvement. (European Commission, 2020) Moreover, in China, CE is incorporated as a law where the main aspect of circularity is focusing on resource use, technologies and protection of the environment. (Congressional-Executive Commission on China, 2013) All of these policy examples include objectives towards more circular resource use and product system. However, even though the CE is implemented in policies around to world in various ways, policies focused on CE are notably fewer than those focused on recycling. (Pathak et al., 2022) Also, these policies generally vary in their

level of provision of sufficient guidance on how to measure the alignment of particular products with circularity principles.

The need for improved product circularity is particularly evident in the resource intense and continuously expanding construction sector. The construction sector tends to devour massive amounts of resources resulting in high GHG emissions and oftentimes embodies a short-sighted perspective on consumption. Therefore, the construction sector has become subject to internal as well as external pressure to become more circular using a variety of approaches. (UNEP, 2021) Several of the proposed main areas of interest for improvement within the building sector are therefore related to resource efficiency, durability, and circular construction materials, highlighting the need for actions relating to prevention of waste through recyclability, reuse, and refurbishment. (Haigh et al., 2021) As such, guidelines on how to measure product circularity would therefore be of great value for the sector to manage the incorporation of a circular approach to a greater extent. A tool that is frequently used within the construction sector to document the environmental sustainability of a product is the Environmental Product Declaration (EPD). The EPD records the environmental impact of a given product throughout its life cycle in a quantitative manner. Along with an increased demand on including life cycle assessments (LCA) for buildings in both practice and policies, the use of EPDs is evidentially increasing as well. (Hauschild et al., 2018) However, although these documents present comprehensive information concerning products environmental performance, they do not currently include information of the product circularity performance.

1.1. The ECO Platform Approach

Through an internship at Ramboll, this thesis is written in collaboration with the ECO Platform Aisbl¹, hereby referred to as the ECO Platform. The ECO Platform is the umbrella organization of national EPD program operators. The mission of ECO Platform is to promote and to contribute to the sustainable development of the building and construction sector. This is accomplished by coordinating the development and provision of credible and scientifically correct environmental data from products to inform designers of construction works and regulators.

In 2020, the European Commission adopted the New Circular Economy Action Plan (CEAP) which is one of the main building blocks of the New Green Deal, the European agenda for sustainable growth. The CEAP aims to reach a high potential for circularity by focusing on sectors with a high potential for reduction of emissions. Within these focuses the CEAP presents initiatives throughout the whole life cycle of products. It targets design, CE processes, sustainable consumption as well as prevention of waste and keeping resources within the European economy for as long as possible. The plan introduces both legislative and non-legislative measures targeting the areas with the potential to bring

¹ www.eco-platform.org

real added value at an EU level and contribute to the implementation of a circularity perspective into the system. Along with public measures, the plan also supports private sector instruments, such as Green Building Councils (GBCs), to include circularity aspects into assessments. (European Commission, 2020)

The ECO Platform actively supports the work of the CEN/TC 350 – Sustainability of Construction Works committee of the European Commission. Their endeavor is to develop horizontal standardized methods for assessing the sustainability aspects of new and existing construction works in the context of the UN Sustainable Development Goals (SDGs) and the CE. The standardized methods support the coherent assessment of sustainability of construction works, including environmental, social, and economic performance of buildings and civil engineering works, and the provision of environmental information of construction products. This includes:

- **Environmental performance assessment**, e.g., circularity principles (the CE in the construction sector), energy efficiency and decarbonization, sustainable use of resources (resource efficiency, waste minimization), protection of the environment and biodiversity;
- **Social performance assessment**, e.g., health and comfort, safety and security, adaptability and accessibility in response to user needs, resilience against external events such impact of climate change, sourcing of materials;
- **Economic performance assessment**, e.g., life cycle cost, whole life costs and impact on economic value, 'green finance' initiatives (taxonomy).

As legislative and non-legislative measures continue to focus on the building and construction sector, manufacturers of construction product will need to further align their business models with the principles of a CE. However, questions remain on how to discern whether the materials of a given product align with circular values. The ECO Platform aim to close this gap by providing a generally recognized method that helps manufacturers to assess how well their products/product materials align with the CE principles of minimal waste and enhanced reuse value. Furthermore, it aims to integrate verifiable circularity information into the EPD-scheme, providing a more comprehensive and accurate picture of the overall sustainability credentials of a construction product.

The goal is to provide a globally accepted standard for the circularity assessment of construction products, complying with the different international regulatory and non-regulatory (e.g., green building rating schemes) developments and requirements. For this purpose, the ECO Platform has established an internal working group consisting of representatives of its member organizations, including EPD program operators, industry associations and construction products manufacturers. As a full member of this working group, the author of this master thesis was tasked with:

- Conducting a desk study to identify science-based CE assessment methodologies for circularity indicators
- Developing and aligning the criteria used to evaluate existing CE methodologies regarding their suitability for construction products within the framework of the EPD program
- Conducting the evaluation of existing CE methodologies against developed criteria
- Preparing and monitoring test calculations with selected companies within the building materials industry
- Analyzing strengths and weaknesses of the CE methodologies based on the test calculations and the objectives of the working group

These tasks were designed to support the achievement of the research objectives listed in the following section.

1.2. Thesis Goal and Objectives

The overarching goal of this thesis is to identify a scientifically robust product circularity indicator which measures product circularity for construction products and is accepted by stakeholders within the construction industry. The goal is also to identify an indicator which would be suitable to be integrated into the EPD-scheme.

1.2.1. Research Objectives

1. *Identify relevant circularity indicators for products.*
2. *Select suitable product circularity indicators relevant to assess construction products.*
3. *Applying the two best suitable indicators in a pilot study to be able to give recommendations on their implementation in the EPD scheme for construction products.*

1.2.2. Thesis Structure

Firstly, a background chapter sets the scene of circularity within the building sector and presents instruments and tools for the implementation within the sector which are relevant for this study. Secondly, chapter 3 provide a more detailed account of the research methodology used throughout the study. Chapter 4 presents the results of the study in a chronological order. It starts with the presentation of the relevant indicators identified (RO1) together with a brief overview of the methodologies for respective indicator. Then follows a presentation of the assessment subjects, criteria and weightings developed based on the ECO Platform task group discussions and interviews with representatives of Green Building Councils (GBC's) (RO2). This section also presents the assessment results (RO2). The final part of the results chapter describes the test

applications of the two indicators that received the highest assessment score (R03). Finally, in chapter 5, a discussion of the results will be presented. This chapter includes a discussion of the application of the indicators together with notes of potential future research required to continue forward and is finalized with the conclusion of the thesis.

2. Thesis Background

This chapter aims to set the scene for the thesis by providing a more detailed context for the CE, presenting useful definitions, as well as relevant policies and initiatives related to product circularity. Moreover, a more specific overview of the status of, and future challenges within, the building sector is presented together with important instruments related to the sector i.e., GBCs and the EPD-scheme.

2.1. Tackling Climate Change and Reaching Sustainability

As previously highlighted, an increased resource efficiency is of the essence, where minimized use of natural resources together with its associated environmental impact plays a key role in developing and shaping sustainable socio-economic systems. (IRP, 2017) This is essential to achieve the climate goals established in the Paris Agreement but also to achieve the SDGs by 2030, particularly SDG 12 – to ensure sustainable consumption and production patterns. The strong demographic growth places a large pressure on the natural resources available on our planet and it is necessary to change existing consumption patterns. Connected to this aspect is the increasing urbanization already taking place around the world that has a significant impact on the environment and the use of available resources. This must change in order to, as much as possible, maintain a sustainable economic, social and environmental development that ensures the wellbeing of the planet and its inhabitants. (Govindan & Hasanagic, 2018) Unfortunately, the current outlook is dim and the fulfillment of the SDGs seems unachievable without increased climate action and improvement of the way we use our resources. (UN, 2022)

2.1.1. Waste and Climate Change

What has become a dominating linear economy through the extensive industrialization of the last few centuries relies on the model of “Take-make-use-dispose” and it is generally acknowledged that such an economy is incompatible with a climate friendly and sustainable future. The transition to a regenerative growth model such as the CE is instead seen as essential to minimize both waste and the dependence on virgin material sources and would pose as a central strategy to support sustainable development. (European Commission, n.d.a.)

The overall emissions related to the waste sector have decreased over the last few decades due to a decisive change in choice of treatment. Through increased recycling and a reduction of landfill waste, the sector’s GHG emissions have decreased with 35% over the last 30 years. (Eurostat, 2022) However, this reduction is comparatively small to the emissions reductions of other sectors over the same time. This goes to show that more regenerative choices of waste treatment, by recirculating materials in the system, are essential to lower the emissions of the continuously growing global economy. This is especially important as material resources are limited and a reduction of use of primary materials is necessary for the effects of climate change to be mitigated. (Eurostat, 2022)

Since the 1980's, the waste hierarchy has been widely known and used as a tool for sustainable waste management. Lately, it has also become a community strategy used primarily to prevent waste production. The most widely acknowledged understanding of the hierarchy consists of five steps being: *prevention, reuse, recycle, recover, and disposal*, preferably applied in that order. Since 2008, this model of the waste hierarchy is also included in EU legislation as part of the Waste Framework Directive. (Van Ewijk & Stegemann, 2016) The same strategy was in 2016 also included in SDG 12 to “substantially reduce waste generation through prevention, reduction, recycling and reuse”. (Pires & Martinho, 2019, p. 298) The waste hierarchy, with the five steps in the preferred order, is shown in Figure 1 below.

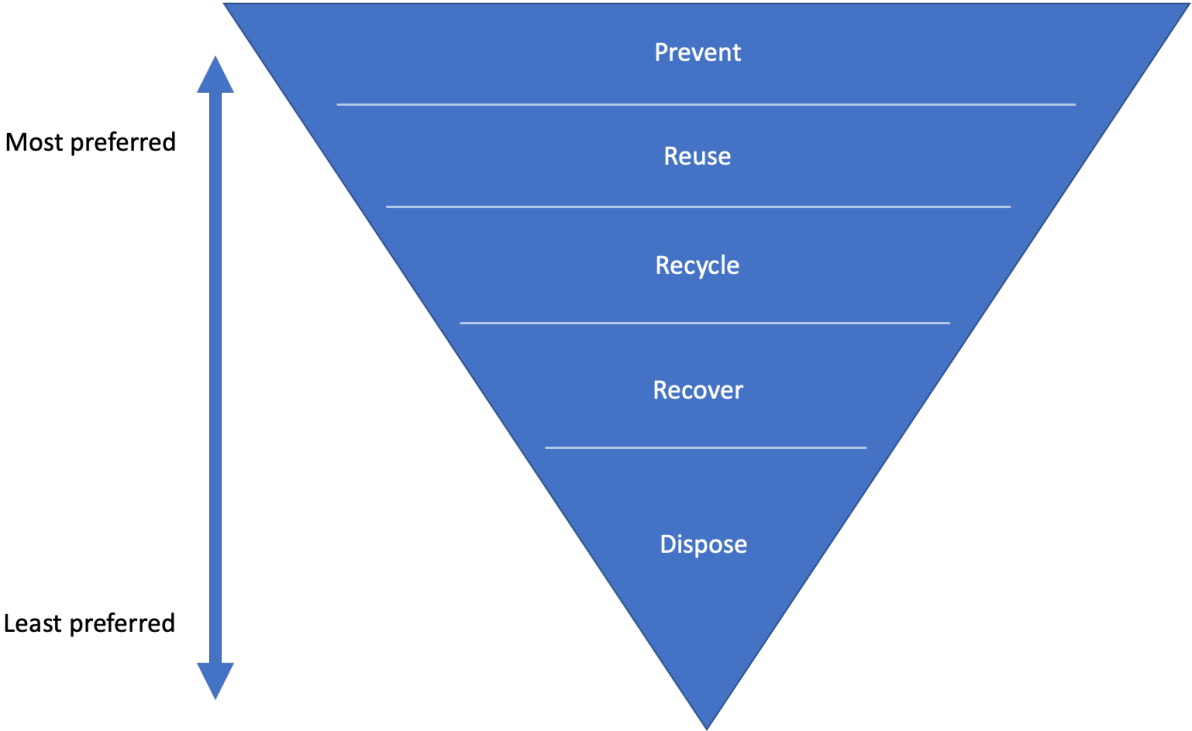


Figure 1. Waste Hierarchy included in the WFD.

2.2. Approaches to Circular Economy

A strive towards a more circular production system is necessary albeit difficult as it requires the substantial feat that is a transition of the current linear global economic system into a CE. Such a regenerative system is considered one of the main building blocks to ensure a sustainable development and sustainable systemic change on a societal level - a context in which it has a notable positive impact. (IRP, 2017) The CE places emphasis on what is often referred to as the 3 R's – reduce, reuse, and recycle – in the pursuit of an ideal economic system where resource use and waste is minimized to realize this objective. (Dong et al., 2021) Saidani et al, (2017a) highlights a few topics that are most

often mentioned when defining the concept. Firstly, the CE focuses on improved resource management within systems and throughout the lifecycle, characterized by closed loops as well as remanufacturing, recycling, and reuse promotion. To enable waste prevention and closing of the loop, a holistic understanding that is rooted in system thinking is mentioned as a key aspect within a CE. (Saidani et al., 2017a)

Amongst several proposed approaches to a CE, one valuable definition of the CE system is provided by Altenburg & Assmann (2017) in their “Green Industrial Policy”:

“In a circular economy, production and consumption systems are designed in a way that products and waste materials are reused and recycled within the production and consumption system. It builds on reduce, reuse, recycle (3Rs) and explores opportunities to promote closed material loops and high levels of resource efficiency in a systemwide approach.” (Altenburg & Assmann, 2017, p. 121)

The above definition emphasizes the need to include responsible resource consumption and sustainable waste management as key components to achieving a CE. Within this context, the definition underscores the ideal system design of the CE as being a closed loop. Thus, the CE becomes an important building block on multiple levels – economic, organizational and product – which signals the importance of a system wide approach to reach sustainability on a larger scale. (Altenburg & Assmann, 2017)

In fact, the system boundaries for a circular system are broad and cover many different aspects. Therefore, it is a challenge to immediately implement circular thinking throughout the whole socio-economic system. By way of dividing society into different levels, circularity can be implemented in a more adaptive and efficient way that meets the different needs and challenges faced throughout society. As such, circular thinking is often discussed and divided into three different levels. The macro level refers to nations, regions, or cities, while the meso level is applied for eco-industrial parks or inter-enterprise contexts. The micro level refers to systems of smaller scale such as companies or, even narrower, specific products. (Bachmann et al., 2021; Niero & Kalbar, 2019; Saidani et al., 2017a; Saidani et al., 2019)

The focus of this thesis is the implementation of circularity on a micro level. For companies, circularity is closely connected to e.g., increased material efficiency, decreased environmental impact and competitive advantages. In combination with the trend of corporate sustainability becoming popularized, the company level signifies a notable opportunity to be a driver of the transformation needed. (Govindan & Hasanagic, 2018)

The micro level includes a variety of aspects that must be considered to ensure circularity for products. According to the Ellen McArthur Foundation (n.d.), three core topics of the CE support the path towards circularity on a micro level: *elimination of waste*, *keeping materials in use* and *regeneration of natural systems*. CE is principally founded upon the idea of minimizing waste and aims to facilitate a more sustainable resource consumption

and an extended product life cycle. Therefore, product circularity and the will to change today's consumption patterns are closely connected. (European Commission, 2020) The material and product circulation - and recirculation - are key components within the product systems and the micro level is therefore highly relevant for a circular system on both a smaller and larger scale. (Saidani et al., 2017a)

2.3. Policies and Initiatives Relating to CE and Product Circularity

Various strategies have been implemented to support the transition to a CE on a national level. Central to these strategies is the connection between circularity on a macro level and product circularity through the focus on more responsible resource systems. For example, in the United States (US), the US Environmental Protection Agency has updated their overall strategy to include the CE approach as an essential part of limiting emissions. This is a key reason for the implementation of the “National Recycling Policy” and the accompanying goals of developing and improving the municipal recycling system. (EPA, 2019) Using another strategy, China put circularity into law in 2008 by implementing “The Circular Economy Promotion Law of the People’s Republic of China”. Legislating circularity entails efforts such as improving resource use and enabling CE. (Congressional-Executive Commission on China, 2013)

A third perspective on promoting a CE is offered by the EU Commission which recently adopted the “New Circular Economy Action Plan 2020” - one of the main building blocks of the New Green Deal, the European agenda for sustainable growth. The plan claims to reach a high potential for circularity by focusing on sectors with a high potential for emissions reduction. It also presents initiatives throughout the whole life cycle of products targeting design, CE processes, sustainable consumption as well as prevention of waste and keeping resources within the EU economy for as long as possible. The plan introduces both legislative and non-legislative measures targeting the areas with the potential to create real added value at an EU level. Along with public measures the plan also supports private sector instruments to include circularity aspects into their assessment schemes. (European Commission, 2020)

The EU’s Sustainable Product Package presented in 2022 is highlighted by the EU as central to the implementation of the New Green Deal and to achieving key objectives of the CEAP. (European Commission, 2022a). The initiatives released along with this package are especially focused on making “sustainable products the norm in Europe” and encompasses the entire life cycle of the product. (European Commission, 2020) One initiative within the package for Sustainable Products is the Eco-design for sustainable products regulation which is intended to be a framework focused on requirements for specific product groups. This eco-design framework aims at enhancing the circularity and energy performance as well as other environmental sustainability aspects within the product group. Some topics included in the initiative are: *Product durability, reusability and reparability, Presence of substances inhibiting circularity, Recycled content,*

Remanufacturing and recycling, Carbon and environmental footprints, Energy and resource efficiency, as well as Information requirements. (European Commission, 2022b)

2.4. Measuring Product Circularity

The implementation and integration of circularity measurements have grown to be an important and highly supported topic in many national policies around the world. However, while CE is a widely explored and analyzed concept, gaps remain to be filled to enable the application of such measurements. For instance, the deficiency of harmonization and standardization is often emphasized as an obstacle to measuring circularity.

A number of studies have noted a gap needed to be filled in terms of measuring circularity on different levels. On a macro level, Ghisellini et al. (2016) notes an evident gap regarding research focused on the design and discussion of indicators for assessing CE strategies. This despite the widely commented need to fill the gap concerning specific evaluation and monitoring tools for a CE. Elia et al. (2017) show how well-designed and effective indicators can overcome this lack of harmonization and fill the gaps, enabling the transition from a linear economy to a CE on the micro level. Similarly, Moraga et al. (2019), states that although numerous useful indicators to measure CE exists, the vague conceptualization and definition of CE hinders the identification of a standardized method that can ensure their practical implementation on different levels. The main question of *what* is to be measured is still a subject for debate which causes widely incoherent conclusions in regard to circularity measurements. As such, the importance of enabling classification of existing indicators is highlighted. (Moraga et al., 2019) However, the difficulties with standardization and harmonization still withstands across all levels.

The existing catalogue of indicators used for measuring circularity on a micro level offer a diverse range of methods to be applied in different contexts and focuses within the global product system. In their respective assessment and reviews of CE indicators on different levels, Elia et al. (2017), Iacovidou et al. (2017) and Moraga et al. (2019) all conclude that there is an indicator which can provide a holistic evaluation of the systems would be necessary but has yet to be identified. The review completed by Moraga et al. (2019) classifies 20 indicators related to the micro level - and more specifically the product system - through six different CE strategies², e.g., how they measure circularity. Mentioned amongst the micro level indicators are for instance the Material Circularity Indicator (MCI), Product-level Circularity Metric (PLCM), and Circularity Potential Indicator (CPI). These three indicators all focus on measurements of circularity for products, components, or materials. (Moraga et al., 2019) Two of the indicators use purely quantitative measures as input data; the PLCM is based on the economic value retained in

² The CE strategies used for classification are *Function* (e.g., reuse, refurbish, remanufacture), *Component* (e.g., reuse, repurpose), *Material* (e.g., recycle, downcycle), *Embodied energy* (e.g., energy recovery, landfill with energy recovery), and *Reference* (e.g., waste generation, landfill without energy recovery).

a circular product system (Linder et al., 2017) while the MCI uses the mass flows throughout the life cycle and the product lifetime as contributions to its resulting indication (Ellen McArthur Foundation, 2019). Contrastingly, the CPI uses qualitative input data and is based on four circularity building blocks³ presented by Ellen McArthur Foundation. The CPI is focused on measuring the circularity potential during phases for (re-)design, development, or benchmarking. (Saidani et al., 2017b)

While previous studies provide an account of available indicators for measuring circularity, this study aims to identify how the different indicators measure product circularity in construction products specifically. The main objective of this thesis is to identify an indicator suitable for implementation in the EPD-scheme, which requires the assessment of existing indicators against specific subjects and criteria. With this in mind, the evaluation of the indicators considers multiple circularity aspects as well as the technical characteristics of the indicators.

2.5. The Importance of a Sustainable Built Environment

From the circularity perspective, carbon emissions arising from the built environment includes emissions from the use of buildings as well as their construction. The emissions stemming from building construction will become increasingly important to mitigate as buildings are more frequently constructed and renovated to higher energy efficiency standards (UNEP, 2021). Therefore, the reduction of GHG emissions inherited from the building and construction sector is highlighted as essential to consistently follow the pathway of 1.5 °C. (GABC & OID, 2021) Notably, there is also an increasing demand for buildings and floor area around the world pushed by population growth and developing economies, drivers that bring increasing emissions and energy use to the sector. The total use of material is expected to have more than doubled by 2060 and a third of the increased amount of material is expected to belong to material used in the building and construction sector. (UNEP, 2021) However, the building and construction sector still possesses great potential to contribute to decarbonizing the global economy. (WGBC, 2022) Because the sector is highly resource intensive, the potential emissions reduction is substantial, something that is often acknowledged in policy as a key strategy to achieve general sustainable development.

2.5.1. Environmental Impact and Resource Efficiency in the Building Sector

The built environment within the EU is responsible for 50% of all material extraction and 35% of the total waste generation within the union. (European Commission, 2020) Because of extraction of materials, manufacturing of construction product, and construction and renovation of buildings, the sector accounts for 5-12% of the national GHG emissions. (European Commission, 2020) However, it is estimated that these

³ The building blocks from Ellen McArthur Foundation upon which the CPI is founded: *Circular product design, New business model, Reverse cycles, and Favorable system conditions.*

emissions levels can be decreased by 80% with improved material efficiency. (European Commission, 2020) Research regarding integration of sustainability practices into the construction sector is widespread and underlines the many environmental issues that must be tackled within the sector. Some of the sector's most often highlighted sources of environmental impact is resource and energy use, pollution, and emissions, as well as waste disposal. (Vasilca et al., 2021)

2.5.2. Circularity in the Building Sector

Together with environmentally focused measures for the construction sector, the extent of implementation of circularity measures in policies increases as well. This is especially noticeable in the CEAP presented by the European Commission (2020). The plan also presents the Strategy for Sustainable Built Environment, to promote the inclusion of circularity principles throughout the life cycle of buildings. This strategy will consider multiple policy areas relating to environmental and circular performance such as "climate, resource and energy efficiency, management of construction and demolition waste, accessibility, digitalization, and skills". (European Commission, 2020 p. 14) Similarly, urgency for action within the sector is also highlighted by the Global Alliance for Buildings and Construction (GABC) & OID (2021) with a focus on an extended life cycle for buildings. The authors emphasize that the life cycle must consider both the building itself as well as the respective products used. This is especially noted in relation to the deconstruction or renovation phase of a buildings' life cycle (GABC & OID, 2021) where the potential for disassembly of a product can play a key role.

2.5.3. Green Building Councils

Because Green Building Councils (GBC's) have been important in shaping how environmental issues are handled in the construction sector, discussing how they view circularity is important. For the private sector, a range of tools are now increasingly becoming available that can be used to plan, measure, and assess environmental performance of buildings, including their circularity. These instruments are exemplified here by the GBCs, independent non-profit organizations with the aim to promote and improve sustainability performance in the building sector by including a life cycle perspective into their certification schemes. (WGBC, n.d.a) The definition of a green building covers a range of aspects, but most importantly it is designed, constructed, and operated to reduce environmental impact and preserve natural resources while also improving life quality and human well-being. (WGBC, n.d.b) The certification systems provided by the GBCs are generally based on a set of criteria relating to specific sustainability, environmental or circularity factors which are weighted against each other. This results in a final grade/label that represents the buildings' performance. (Wangel et al., 2016)

GBC's aim to promote sustainable practices by educating professionals and assess and certify buildings according to their sustainability potential in relation to a variety of

factors. However, the GBC's green building rating schemes are not subject to a standard structure but vary in design, framework, and characteristics. They tend to consider different factors in their assessment systems depending on their individual strategies and objectives, but they often follow a similar method of assessment. (Sedlacek & Maier, 2012) The use of these strategies and certification systems are not in any form mandatory within the building sector, but they are oftentimes used as a tool to assess a building's environmental impact and/or for marketing purposes of new buildings. (Wangel et al., 2016)

The following paragraphs will present a few certification systems for sustainable buildings from different countries or unions as potential end users of the identified circularity indicators.

Building Research Establishment Environmental Assessment Method (BREEAM), developed by the UK-based BRE Group, is a profit for purpose organization and provides a third-party certification with a holistic sustainability perspective in the building sector by assessing the sustainability value in several categories and validating the building performance. (Bregroup, n.d.a) The main circularity aspects included in the scheme is relating to resource use and efficiency throughout the supply chains. By linking building design and construction phase with finished building performance and the use phase of the building, resilience across the building life cycle can be ensured. As such, through these key circularity targets the BREEAM certification aims at encouraging durable design for resilient assets, ensuring responsible use of materials, reducing water and energy consumption, as well as providing more sustainable methods for reducing waste. (Bregroup, n.d.b)

The German Sustainable Building Council (DGNB), founded in 2007 by 16 specialists from the construction industry with the goal of "promoting sustainable building in the future" (DGNB, 2022a). The non-governmental organization aims to contribute to the promotion of sustainable change of the building and property market. (DGNB, 2022b) In the "Circular Economy" Report published by DGNB in 2019, the council puts emphasis on CE and describes how it is considered within the DGNB system. The reports notes that circularity and life cycle-oriented planning has been included as a criterion since the birth of the system in 2008 (DGNB, 2019). In the 2018 updated version, circularity bonuses were introduced, enabling assessment and measurement with focus on solutions as part of the certification framework. The bonus points are considered to incentivize solutions and innovation and cover areas such as life cycle cost, deconstruction, recyclability, and construction.

Leadership in Environmental Design (LEED) is the green building and performance management system developed by the US Green Building Council (USGBC) which delivers a comprehensive framework for green building design, construction, operations and performance. (USGBC, 2022) When looking closer into how the CE approach is considered in the different LEED systems, it becomes clear that the focus areas are closely related to

resource use and material selection. Furthermore, the system has a clear focus on sustainable choices covering the full life cycle of the building, reducing waste upstream, incentivizing reduction of unnecessary building materials, as well as encouraging responsible use and sourcing of building materials. (USGBC, 2019)

Sweden Green Building Council (SGBC) offers the most recent version of Miljöbyggnad, Miljöbyggnad 4.0, as their certification system for buildings. (SGBC, 2022a) In regards to circularity, the main aspects considered are related to construction materials and a circular building process. The indicators evaluated in this category are focused on flexibility and potential for disassembly, circular material flows, waste management, as well as available information about construction products. Through the mentioned indicators, topics like resource use and efficiency, adaptability, recycled and reused material, and reducing construction waste collected for landfill and increase collection for recycling. (SGBC, 2022b)

Although, Level(s) is not a GBC, it is the European framework for sustainable buildings, providing assessment and reporting guidelines for a buildings sustainability performance which is applicable for both residential and office buildings. The framework is based upon a few core sustainability indicators aimed to measure carbon, materials, water, waste management (including reuse and recycling possibilities), health, comfort, and climate change impacts throughout the life cycle of the building. (European Commission, n.d.b.) The framework can be applied on three different levels depending on the focus of the assessment and is based on both qualitative and quantitative information covering a range of sustainability aspects. (European Commission, n.d.c.)

2.6. Environmental Product Declarations

Some certification systems come with requirements of presenting calculations of climate impact from a life cycle perspective as well as the environmental product declarations (EPD's) that underpin these calculations and the material used. Because legislation concerning climate impact declarations for buildings is becoming increasingly prevalent, the use of environmental declarations has increased within the building and construction sector. This is believed to be due to the specific reference to EPD's in the EU regulations from 2011 which mentions the use of EPD's for the assessment of sustainable use of resources as well as for the environmental impact of construction works. (Hauschild et al., 2018)

The EPD is used as a tool to compare and highlight specific qualities of a given product and determine its average environmental impact. To enable product comparison is an essential characteristic of an EPD that allows continuous improvement of product impact over time. (Environdec., n.d. a) The structure of an EPD generally includes:

- specific product information,
- explanations of the considered life cycle stages,

- indicators for resource use, environmental information and environmental impact,
- scenarios and additional technical information and
- impact of hazardous substances during the use phase on air, soil and water.

The EPD is aligned with standards developed by the International Standards Organization (ISO). They are acknowledged globally as guiding the formation of best management practice in terms of assuring quality and management of a range of activities. By bringing together global experts and subject matter specialists to develop the standards, the ISO set a global standardization of requirements. (ISO, 2019) Although one is not obliged to follow the standards, compliance with these is encouraged in most sectors and they are widely used. A range of different collections of standards apply within different fields, including environmental information within the product system.

In accordance with the ISO, environmental labels and declarations are classified into three different categories; type I, II and, III, to ensure that that the environmental information is communicated in a simple, accurate and reliable manner. (Bovea et al., 2014) This study is limited to type III environmental declarations, which is why type I and II will only be presented briefly. Type I environmental labels are voluntary third party verified labels which are based on a life cycle perspective of a product or service within a specific product category and aims to indicate the overall environmental preference. Type II, being self-declared environmental claims, is neither based on a life cycle perspective nor third party verified. As such, the ISO standard for this type is mainly used to reduce misleading inaccuracies relating to these claims. (Hauschild et al., 2018)

As for the third type, the ISO 14025:2006 standard establishes the principles and procedures of how to develop type III environmental declarations and associated programs. Type III environmental declarations, such as the EPD's, provide independent quantified data and information regarding the environmental performance throughout a product or service life cycle. It is, similarly to the type I environmental labels, third party verified. (Hauschild et al., 2018; Manzini et al., 2006) Therefore, EPD's are generally considered to be highly credible and particularly suitable for procurement purposes. (Environdec., n.d. b)

EPD's are consistently based on environmental data that stem from LCA's based on the ISO 14040 standardization of LCA frameworks and principles. They are also developed according to a set of pre-defined product category rules which categorizes different products according to their function and sector to enable standardization. (Minkov et al., 2015) The main function of the product category rules is to enable the transparency and comparability between EPD's, by requiring a presentation of information about the functional unit for the product category, allocation rules, system boundaries, Life Cycle Impact Assessment (LCIA) methods and data sources. (Hauschild et al., 2018)

A key intention of EPD's is business-to-business communication and to enable comparison between similar products with the same application. However, this requires

that the declarations are conducted in a consistent manner. (Hauschild et al., 2018; Manzini et al., 2006) Harmonization between different declaration schemes is encouraged through standards such as the EN 15804:2012+A2:2019, published by the European Committee for Standardization. This standard provides core product category rules for the structure of EPD's, particularly for building products or services and construction processes.

3. Research Methodology

This section of the thesis describes the choice of method used for the different parts of the study. Due to the nature of the project, there has been a need to use various methods to accomplish all relevant steps. The thesis as a whole and selection of relevant research methods are based on an extensive review of relevant scientific literature, official documentation for the indicator’s respective assessment methodologies, qualitative interviews, and task group discussions with experts within relevant fields. While the literature review serves to provide a solid scientific foundation, interviews and discussions with expert professionals and subject matter specialists within the field aims to place the assessment of indicators in a practical context. Additionally, to be able to evaluate the applicability of the product circularity indicators, a limited pilot study has been conducted. As such, the study ensures the inclusion of different perspectives on the implementation of circularity information into the EPD-scheme. It also evaluates in what way this information can contribute to a sustainable development. This is necessary to, in the best way possible, ensure that the result of the study would be possible to put into practice and that it supports the achievement of sustainable development goals, which requires the inclusion of multiple perspectives. Figure 2 shows the workflow throughout the study. Each step provides guidance regarding how the respective choice of method contributes to the resulting analysis and final findings of the thesis.

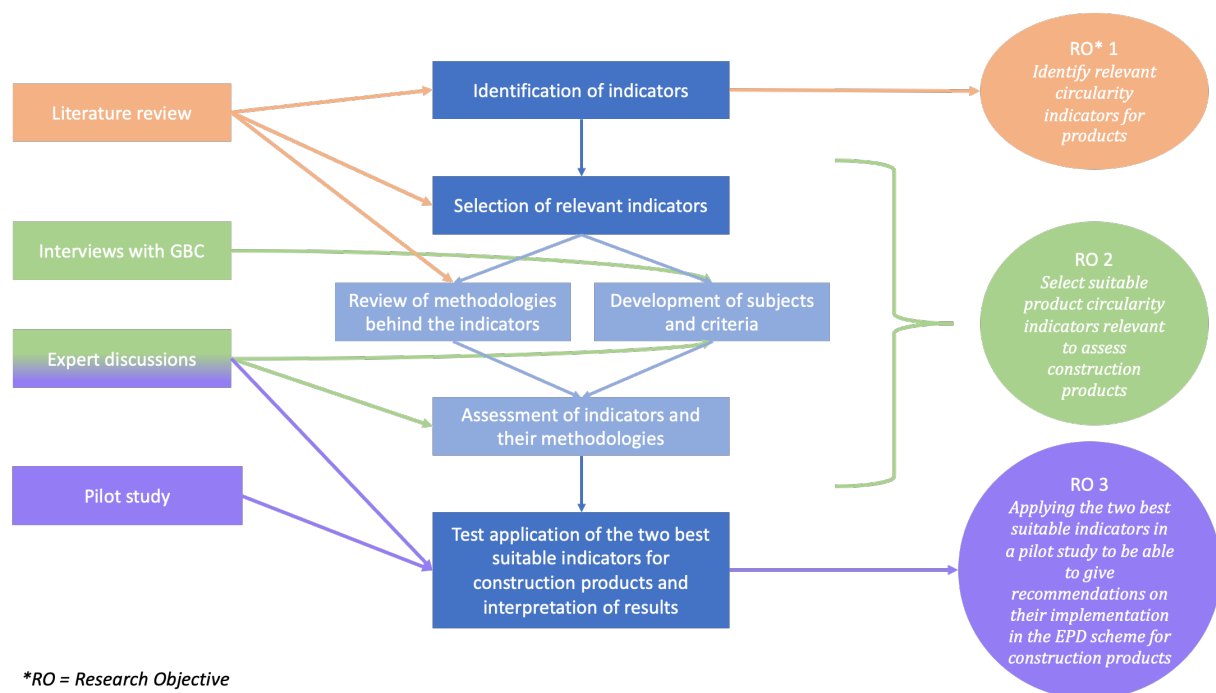


Figure 2. Overview of workflow of the thesis. The different colors represent the connection between method of choice and their main contributions to the research objectives. The blue areas describe specific activities where the methods have been applied.

3.1. Literature Review

3.1.1. Background

To understand the background context concerning CE and the most important drivers, stakeholders, and regulatory trends, a literature review has been conducted. The theoretical chapters are mainly based on a literature review of published scientific articles. These articles have been written and peer reviewed by several different researchers in widely acknowledged journals. The main search engines used for the literature review have been google scholar and the search engine at KTH library, Primo. The main keywords used for all literature searches for the study are e.g., “*Circular economy*”, “*Product circularity*”, “*Indicator*”, “*EPD*”, “*Construction products*” and “*Green buildings*”. The use of academic journals has aided the process of establishing a theoretically sound background for the project. The literature used mainly consist of articles that consider previous research and the current discussions on incorporation of CE on different levels in society. The review also includes official documentation and reports by national governments, the European Union, and European Commission and to some extent non-governmental organizations (NGOs). This to ensure an understanding of the context within which the methods would be applied and how they could add value to the setting and society within which they are used.

3.1.2. Review of Background Information for Product Circularity Indicators

Related to the first research objective, a previously conducted meta study by Saidani et al. (2019) provides a categorization and mapping of circularity indicators and constitutes the foundation of this thesis. The study is based on an extensive literature review and desk study with the purpose of mapping out the existing indicators that in any way assess the concept of CE. These indicators were in the study categorized into three different categories based on the level which the methodology concern – societal, company, or product level. They were also sorted according to the type of data which the indicators are based upon, quantitative or qualitative information. See chapter 4 for a list of the selected indicators based on this categorization.

The study of the relevant indicators, with a focus on product circularity, is then based on a review of official documentation for each of the respective methodology in the form of research articles and reports. Furthermore, a desk study of available official webpages for the specific indicators has been conducted. Most of the researchers / organizations have provided public access to documentation regarding the development of the methodologies of the indicators. For some of the indicators, the material has been more difficult to access. Therefore, a request for access has been sent to their respective creator. However, this approach was unsuccessful in some cases, as only a few of the researchers / organizations provided access to their documentation upon request.

For an indicator to be considered relevant, its availability and accessibility is important. Based on these two requirements, five of the selected indicators have been excluded from the study. A lack of available documentation was identified as an obstacle to ensuring sufficient understanding of the underlying methodology behind some indicators. Public access to available documentation as well as to potential calculation tools is essential for the indicator to be applied in the context of this thesis.

3.2. Suitability Assessment of Product Circularity Indicators for Inclusion in Construction Product EPDs

To answer the second research objective, two main methods have been applied – task group discussions and qualitative interviews.

3.2.1. Expert Group Discussions

Firstly, the discussions with the ECO Platform task group have had a particularly valuable impact on the general discussion about results and project development as well as analysis support related to information contained in EPDs. The task group members have different areas of expertise and work in various fields and types of organizations located in a range of European countries, e.g., EPD program operators, industry associations and construction product manufacturers, but have in common that their expertise is connected to the focus of this study. In this way, the discussions and on-going dialogue within the task group has contributed with added value to a wide range of aspects of the project at large as well as specific questions. As support throughout the writing of the thesis, the opportunity to participate in meetings with experts within the topic has contributed with an important in-depth knowledge of relevant themes, aiding the focus of the study. These meetings have been structured in the form of a workshop where each meeting has had a specific focus related to the topic. Since the author joined the project in March 2022, 8-10 meetings of approximately 90 minutes each have taken place. It should be noted that there is a risk of bias associated with the inclusion of expert and stakeholder opinions. However, the expert discussions have strived towards ensuring scientific objectivity through a diversity in backgrounds, opinions, profiles, and an adaptive and inclusive perspective.

3.2.2. Qualitative Interviews with Green Building Councils

Semi-structured qualitative interviews have been conducted with two GBCs consisting of around 4-5 questions to be answered with a duration of approximately one hour. The interviews have aimed to provide a more in-depth knowledge about green building rating systems and understand circularity in connection to a building level. The interviews were conducted with representatives from the systems BREEAM and DGNB. See Appendix 2 for the list of questions asked in the respective interview. According to the description of a semi structured interview from Kvale and Brinkmann (2014), the interviews were structured in a way so that the interviewees had the opportunity to give broad and

elaborated responses while constantly focusing on contributing to the purpose of the thesis. As such, each of the interviewees were provided the opportunity to present their most important focus areas according to their own expertise and experience. In this way, their core aims have been able to be communicated and explained in more detail.

The intention of using interviews as a research method is to facilitate the inclusion of in-depth stakeholder perspectives related to CE. Moreover, it is to allow practitioners to contribute with a perspective on the application of a product circularity indicator and how it could be useful for circularity assessments on a building level. Additionally, it serves as an efficient way to bring attention to stakeholder needs and gaps, identifying areas of improvement in relation to circularity. It guarantees that any future adjustments or additions are aligned with the desires and needs of the practitioners, safeguarding real-world relevance and applicability.

3.2.3. Development of Method for Assessment of Product Circularity Indicators for Construction Products

As mentioned, the above two methods have been instrumental in developing subjects, criteria and weightings laying the foundation of the assessment of indicators. This specific set of subjects, criteria and weightings can be found in chapter 4. The overall aim of the subjects and criteria development was to ensure applicability and relevance to circularity in the context of construction products as well as to identify the one most suitable to be incorporated into the EPD-scheme. To ensure alignment with the needs of the sector, insights from relevant stakeholders on these topics must be considered.

To assess the alignment of relevant circularity topics within the construction sector, a set of 8 assessment subjects were developed. The task group discussions have provided essential perspectives from the industry, including insights from varying experiences and backgrounds, enabling a holistic approach to circularity as a concept. Members of the task group and their insights have thus been essential to the development of subjects covering the main topics of circularity. Furthermore, the expertise from GBCs have provided useful contributions to the development of assessment subjects, where additional aspects of importance were highlighted from the perspective of stakeholders on the building level. By including the perspectives of professionals working with e.g., EPDs, resource relating matters or areas closely related to CE principles within the respective scheme, a broader insight on different approaches to circularity on a building level is allowed. It was highlighted in both interviews that the current use of EPDs in the councils' certification schemes is limited. However, both BREEAM and DGNB look positively upon including further circularity information into their building assessments, which is why a circularity indicator must consider relevant topics for potential inclusion in the future.

Each of the previously mentioned circularity subjects have then been assessed through a set of criteria. These criteria were developed through discussions within the task group

with the objective of ensuring that the subject considerations are relevant and applicable to the goals of the study. Particularly, the task group meetings have supported the discussion of the most important criteria to be fulfilled for an EPD. As such, the criteria are aimed at evaluating how the methodology behind the indicator consider these subjects.

Similar to the development of the criteria, the respective weightings were developed based on expert discussions where the different levels of importance were prioritized. Notably, the weightings are important for the assessment procedure but should be handled with caution. Although the weightings were conducted with the intention of being objective, the risk of bias should always be noted when ranking subjects against each other. These potential uncertainties are important to be aware of in further use of the results.

3.2.4. Assessment of Product Circularity Indicators for Construction Products

Each circularity indicator has been assessed against the same set of subjects and criteria resulting in a single score, enabling their comparison. The assessment was made based on available documentation for the methodologies behind the indicators.

To begin with, the author created a template table in excel which has been used for each of the indicators enabling their comparison, as shown in Figure 6. Secondly, the documentation was reviewed by the author with the consideration of whether the assessment subjects are included in the scope of the methodology or not. Due to the diversity in scope, structure and CE perspective, the assessment is based on an interpretation of the documentation available and to what extent they cover the subjects at hand. It ought to be noted that due to sometimes unclear definitions, there has been a need for interpretation of information. The third step was to investigate *how* the methodology handles the subjects considered to be included to the scope. The criteria checked for this step concerns whether the subject is based on quantified information and if this information would be applicable to an LCA. Finally, a resulting score was concluded and presented by the author to the task group in a meeting where it was analyzed and discussed. Throughout the study, the assessment result was regularly presented and discussed with the ECO Platform task group and field experts allowing input or questions regarding the result. As such, the task group members have not only provided their perspectives in relation to the development of the criteria, but also in the interpretation of the results. Because all assessments have been conducted in the same manner, and despite the need for interpretation, the indicators have continuously been assessed strictly in relation to the set criteria.

The assessment process resulted in the identification of two indicators able to provide methodologies that could be suitable for inclusion in the EPD-scheme. They also cover a wide range of the subjects highlighted for a CE in accordance with the criteria.

The review and assessment of each indicator resulted in a respective specification sheet, see Appendix 1, where each one of the methods has been summarized separately. Each of these specification sheets include a short presentation of the most essential parts of the given method. The specification sheets also include the scoring against each criterion, a short explanation of the assessment and an explanation of why the indicator received the specific score.

3.3. Pilot Study

In close collaboration with ECO Platform, a shorter pilot study was conducted. This to enable the evaluation and understanding of the applicability of the best suited methodologies from the perspective of a manufacturer. In discussions within the task group, potential pilot partners were identified and then contacted regarding their possible participation. The potential pilot partner consists of manufacturers of construction material/products. Out of the contacted manufacturers, one partner was included as a participant. The objective is to conduct a larger pilot study with several partners in order to get a wider range of insights. However, due to limited time, this pilot study was kept small and therefore only includes the test application and a discussion of the two indicators methodologies' applicability for the one manufacturer. The pilot study started in September 2022 and is currently in progress. Although the result has been collected from this specific pilot case, the pilot study should therefore be considered as on-going.

In preparation of the pilot study, data collection sheets for the respective methodology were prepared in Excel by the author to enable the collection of information from the manufacturer. An example of such a data collection sheet is shown in Figure 3. As the pilot study is conducted in collaboration with ECO Platform, a group of representatives from the task group have been responsible for the data collection for one of the identified indicators. The author of this thesis has been responsible for the data collection of the other identified indicator in this context.

The first step was to organize a meeting with a representative from the company where the objectives of the study, the two indicators' methodologies, and the respective data collection sheets were presented in more detail. The data collection sheets were then shared with the manufacturer to gather the product related data available. The company was given 4-6 weeks to complete the data collection. However, which was noted during the study, more time for collecting data was necessary. When all data was collected, the next step was to calculate the circularity performance of the agreed upon pilot product according to the two methodologies. In addition to the test applications, a sensitivity

4. Result

This chapter shows the findings of the study. First, the chapter introduces the selection of relevant indicators and exclusion of indicators that are not considered applicable in this context. The following section presents a general overview of the selected indicators and their methodologies. Next, the developed set of subjects, criteria and weightings applied in the assessment are covered. The fourth section provides the resulting assessment and scoring of the indicators. The final part of the result details the two highest scoring indicators and their calculations methodologies and presents the results of their respective pilot application.

4.1. Selection of Product Circularity Indicators

For the purpose and the goal of this thesis, the focus is on indicators that address circularity on a product level in a quantitative manner. Therefore, the indicators that Saidani et al. (2019) placed in this category are of interest. The need for a quantitative indicator is due to the nature of the EPD-scheme, which is mainly based on numerical information and indicators relating to the environmental performance of a product. In addition to the indicators mentioned by Saidani et al. (2019), another recently developed product circularity indicator, the New Circularity Index (NCI), is also included. A full categorization of the identified indicators is shown in Table 1. The 15 indicators marked in grey will be evaluated further in the proceeding study.

To better understand the categorization, it is important to recognize the differences between circularity on the three different levels - society, company, and product - as well as the representation of the data types. These three levels as well as the difference between quantitative and qualitative data are described briefly in the thesis background.

Table 1. Categorization of methodologies assessing circularity, which levels they are mainly focused on and what type of data they are based upon.

Level / Type of data	Qualitative	Quantitative
Measuring CE on a Society level	<ul style="list-style-type: none"> • Circle Assessment (CA) • Circular Benchmarking Tool (CBT) • Circular Economy Index (CEI) • Circular Economic Value (CEV) • Super-efficiency Data Envelopment Analysis Model (DEA) • Evaluation of CE Development in Cities (ECEDC) • Evaluation Indicator System of Circular Economy (EISCE) • Evaluation of Regional Circular Economy (ERCE) • Indicators for consumption for CE in Europe (ICCEE) • Indicators for Eco-design for CE in Europe (IECEE) • Indicators of Economic Circularity in France (IECF) • Indicators for Material Input for CE in Europe (IMCEE) • Indicators for Production for CE in Europe (IPCEE) • Measuring Regional CE–Eco-Innovation (MRCEEI) • Resource Productivity (RP) 	<ul style="list-style-type: none"> • Material Reutilization Part (C2C) • Circle Assessment (CA) • Circular Benchmarking Tool (CBT) • Circular Economy Monitoring Framework (CEMF) • Circular Economic Value (CEV) • Economy Wise Material Flow Analysis (EWMFA) • Integrative Evaluation on the Development of CE (IEDCE) • Industrial Park Circular Economy Indicator System (IPCEIS) • National Circular Economy Indicator System (NCEIS) • Regional Circular Economy Development Index (RCEDI) • EU Resource Efficiency Scoreboard (RES) • Recycling Rates (RRs) • Value-based Resource Efficiency (VRE) • Zero Waste Index (ZWI)
Measuring CE on a Company level	<ul style="list-style-type: none"> • Assessing Circular Trade-offs (ACT) • Circle Assessment (CA) • Circular Benchmarking Tool (CBT) • Circular Economy Index (CEI) • Circular Economy Toolkit (CET) • Circular Economy Toolbox US (CETUS) • Closed Loop Calculator (CLC) • Measuring Regional CE–Eco-Innovation (MRCEEI) 	<ul style="list-style-type: none"> • Circle Assessment (CA) • Circularity Assessment Tool (CAT) • Circular Benchmarking Tool (CBT) • Circular Pathfinder (CP) • Five Criteria Index Method (FCIM) • Material Circularity Indicator (MCI) • Sustainable Circular Index (SCI)
Measuring CE on a Product level	<ul style="list-style-type: none"> • Eco Efficient Value Ratio (EVR) 	<ul style="list-style-type: none"> • Building Circularity Indicators (BCI) • Material Reutilization Part (C2C) • Circularity Calculator (CC) • Circular Economy Indicator Prototype (CEIP) • Circularity Index (CI), material-based • Circularity Potential Indicator (CPI) • End-of-Life Recycling Rates (EoL RRs), material-based • Circularity Indicator Project, Viktoria ICT (ICT) • Input-Output Balance Sheet (IOBS) • Material Circularity Indicator (MCI) • Product-Level Circularity Metric (PCM) • Resource Duration Indicator (RDI) • Recycling Indices (RIs) for the CE • Reuse Potential Indicator (RPI) • New Circularity Index (NCI)*

* The NCI was not part of the Meta study by Saidani et al. (2018). It has been added for the purpose of this study.

4.1.1. Exclusion of Inapplicable Indicators

Some indicators have been excluded as they do not reach all the requirements. In terms of availability of the documentation, the CC and the IOBS falls short since documentation is unavailable leading to a lack of sufficient information about the methodology behind the indicator. In terms of enabling public access to the indicator, neither the CC, C2C nor BCI meet the requirements as all three indicators are created for commercial use, leading to their exclusion. Moreover, the C2C is created as a label rather than an indicator, which makes it inapplicable to the purpose of this study. Finally, upon closer inspection, two of the indicators identified are based on the same methodology, the PLCM and the ICT, making one of them redundant. The ICT was consequently excluded as it also failed to provide an equally accessible information as compared to the PLCM.

Although the above indicators are excluded from the study, they are included in the list below for the purpose of transparency, see Table 2. All 15 indicators are listed along with the year and the author(s)/founder(s) of their respective published documentation. The excluded indicators are highlighted in red. Going forward, the study will cover the other 10 indicators.

Table 2. First selection of product circularity indicators (15) and their respective authors/founders. The indicators marked in red have been excluded from the study.

Name of the Indicator	Author / Founder (year)
Material Circularity Indicator (MCI)	Ellen McArthur Foundation (2019)
Building Circularity Indicator (BCI)	Alba Concept (2022)
Material Reutilization Part (C2C)	Cradle2Cradle (2021)
Circularity Calculator (CC)	Circularity Calculator (2017)
Circular Economy Indicator Prototype (CEIP)	Cayzer et al. (2017)
Material based Circularity Indicator (CI)	Cullen J.M (2017)
Circularity Potential Indicator (CPI)	Saidani et al. (2017b)
Material based End-of-Life Recycling Rates (EoL RRs)	Eurometaux and Eurofer (2006)
Circularity Indicator Project (ICT)	Linder et al. (2017)
Input-Output Balance Sheet (IOBS)	Enel (2018)
Product-Level Circularity Metric (PLCM)	Linder et al. (2017)
Resource Duration Indicator (RDI)	Franklin-Johnson et al. (2016)
Material based Recycling Indices (RIs) for the Circular Economy	Van Schaik & Reuter (2016)
Material based Reuse Potential Indicator (RPI)	Park and Chertow (2014)
New Circularity Index (NCI)	EnelX and ICMQ (2022)

4.2. Origin of identified Product Circularity Indicators

The following part provides an overview of more general findings based on the review of the documented methodologies for respective indicator to give an idea of the origin of the identified indicators. This includes the developers behind the indicators and the input data required for the different calculation methodologies behind the indicators.

The overview shows that the developers behind the indicators can be categorized into six different groups as presented in Figure 4 below. Based on somewhat limited accessible information about the creators, the review shows that most of the creators are independent researchers, while the second biggest category is represented by research institutes. The rest of the indicators are developed by either companies, NGOs, a collaboration between the two, or charity foundations. Notably, none of the indicators are developed by an authority, although, this is not excluding any collaboration between the previous mentioned developers and authorities.

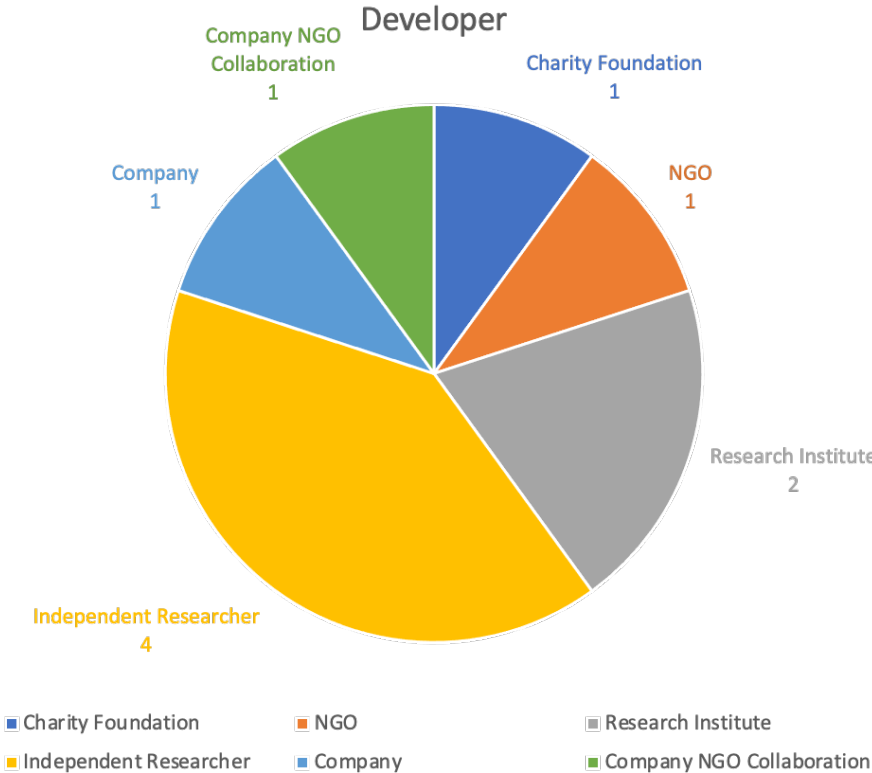


Figure 4. Developer behind the methodologies reviewed.

Because the methodologies exemplify several different ways to measure circularity, they also use different types of input data. As shown in Figure 5, most of the indicators require quantitative input data for their evaluations. However, the rest are either based on qualitative input data or a mix type of input data using both qualitative and quantitative information to calculate the results. Nevertheless, all the methodologies included and reviewed in this study generates a quantitative resulting indicator for circularity no matter what type of input data the methodology is based upon.

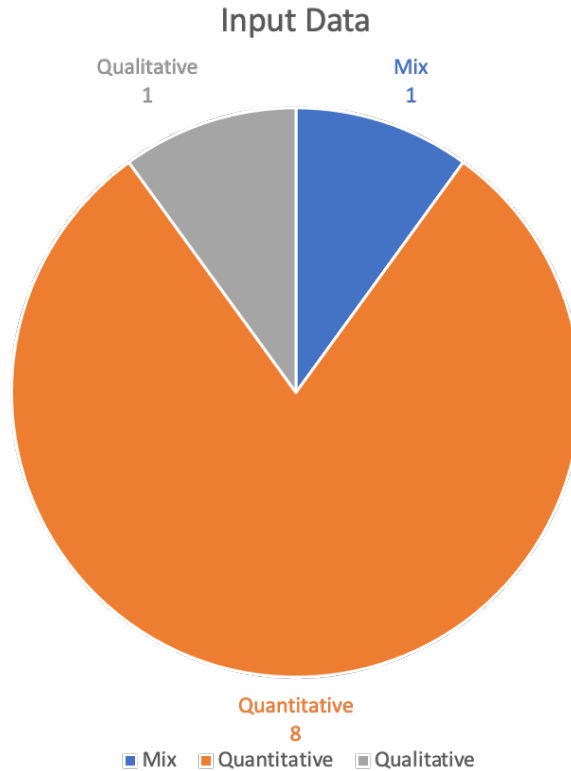


Figure 5. The type of input data that the reviewed methodologies are based upon.

All the reviewed methodologies included in this study present indicators that measure product circularity in some way. However, while they are developed to contribute to a CE, the indicator provides different focuses within the product system. While most of the indicators are aimed towards measuring material flows, some are focus exclusively on other angles, such as the PLCM which includes the focus of economic values. Moreover, most indicators include multiple aspects throughout the different stages of the product life cycle, supporting the wide scope of circularity. However, this does not apply to all. For instance, the EoL RRs only focuses on the EoL stage of the life cycle and is limited to metals as a material in its development. It is therefore important to mention that all indicators are structured differently in how they choose to include, weight, and prioritize the different stages or variables, affecting the interpretation of the resulting circularity performance of the product.

4.3. The Method for Assessing the Suitability of Product Circularity Indicators for Construction Products

The development of the specific assessment subjects, criteria and their respective weightings is described in more detail in following sections.

4.3.1. Assessment Subjects

Assessment subjects were developed through expert discussions and interviews. The expert discussions mainly contributed to the development of the first five subjects applied

to the assessment scheme for product circularity indicators. The first five subjects are *Method General*, *Recycled Content*, *Recyclability*, *Renewable*, and *Quality of recycling*.

Resource efficiency and waste are core circularity aspects for both BREEAM and DGNB. The waste hierarchy, and especially prevention of waste, is noted as highly relevant for both schemes. As such, the assessment subject of *Design for reuse* has been added as one core topic for the assessment subjects for this study.

Especially highlighted in the interview with DGNB, topics related to the use- and EoL phase is of great importance. During the use phase, the need for maintenance and possibility for repair are key components to prolong the lifetime of the construction product. As such, ensuring that the material is designed with these intentions is highlighted as crucial. For the EoL phase of the products used in a building, the possibility to disassemble the product without demolishing the building is of high relevance. This to increase a buildings circularity performance. However, as noted in the interview with DGNB, there is a lack of consideration of this in most indicators available today. This makes it a subject of interest to consider in a future implementation of useful and comprehensive product information.

Based on these additional aspects - highlighted from a building perspective - the decision to include 3 more assessment subjects to this study was made. The 3 additional subjects are *Design for reuse*, *Design for low maintenance and repair*, and *Design for disassembly*.

All of the 8 assessment subjects, phrased in collaboration with the expert group, and their definitions are presented in Table 3. All subjects are essential to consider for a functioning regenerative product system with focus on resource use, material flows, and waste management.

Table 3. Assessment subjects and definitions

Subject	Definition
Method General	General characteristics of the methodology
Recycled Content	The share of secondary material input for product manufacturing
Recyclability	The ability to recycle the product at the end of its useful life, quantified with appropriate measures
Renewable	The understanding is that “renewable”/“non-renewable” should refer to the source of raw materials from agricultural or forestry supply chains, but avoid a definition with regards to a final material (i.e. no assignment of a “renewable” attribute to a final material based on a certain share of renewable raw materials or similar)
Quality of recycling product	A measure to differentiate between “downcycling”, “recycling” and “upcycling” (while these terms are not generally defined) to deliver an interpretation of the level of recycling (e.g. it is possible to have smaller quantities or recycling that deliver a high quality recycled product or larger quantities of recycling delivering a lower-quality product, and for both approaches it should be possible to deliver an assessment)
Design for disassembly	Designing for disassembly allows the original materials and components to be taken apart and reused/recycled for other products to maximize their lifespan. This criterion enables circular economy to take place by positively contributing to the recyclability of the product.
Design for low maintenance and repair	Designing for low maintenance and repair contributes to the length of the use stage of the product. It also contributes to the circularity of the product by accounting for reduction in the waste stream in a given amount of time for products that have a longer lifetime than the industry average.
Design for reuse	Reusing avoids the energy consumption for extracting and processing resources and the energy consumption for recycling a secondhand resource. As it does not require further process for its next life cycle, reusing provides an even greater environmental benefit than recycling and can positively contribute to the circularity of the product.

4.3.2. Assessment Criteria

Two sets of criteria were developed. The first set of criteria aims at analyzing the general usability and adaptability of the indicator and the methodology upon which it is built. This set of criteria is applied to the *Method General* subject. These criteria are *Aggregating across topics*, *Expandability*, *Easy/direct or very processed*, and *Helpful*.

The second set of criteria concerns the other 7 subjects and how these subjects are included in the methodologies behind the indicators. Firstly, this set of criteria aims to evaluate whether the subjects are considered or not. Secondly, it assesses their alignment

with the structure of the EPD scheme. As the EPD scheme mainly consists of quantified information and covers the different stages throughout the life cycle of a product, these traits are important to consider in the evaluation. The set of criteria consists of 3 criterions: *Included in the scope*, *Quantified*, and *Ready for LCA*. The criteria are described in greater detail in Table 4 which also includes explanations phrased in collaboration with the expert group.

Table 4. Assessment criteria and definitions

Criteria	Definition
Aggregating across topics (only for the subject <i>Method General</i>)	Is an indicator / a method used in LCA able to deliver results as a sum across different inputs and along process chains, accounting for full supply chains and multi-raw material products?
Expandability (only for the subject <i>Method General</i>)	Is an indicator / a method able to be expanded in the calculation methodology to account for additional aspects that may be considered relevant in the upcoming discussions?
Easy/ direct or very processed (only for the subject <i>Method General</i>)	Is an indicator directly retrieved from e.g., product information and thus rather easy to interpret (e.g., “recycled content”) or is it an indicator that is calculated e.g., to a dimensionless index integrating several aspects that may need additional interpretation? The understanding is that a processed indicator that can utilize several aspects is preferential to a directly retrieved, single-topic quantity.
Helpful (only for the subject <i>Method General</i>)	Is an indicator / a method overall useful, can it be supported by data that is available and can it be calculated, or does the indicator / method not support conclusions and decision making towards the circularity of products?
Included in the scope	Is that assessment subject included in the indicator’s / method’s scope?
Quantified	Does the indicator / method generate a quantitative result for this assessment subject?
Ready for LCA	Is the proposed approach for the assessment subject generally usable in LCA, i.e., is data available to support the required calculations, is it possible to make the necessary aggregations along supply chains and across different inputs etc.)?

4.3.3. Weightings

Each assessment subject is assigned a specific weight according to the prioritization. Following the same procedure, the weightings for each subject are distributed over the specific set of criteria. As such, the weights between the different subjects and criteria may differ. The final weightings are presented in Figure 6.

Weight for assessment subject	Ranking of assessment subject	Assessment subject	Assessment criteria	Weight	Available answers				Score per criteria
15%	least important	Method General	Aggregating across topics	2,5%	Yes = 1	Medium = 0,5	No = 0	Unknown = 0	
			Expandability	2,5%	Yes = 1	Medium = 0,5	No = 0	Unknown = 0	
			Easy / direct or very processed	5,0%	Direct = 1	Medium = 0,5	No = 0	Unknown = 0	
			Helpful	5,0%	Yes = 1	Medium = 0,5	No = 0	Unknown = 0	
10%	less important than recyclability	Recycled Content	Included in the scope	5,0%	Yes = 1		No = 0	Unknown = 0	
			Quantified	2,5%	Yes = 1		No = 0	Unknown = 0	
			Ready for LCA	2,5%	Yes = 1		No = 0	Unknown = 0	
30%	most important	Recyclability	Included in the scope	15,0%	Yes = 1		No = 0	Unknown = 0	
			Quantified	10,0%	Yes = 1		No = 0	Unknown = 0	
			Ready for LCA	5,0%	Yes = 1		No = 0	Unknown = 0	
10%	less important than recyclability	Renewables	Included in the scope	5,0%	Yes = 1		No = 0	Unknown = 0	
			Quantified	2,5%	Yes = 1		No = 0	Unknown = 0	
			Ready for LCA	2,5%	Yes = 1		No = 0	Unknown = 0	
20%	important	Quality of recycling	Included in the scope	10,0%	Yes = 1		No = 0	Unknown = 0	
			Quantified	5,0%	Yes = 1		No = 0	Unknown = 0	
			Ready for LCA	5,0%	Yes = 1		No = 0	Unknown = 0	
5%	nice to have	Design for disassembly	Included in the scope	3,0%	Yes = 1		No = 0	Unknown = 0	
			Quantified	1,0%	Yes = 1		No = 0	Unknown = 0	
			Ready for LCA	1,0%	Yes = 1		No = 0	Unknown = 0	
5%	nice to have	Design for low maintenance and repair	Included in the scope	3,0%	Yes = 1		No = 0	Unknown = 0	
			Quantified	1,0%	Yes = 1		No = 0	Unknown = 0	
			Ready for LCA	1,0%	Yes = 1		No = 0	Unknown = 0	
5%	nice to have	Design for reuse	Included in the scope	3,0%	Yes = 1		No = 0	Unknown = 0	
			Quantified	1,0%	Yes = 1		No = 0	Unknown = 0	
			Ready for LCA	1,0%	Yes = 1		No = 0	Unknown = 0	
Total score								0	

Figure 6. Weightings for each assessment subject and criteria in the assessment template used for the assessment of product circularity methods

4.4. Resulting Assessment of Product Circularity Methodologies

As Table 5 shows, the different indicators and their methodologies vary in how they take different **Error! Reference source not found.** into account when assessing circularity. The assessment subjects considered for the respective indicator is marked in green in Error! Not a valid bookmark self-reference.. The general trend among the indicators' methodologies is to focus on Recycled content, Recyclability and Design for low maintenance and repair. However, as becomes clear in the table below, many disregard the Renewables, Quality of recycling and Design for disassembly aspects, proven by the lack of inclusion of these subjects. Generally, there are notable differences between the methodologies in how and to what extent they evaluate the full life cycle of products. Not one methodology considers all seven subjects. Although five methodologies include as many as five out of seven subjects.

Table 5. Description of to what extent the product circularity indicators consider the assessment subjects of the study. The green marked squares are representing the subjects considered in the indicators' specific methodology.

Name of the method	Recycled content	Recyclability	Renewables	Quality of recycling	Design for disassembly	Design for low maintenance and repair	Design for reuse
MCI							
CEIP							
CI							
CPI							
EoL RRs							
PLCM							
RDI							
RIs for CE							
RPI							
NCI							

The perspectives of circularity that the indicators exemplify vary in terms of their relative focus on categories of data, which can shape how they view and consider the subjects in their methodologies. However, some trends on how they include and choose to represent the different variables can still be distinguished.

The most apparent trends can be found for two subjects often included by the indicators, *Recycled content* and *Design for low maintenance and repair*. *Recycled content* is in most cases included as the mass of recycled material used as input while *Design for low maintenance and repair* is represented by functional units or service lifetimes of the products. However, a subject which is often considered – *Recyclability* – shows no clear trend in term of its representation as its inclusion generally vary in nature.

4.4.1. Final Assessment Scores

Upon closer inspection and analysis of the existing methodologies for product circularity indicators against defined subjects and criteria, their individual strengths and weaknesses are highlighted. The assessment presented below is based on respective methodology's consideration of circularity topics as well as the key consideration of their applicability to the EPD-scheme. The subjects and criteria are presented in

Table 3 and Table 4. Figure 7 shows respective methodologies achieved final score and its inclusion of assessment subjects, facilitating their final comparison.

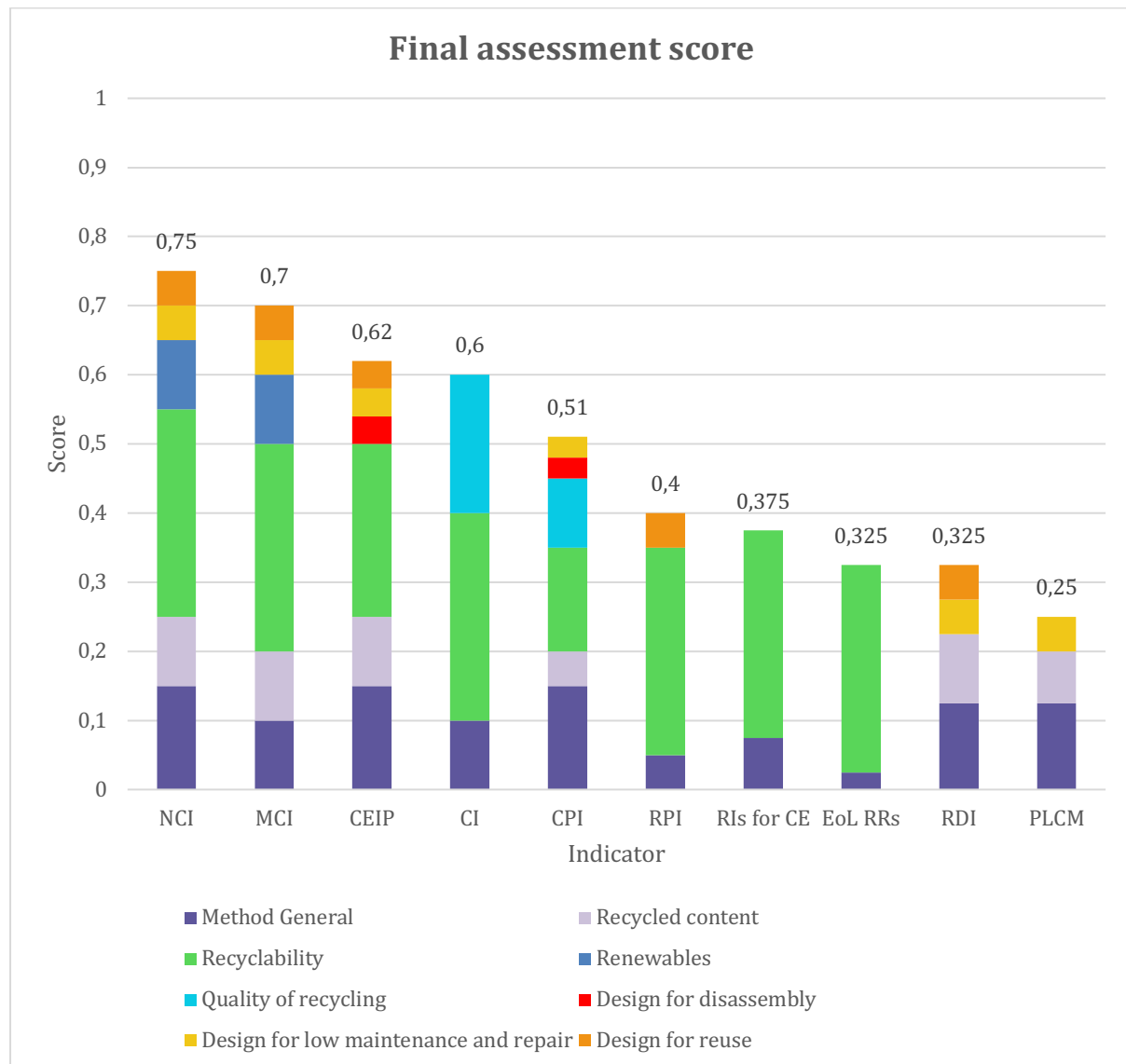


Figure 7. Final assessment score and the extent of inclusion of assessment subjects for all indicators included in the assessment for product circularity subjects and suitability for the EPD-scheme. Each of the bars represent the different indicators assessed and the colored fields represent the included assessment subjects.

Out of the 10 assessed indicators, two received the highest score – the MCI and the NCI methods – based on their ability to, in accordance with the criteria, consider a wide range of the subjects highlighted for a CE and possible suitability to be included in the EPD-scheme. Figure 8 shows how the two indicators score against respective assessment subject. What is notable in this comparison is that they score very similar except for the first subject, *Method General*, where the NCI reaches a slightly higher score than the MCI. What is also noted is that neither of the indicators consider *Quality of recycling* nor *Design for disassembly*.

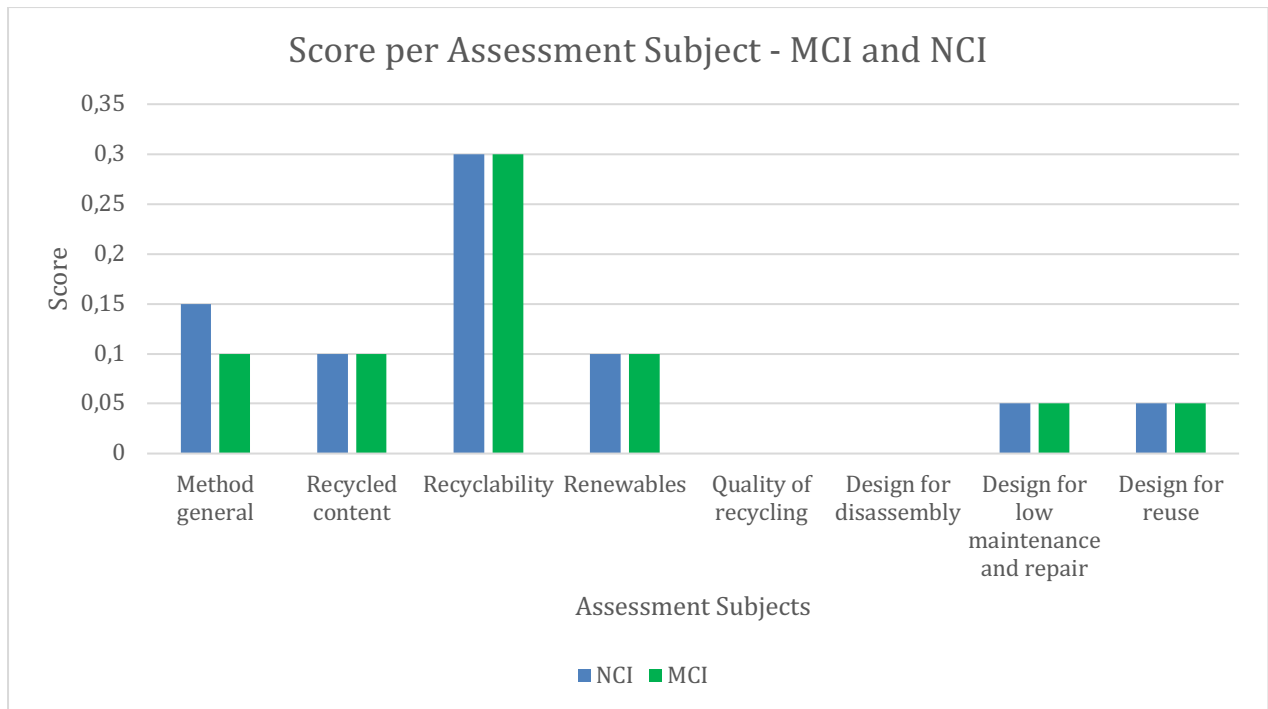


Figure 8. Comparative overview of how the MCI and the NCI score for each assessment subject

4.5. Pilot Study of the MCI and the NCI

The first two sections of this part present the calculation methodologies behind the two highest scoring indicators. This result is based on the review made of the official documentation for the methodologies. Following these sections, the result concerning the pilot study and test applications are shown together with the respective indicators resulting product circularity indication as well as a sensitivity analysis.

4.5.1. MCI Specifications

The Material Circularity Indicator (MCI) method measures to what extent linear flow is minimized and restorative flow is maximized for product materials. This is calculated by considering the origin of the input material, waste fractions in the EoL as well as the products lifetime and utility into account. The MCI can be applied on a product- as well as company level and targets industry decision-makers concerning both product development and business models. In general, the methodology focuses specifically on products although this in turn influences circularity on the company level. (Ellen McArthur Foundation, 2019) Figure 9 shows the system boundaries for the material flows related to a fully linear respectively circular product.

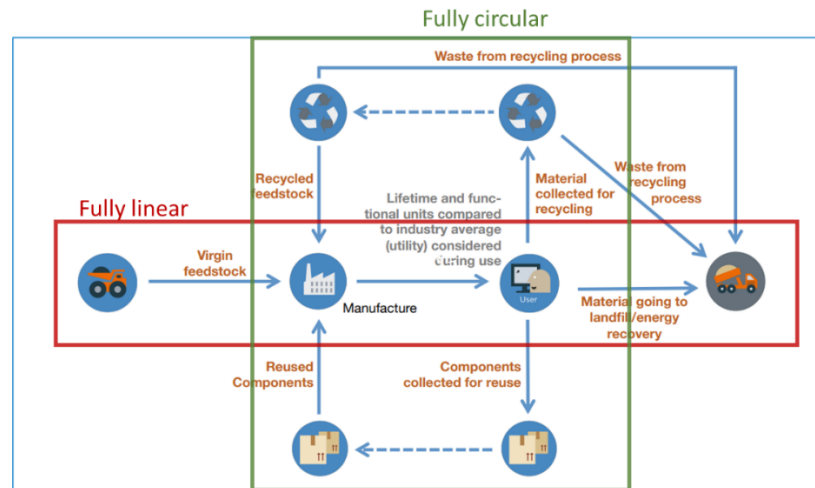


Figure 9. Circular versus Linear flows based on the MCI

Input data

Input data required for the MCI calculations are primarily product specific data collected from companies and average product data. (Ellen McArthur Foundation, 2019).

The calculation itself considers:

- mass flows throughout the life cycle
- the utility or function of the product, via timespan of usage (including durability of products, repair/maintenance, and shared consumption business models) and intensity of usage
- rates and flows at the EoL that are going to landfill (or energy recovery), collected for recycling, and collected for reuse
- the rates and flows of recyclable materials
- and composting and energy recovery from biological materials

The input data used for the MCI respond to variables that can be categorized in to following life cycle stages:

- A1: production of raw materials
- B: use phase of the product
- C3: recycling and C4: disposal

Calculations

Calculating V , the **virgin material** in the product:

$$V = M (1 - F_R - F_U - F_S)$$

Equation 1

Where M is the total mass of input material, F_R is the secondary material from recycling, F_U is the secondary material that is being reused and F_S is representing the fraction of biological materials originating from sustained production.

Waste fractions

For the overall amount of unrecoverable waste, W :

$$W = W_0 + \frac{W_F + W_C}{2}$$

Equation 2

Where W_F is the unrecoverable waste generated in the process of producing recycled feedstock and W_C is unrecoverable waste of the recycling process at EoL. For both terms, the parameter for recycling / reuse efficiency is included as a factor M .

W_0 is the **unrecoverable waste** going to landfill or incineration and is calculated according to:

$$W_0 = M (1 - C_R - C_U - C_C - C_E)$$

Equation 3

Where C_R is the fraction of waste collected for recycling, C_U is the fraction collected for reuse, C_C is representing the mass of biological material used that is being composted and C_E is representing the mass of biological material coming from sustained production that is used for energy recovery. For energy recovery to be applicable as a circular strategy (only for biological material) the material must fulfill all of the following criteria:

Criteria for inclusion of energy recovery at EoL biological material from sustained sources:

- The product / material is not either economically or practically recyclable or compostable.
- Biologically sources material
- The material has to be proven to be of a sustained production (e.g.,)
- It can not be contaminated by any technical materials (e.g., fillings, coatings or preservatives, unless they are evidentially non-toxic and inactive)
- The energy recovery of this material must bring more value than non-renewable options
- The by product from energy recovery of the material must have a biological positive impact

(Ellen McArthur Foundation, 2019).

As such when energy recovery of biological material is applied, C_E is calculated as follows:

$$C_E = (E_E * B_C)$$

Equation 4

$$E_E = \left(\frac{E_R}{(HHV * M_B)} \right)$$

Equation 5

Where E_E is representing the efficiency of the energy recovery process and B_C is representing the carbon content of the biological material that is meeting the requirements for energy recovery to be considered as a part of the CE. E_R is the energy recovered, HHV is the Higher Heating Value and M_B is the mass of eligible biological material meeting the requirements for inclusion of energy recovery in CE.

W_C and W_F is calculated according to the equations below:

$$W_C = M * (1 - E_C) * C_R$$

Equation 6

$$W_F = M * \frac{(1 - E_F) * F_R}{E_F}$$

Equation 7

Where E_C is the efficiency of recycling the product material in the end of its life⁴, E_F is the recycling efficiency for the production process of recycled feedstock⁵ and F_R is the fraction of recycled material in the product.

As such, **The Linear Flow Index** (LFI) measures the extent that material is flowing in accordance with a linear model, meaning material sourced from virgin material which then ends up as unrecoverable waste. This index is then calculated as follows:

$$LFI = \frac{V + W}{2M + \frac{W_F - W_C}{2}}$$

Equation 8

If E_C and E_F are considered equal, $E_C = E_F = 1$, then W_C and W_F can be considered as $W_C = W_F = 0$ and

$$LFI = \frac{V + W}{2M}$$

Equation 9

Furthermore, the **Material Circularity indicator** (MCI) and taking the products utility function into account can be calculated as follows:

⁴ **EC example:** In the end of life of the product, 1 kg of material is collected for recycling. Out of this 1 kg of material, how much material is generated as recycled material (as output) after the recycling process?

⁵ **EF example:** If we have 1 kg of recycled feedstock used as an input to the product, how much of the specific material have to be recycled in order to give us the 1 kg of recycled feedstock to use as input material?

$$MCI = 1 - LFI * F(X)$$

Equation 10

Where **the utility function F(X)**, is calculated as:

$$F(X) = \frac{0.9}{X}$$

Equation 11

representing the use stage of the product life cycle and defined as follows:

$$X = \frac{L}{L_{av}} * \frac{U}{U_{av}}$$

Equation 12

Where L/ L_{av} is the lifetime compared to the average value for the lifetime of similar products and U/U_{av} is the utility compared to the average utility factor of similar products. Most often only one of the two factors are applied. (Ellen McArthur Foundation, 2019)

Presentation of results

The resulting indicator for the whole product is calculated by the sum of

It is a quantitative method resulting in a single score indicator, according to the information below, being a value between 0 and 1. As such, the calculation results in a value of the MCI on a scale of 0 to 1, indicating that the product is fully linear when the value is 0 and fully circular when the value is 1, see Table 6. (Ellen McArthur Foundation, 2019)

Table 6. Guidance of interpretation of the resulting circularity indicator using the MCI

For max circularity	For min circularity
$LFI = 0$	$LFI \approx 1, \text{ and } X = 1 \rightarrow MCI = 0.1$
$MCI = 1$	$LFI \approx 1, \text{ and } X < 1 \rightarrow MCI < 0.1$

4.5.2. NCI Specifications

The New Circularity Index developed by EnelX and ICMQ has the aim to measure the relevance of non-virgin materials and renewable energy consumed in a product life, calculated as a relative percentage of total material and energy flows. The NCI is applicable to products for which a function is identifiable on its whole life, according to a from cradle to grave scenario. The calculation model takes into account the amount of materials, water, energy and transports involved in the process and the produced waste;

the outcomes highlight the circularity index of materials, energy, water and waste. (ICMQ, 2022)

Input data

The input data required for the NCI calculation have to be specific for the product and calculated according to its functional unit, in a life-cycle approach.

The specific inputs are:

- functional unit according to the product category
- reference service life according to the product category and a specific RSL is the producer can justify a different scenario
- materials as raw materials and components, packaging materials, auxiliary materials for production, consumable materials in use stage, materials for maintenance and their packaging, materials for remanufacturing and their packaging
- energy as electrical energy and thermal energy consumed in production, installation, use, maintenance, decommissioning, remanufacturing, and transport in all life stages
- water as water consumed in production and use
- waste as waste generated during production, maintenance, end of life and remanufacturing

Calculations

The NCI analyses the flows of material, energy, water and waste that are involved in all the stages of the product life. In each of the four categories, NCI is the relationship between the circular inputs and the total inputs involved in the product life, as described below.

Materials

$$NCI \text{ of materials} = \frac{\textit{Circular materials}}{\textit{Circular materials} + \textit{Non circular materials}}$$

Equation 13

Where:

- *Circular materials = Renewable virgin materials + Recycled materials + Reused materials*

Equation 14

- *Non circular materials = Non renewable virgin materials*

Equation 15

Energy

$$NCI \text{ of energy} = \frac{\text{Circular energy}}{\text{Circular energy} + \text{Non circular energy}}$$

Equation 16

Where:

- *Circular energy = Renewable electrical energy + Renewable thermal energy + Transport by electrical vehicle + Transport by train*

Equation 17

- *Non circular energy = Non renewable electrical energy + Non renewable thermal energy + Diesel + Unleaded petrol + Transport by truck + Transport by ship + Transport by aircraft*

Equation 18

Water

$$NCI \text{ of water} = \frac{\text{Circular water}}{\text{Circular water} + \text{Non circular water}}$$

Equation 19

Where:

- *Circular water = Recycled water*

Equation 20

- *Non circular water = Well water + Tap water*

Equation 21

Waste

$$NCI \text{ of waste} = \frac{\text{Circular waste}}{\text{Circular waste} + \text{Non circular waste}}$$

Equation 22

Where:

- *Circular waste = Waste to energy recovery + Waste for recycling + Waste for reuse*

Equation 23

- *Non circular waste = Waste to disposal*

Equation 24

It is also calculated a material share and an energy share, as the material and energy contents for each year of reference service life, according to the functional unit. (ICMQ, 2022)

Presentation of results

The "PRODUCT NCI" is a set of four specific NCIs, which represent:

- NCI of materials
- NCI of energy
- NCI of water
- NCI of waste

For the materials category, the following four values are presented:

- Quantity of Non-Circular inputs as: Non-renewable virgin materials (kg)
- Percentage of Non-Circular inputs as: Non-renewable virgin materials (% on total materials)
- Quantity of Circular inputs as: Circular materials (kg)
- Percentage of Circular inputs as: NCI of materials

The other three categories of energy, water and waste follow the same structure in results presentation.

Comprehensive level of circularity

To generate a single score resulting indicator for the circularity performance of the product, the four specific NCI results are weighted into a comprehensive level of circularity. All four NCI results are weighted the same with a factor of 0,25. As such the final single score will provide a per centage which represents the final circularity performance of the product. Depending on the per centage, the circularity performance is divided into 5 different levels. (ICMQ, 2022)

4.5.3. Test Application - MCI

The test calculations are performed mainly based on the data collection made by the pilot company. However, for the variables which were not possible to provide for the company, additional research is required. This is the case for the specific recycling efficiencies to

produce recycled input material (EF) or material which, at the EoL, were collected for recycling (EC). For this case, the EC and the EF are assumed to be the same for all recycling processes which would represent a closed loop scenario, i.e., all recycled material is recirculated into the specific production process of the product. For respective type of material, the same recycling efficiency is also assumed, not considering the different variants of the material.

Moreover, additional research was also necessary for the average functional unit as well the service lifetime, both specific and industry average. The industry average for the functional unit was based on two different PCRs⁶ for similar products, in this case the category for windows and doors. The values for the service lifetime were based on research made on different EPDs⁷. The specific service lifetime was based on the EPD created for this product and the industry average on EPDs related to similar products with the same function. As such, these values are noted as assumptions used for the calculations.

Figure 10 shows the resulting MCI for the product applied in the test calculations described above without packaging (left) and the resulting MCI for the product including packaging (right).

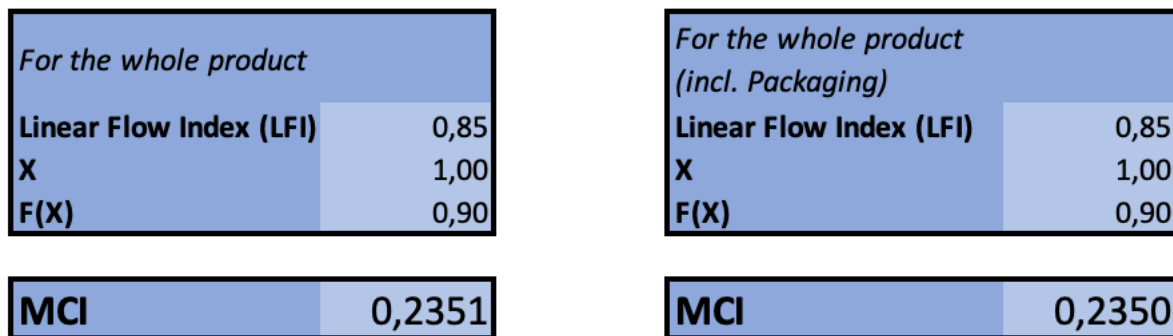


Figure 10. Resulting MCI for the product itself (to the left) and the resulting MCI for the product incl. packaging (to the right).

Notably, as the LFI is closer to 1 and the MCI is relatively low on the scale 0-1, (according to Table 6) it can be concluded that the represented product is more linear than circular.

Sensitivity Analysis - MCI

The sensitivity analysis considers 3 different cases to evaluate the impact on the result, see Table 7. Only the variable for which the impact is evaluated is changed for the different cases. As such, all other variables are kept the same as for the test calculations.

Case 1 aims to evaluate how sensitive the methodology behind the MCI is to the input mass of glass, representing most of the input material, for this product. As such, the mass

⁶ Functional Unit, Industry Average: based on the IBU PCR and EPD international PCR
⁷ Service Lifetime, Industry Average: EPD for the specific pilot product used in this study

of glass is firstly removed, meaning that the product then only consists of an aluminum frame. The rest of the variables are kept the same while only this input mass is modified.

Case 2 concerns an increase in packaging material. However, for the MCI, there are no distinctions between the packaging material and the product specific material meaning that a similar effect as from the glass was expected.

Case 3 helps to investigate to what extent the waste hierarchy is considered for the two indicators. This is done by shifting the amount of waste collected for recycling to reuse instead. As such, the impact of the different fractions is to be evaluated.

Table 7. Sensitivity analysis for the MCI

Case	Variables modified	Resulting MCI
Case 1	$M_{\text{glass}} = 0$	0,61
Case 2	$M_{\text{packaging}} = 25 \text{ kg}$	0,19
Case 3	All amount (0,2 kg) for recycling is instead collected for reuse	0,2445

4.5.4. Test Application - NCI

Regarding the application of the NCI, it is based mainly on the data collection received from the pilot company, see appendix 3. For a few variables, e.g., transport distance and type, assumptions were necessary. These variables were assumed to be around 500 km with truck running on diesel. What is important to note is that the NCI covers circularity aspects which are not included in the scope of the MCI, meaning that the calculation relies on an extensive data set including additional information.

The resulting NCI for material, energy, water, and waste was calculated and is shown in Figure 11.

NCI of materials		NCI of energy		NCI of water		NCI of waste	
Non-renewable virgin materials [kg]	Circular materials [kg]	Non-renewable energy [MJ]	Renewable energy [MJ]	Virgin water [l]	Recycled water [l]	Waste to disposal [kg]	Waste to recycling [kg]
43,95	5,16	55,51	7,15	10,00	0,00	28,21	20,47
89,50%	10,50%	88,60%	11,40%	100,00%	0,00%	57,94%	42,06%

Figure 11. Resulting NCI for the pilot product. Including the NCI for material, energy, water, and waste

The four categories show numbers representing the linear and circular contributions to the product performance. As shown in Figure 11, the largest circular contributions to the product performance inherit from the waste. However, noted for all four categories, is that the linear flows are predominant. This also becomes evident when calculating the comprehensive level of circularity for the product which generate the result of **15,99%**, corresponding to **level 1** of product circularity.

Sensitivity Analysis - NCI

For comparability reasons, the same cases are used for the NCI as for the MCI in the sensitivity analysis. The first case evaluates the impact from the mass of glass and the second case the impact of packaging material for the final product. The third case is used to assess the extent of consideration of the waste hierarchy at the EoL phase. The results for the sensitivity analysis conducted for the NCI is presented in Table 8.

Table 8. Sensitivity analysis for the NCI

Case	Variables modified	Comprehensive level of circularity
Case 1	$M_{\text{glass}} = 0$	39,91%
Case 2	$M_{\text{packaging}} = 25$	15,96%
Case 3	All amount (0,2 kg) for recycling is instead collected for reuse	15,99%

5. Discussion

The following chapter aims to highlight some of the main topics of discussion. Firstly, trends regarding all the studied indicators' consideration of subjects related to product circularity are reflected upon. Secondly, usability and applicability will be discussed together with the main findings from the sensitivity analysis of the two highest scoring indicators, the MCI and the NCI. Thirdly, the suitability of the MCI and the NCI to be integrated into the EPD scheme is examined with a focus on the nature of the data as well as to what extent the indicators provide a comprehensive inclusion of circularity information. This to establish if the indicators fill the gap regarding the EoL phase in the EPD. Fourthly, a brief critical reflection and discussion regarding the method used for this study to evaluate product circularity indicators is offered with a focus on the development of subjects and criteria. Lastly, a proposal on future research is presented with regards to what remains to be studied to close important gaps for a final implementation of the indicator.

5.1. Consideration of Circularity Subjects in Assessed Indicators

In terms of inclusion of circularity aspects, it should be noted that none of the studied indicators cover all the subjects. In general, most cover *Recycled content*, *Recyclability* and *Design for low maintenance and repair*. On the contrary, the least considered subjects are *Renewables*, *Quality of recycling* and *Design for disassembly*, which are only considered by 2 indicators respectively. While this highlights a demand for environmentally friendly products, it also shows a lack of consideration of the waste hierarchy and its importance for the concept of circularity. This, in turn, highlights a general lack of inclusion of the full life cycle which would be necessary to assess the full circularity performance of a product.

Also notable is the general lack of harmonization in how the indicators take the subjects into consideration. Only *Recycled content* and *Design for low maintenance and repair* shows potential trends in how the subjects are taken into consideration. On another note, *Recyclability* is the subject with a clear lack of trends, most likely due to its generally wide definition. Despite these uncertainties, the subject is still overrepresented among indicators while also being assigned a relatively high weighting for the assessment in this study. Therefore, this subject becomes one of the main points that shape the assessment results. This can be exemplified by the CI which only includes 2 out of 8 subjects but still managed to achieve a high final assessment score, generally attributed to the inclusion of this subject.

5.2. The Importance of Usability and Applicability

In relation to the test applications of the two highest scoring indicators, the topics of usability, availability of data and sensitivity are of particular interest for the discussion.

These aspects are essential topics of consideration as they point to the potential use of the indicators in practice.

The collection of data together with feedback received from the pilot partner are both central to evaluate the usability of the indicator and availability of data. Firstly, due to the differences in scope, the amount of data necessary differs significantly between the two indicators. As the NCI covers a much larger scope, by including additional circularity aspects compared to the MCI, the data collection also becomes more time consuming. Not only is this due to the large scope, but also due to the lack of availability of some required data as noted by the pilot partner. As such, the difficulties related to the data collection make up one of the main points to consider in terms of the usability of the NCI. On the contrary, the MCI is considered more user friendly as it requires less data which in this case also was proven to be more available. However, as the MCI still required data which had to be based on additional research, the time for data collection was prolonged and the amount of assumptions made for the calculations increased. For example, additional research was necessary especially for the efficiencies of the material specific recycling processes as well as for the specific and average lifetime of the product. So, from the experience of data collection and feedback from the pilot partner, the two indicators clearly differ somewhat in terms of ease of use.

Further conclusions can be drawn based on the sensitivity analysis performed for the two indicators. This analysis was conducted as it effectively highlights the two indicators' differences in how they consider material flows throughout the product system, especially in relation to input material and material collected at the EoL of the product.

The first case of the sensitivity analysis, where the glass was removed from the product, shows that both indicators are sensitive regarding the specific product material input and its origin. This is evident through the significant increase seen in both resulting indicators for this case, which is most likely due to the glass corresponding to most of the product mass.

The same behavior is recognized for the MCI when the mass of packaging material is increased, causing a notable decrease of the final indicator. However, in this case, the MCI considers the mass of packaging material in the same way as any other material input for the actual product, something that might be somewhat misleading. This is not the case for the NCI where this instead results in a small decrease of the final level of circularity. This is most likely due to the packaging material being included as auxiliary material, which is not factored in on the result in the same way as the product specific material. Hence, the NCI, with its inclusion of four different circularity focuses, does not show the same sensitivity for changes in the material flow specifically. In comparison, the sensitivity regarding the input mass is especially noticeable for the MCI. However, this could easily be explained by the limited focus on the mass flows throughout the product life cycle.

The case where all material collected for recycling instead was included as collected for reuse, allows for conclusions to be drawn about the indicator's consideration of the EoL phase. Although both indicators include recycling and reuse as possible waste fractions contributing to the circularity performance of the product, the differences between these waste fractions are not necessarily distinguished. This is especially interesting in relation to whether the indicators consider the waste hierarchy to its full extent or not and what impact it has on the resulting product circularity indicator.

The NCI clearly does not include the waste hierarchy to its full extent. This is based both on the review of the calculations and on the abovementioned result for case 3 in the sensitivity analysis. In this case, the two waste fractions - recycling and reuse - contribute to the circularity performance equally as the resulting NCI does not differ based on where the amount of material collected for reuse or recycling is placed. The same goes for all categories considered as circular waste fractions.

On the contrary, the fractions for reuse and recycling are not treated similarly for the EoL phase in the MCI. This becomes evident through the difference in the equations for the two waste fractions but also through the result of the sensitivity analysis which shows a small increase in the resulting MCI. The size of the increase is most likely explained by the small amount of material collected for this fraction in the first place. Nevertheless, waste collected for reuse have a positive impact on the result. The different contributions to the circular flows from material collected for recycling and reuse are distinguished by the waste fractions generated through the recycling process, which is not present in the case of reuse. Consequently, this goes to show that the MCI include the waste hierarchy to a larger extent than the NCI.

5.3. Circularity Subjects and Suitability to the EPD-scheme

Moving forward to the possibility to implement one of the two indicators into the EPD scheme, some topics are especially important to consider. Firstly, as the EPD-scheme is mainly based upon quantitative data and on the structure of the products life cycle, it is important that the indicators are structured in a similar manner. Both the MCI and the NCI meet these requirements and could therefore be suitable options in terms of data. As a type 3 declaration, it is important that indicators and quantitative data included in an EPD provides objective information regarding the products environmental and, in this case circularity, performance. Therefore, the MCI and the NCI must comply with these requirements, which they do. Yet, it is ought to be noted that the final score for the NCI is based on weightings and should therefore be handled with caution. But, as long as the four aspects in the NCI are weighted equally, it is possible to ensure a certain level of objectivity.

Secondly, to ensure that the potential implementation of a new indicator provides comprehensive information on the circularity performance of a product, the indicator must consider the full product life cycle. Additionally, this aspect is especially important to be included by the indicator because of the general lack of information regarding the EoL phase in the EPD scheme at the time of writing. Applying these requirements to the NCI and the MCI, both indicators still contain gaps - especially related to the EoL phase of the product. This is evident as both indicators lack the inclusion of the two subjects *Quality of recycling* and *Design for disassembly*, which are both closely related to the EoL phase. The waste hierarchy is another important concept in relation to the EoL phase and to promote enhanced reuse value and minimize production of waste. As previously mentioned, this is not the case for both indicators as the NCI does not include the hierarchy to its full extent. The NCI simply separates linear and circular flows without further consideration of differences between the waste fractions contributing to the circularity performance of the product.

Thirdly, in terms of usability, it is essential to implement an indicator which is easy to interpret and understand. Therefore, the level of complementary information needed to understand the value of the indicator is crucial for the end use in an EPD scheme. Regarding both the MCI and the NCI, this is important to highlight as implementation of either of the indicators would require additional, complementary explanations. This would aid an improved and greater understanding of what the indicator entails as well as to ensure the indicators transparency as part of the EPD-scheme. Such an explanation would have to explain which circularity aspects are contemplated as well as how the indicator considers these aspects.

5.4. Discussion on Method of Assessment

Because this thesis' assessment of the indicators considered is based on a methodology of ranked subjects and criteria through weightings, further use of the result should be handled with caution. It is impossible to ensure complete objectivity when including weightings of any sort, and therefore these kinds of uncertainties should be addressed. However, in the case of this study, the subjects, criteria, and weightings have all been based upon expert discussions and stakeholder perspectives, including a wide range of areas of relevant expertise and with the aim to be as objective as possible. Still, full objectivity is impossible to guarantee.

The weighted subjects and criteria also shape the assessment result accordingly. This is especially noticeable when considering the assessment subjects weighted the highest, *Recyclability* and *Quality of recycling*. By merely including these subjects fully, the indicator's assessment score increases significantly. This means that an indicator can receive a rather high score by simply including one or both of these subjects and neglect other subjects that are equally important to the concept of circularity.

5.5. Further Research

The final indicator proposed is intended to be incorporated into EPDs, especially for construction products, and aimed at supporting the building sector at large. Therefore, a wider perspective on the inclusion of such an indicator is of highest relevance. As such, it is proposed that further research should focus on ensuring a greater extent of stakeholder inclusion in this sector. The indicator is expected to contribute to full circularity assessments of buildings and therefore more in-depth insights on the needs and demands of GBCs are essential.

Additionally, an assessment of how the indicators can be developed to close the gaps regarding the circularity subjects not fully addressed must be considered. This to ensure complete information about a product's circularity performance.

Moreover, this study does not address potential risks to the future implementation and use of such an indicator in the EPD scheme. To ensure a robust and resilient indicator, it would be necessary to conduct an extended risk assessment.

6. Conclusion

As evident throughout this study, the nature of the concept of circularity is disputed and therefore difficult to assess as well as apply. A wide variety of understandings of circularity is why a range of alternative indicators are available on the market today. Of the indicators identified in this study, the NCI and the MCI are concluded to be suitable options for inclusion in the EPD. The indicators include most of the circularity subjects considered in ways that comply with the nature of the current structure of the EPD. In terms of usability and practical applicability, the two indicators differ. The pilot study shows that the main differences are the amount of data needed and the time it takes to complete their data collection due to the different scopes and level of complexity. While the NCI covers a wider scope, this leads to it being more complex in its application. With a narrower scope, the MCI becomes more direct but less inclusive of additional aspects relevant to circularity. Moreover, neither indicator fully includes all stages of the life cycle of the product and only partially includes the EoL phase, which is central to the provision of comprehensive circularity information. Especially important to note is the NCI's lack of inclusion of the waste hierarchy as compared to the MCI. In conclusion, neither the MCI nor the NCI can provide the comprehensive circularity information requested but they remain the two indicators best suited for implementation into the EPD scheme.

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Appendix 1

Specification sheets for the methodologies behind respective product circularity indicator

Material Circularity Indicator (MCI)

Ellen McArthur Foundation & Granta Design

2019

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Specific approach

The Material Circularity Indicator (MCI) method measures to what extent linear flow is minimized and restorative flow is maximized for product materials. This is calculated by considering the origin of the input material, waste fractions in the end of life (EoL) as well as the products lifetime and utility into account. The MCI can be applied on a product- as well as company level and targets industry decision-makers concerning both product development and business models. In general, the methodology focuses specifically on products although this in turn influences circularity on the company level. (Ellen McArthur Foundation, 2019)

Input data

Input data required for the MCI calculations are primarily product specific data collected from companies and average product data. (Ellen McArthur Foundation, 2019).

The calculation itself considers:

- mass flows throughout the life cycle;
- the utility or function of the product, via timespan of usage (including durability of products, repair/maintenance, and shared consumption business models) and intensity of usage;
- rates and flows at the EoL that are going to landfill (or energy recovery), collected for recycling, and collected for reuse;
- the rates and flows of recyclable materials
- and composting and energy recovery from biological materials.

Calculations

Calculating V , **the virgin material** in the product:

$$V = M (1 - F_R - F_U - F_S)$$

Where M is the total mass of input material, F_R is the secondary material from recycling, F_U is the secondary material that is being reused and F_S is representing the fraction of biological materials originating from sustained production.

Waste fractions

For **the overall amount of unrecoverable waste**, W :

$$W = W_0 - \frac{W_F + W_C}{2}$$

Where W_F is the unrecoverable waste from recycling and W_C is unrecoverable waste for reuse. For both terms, the parameter for recycling / reuse efficiency is included as a factor M .

W_0 is **the unrecoverable waste** going to landfill or incineration and is calculated according to:

$$W_0 = M (1 - C_R - C_U - C_C - C_E)$$

Where C_R is the fraction of waste collected for recycling, C_U is the fraction of collected for component reuse, C_C is representing the mass of biological material used that is being composted and C_E is representing the mass of biological material coming from sustained production that is used for energy recovery.

As such when energy recovery is applied C_E is calculated as follows:

$$C_E = (E_E * B_C)$$

$$E_E = \left(\frac{E_R}{(HHV * M_B)} \right)$$

Where E_E is representing the efficiency of the energy recovery process and B_C is representing the carbon content of the biological material that is meeting the requirements for energy recovery to be considered as a part of the circular economy. E_R is the energy recovered, HHV is the Higher Heating Value and M_B is the mass of eligible biological material meeting the requirements for inclusion of energy recovery in circular economy.

W_C and W_F is calculated according to the equations below:

$$W_C = M * (1 - E_C) * C_R$$

$$W_F = M * \frac{(1 - E_F) * F_R}{E_F}$$

Where E_C is the recycling efficiency for the production process of recycled feedstock, E_F is the efficiency of recycling the product material in the end of its life and F_R is the fraction of recycled material in the product.

As such, **The Linear Flow Index (LFI)** is then calculated as follows:

$$LFI = \frac{V + W}{2M + \frac{W_F - W_C}{2}}$$

If E_C and E_F are considered equal, $E_C = E_F = 1$, then W_C and W_F can be considered as $W_C = W_F = 0$ and

$$LFI = \frac{V + W}{2M}$$

Furthermore, the **Material Circularity indicator** (MCI) and taking the products utility function into account can be calculated as follows:

$$MCI = 1 - LFI * F(X)$$

Where **the utility function F(X)**, is calculated as:

$$F(X) = \frac{0.9}{X}$$

representing the use stage of the product life cycle and defined as follows:

$$X = \frac{L}{L_{av}} * \frac{U}{U_{av}}$$

Where L/ L_{av} is the lifetime compared to the average value for the lifetime of similar products and U/U_{av} is the utility compared to the average utility factor of similar products. (Ellen McArthur Foundation, 2019)

Presentation of results

It is a quantitative method resulting in a single score indicator, according to the information below, being a value between 0 and 1. As such, the calculation results in a value of the MCI on a scale of 0 to 1, indicating that the product is fully linear when the value is 0 and fully circular when the value is 1. (Ellen McArthur Foundation, 2019) (See table 1)

Table 1. Guidance of interpretation of the resulting circularity indicator.

For max circularity	For min circularity
$LFI = 0$	$LFI \approx 1, \text{ and } X = 1 \rightarrow MCI = 0.1$
$MCI = 1$	$LFI \approx 1, \text{ and } X < 1 \rightarrow MCI < 0.1$

Assessment score

MCI			
Assessment subject	Assessment criteria	Weight	Score per criteria
Method General	Aggregating accross topics	2,5%	0,025
	Expandability	2,5%	0,025
	Easy / direct or very processed	5,0%	0
	Helpful	5,0%	0,05
Recycled Content	Included in the scope	5,0%	0,05
	Quantified	2,5%	0,025
	Ready for LCA	2,5%	0,025
Recyclability	Included in the scope	15,0%	0,15
	Quantified	10,0%	0,1
	Ready for LCA	5,0%	0,05
Renewables	Included in the scope	5,0%	0,05
	Quantified	2,5%	0,025
	Ready for LCA	2,5%	0,025
Quality of recycling	Included in the scope	10,0%	0
	Quantified	5,0%	0
	Ready for LCA	5,0%	0
Design for disassembly	Included in the scope	3,0%	0
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
Design for low maintenance and repair	Included in the scope	3,0%	0,03
	Quantified	1,0%	0,01
	Ready for LCA	1,0%	0,01
Design for reuse	Included in the scope	3,0%	0,03
	Quantified	1,0%	0,01
	Ready for LCA	1,0%	0,01
		Total score:	0,7

Figure 1. Overview of assessment for the MCI.

Based on the assessment made on the MCI, the method is assigned a single score of 0.7.

Identification of gaps related to circularity information in the EPD

Based on the assessment above it is possible to identify some gaps that should be filled for the method to be able to contribute with the circularity information that would be useful in an EPD. The MCI provides an in-depth and thorough formula for assessing the material circularity of a product and contributes to circular economy by assessing the main building blocks for circularity measures. However, based on the criteria for this assessment, it lacks a few vital parts to fulfill the goal of being a fully developed indicator for product circularity. The most prominent concepts that are not fully addressed are: “Quality of recycling” as it assumes that the quality remains the same throughout the cycle/process and “Design for disassembly” is not taken into consideration in the calculations regarding the design of a circular product. Nevertheless, in terms of reuse of the product as a whole or its components separately, the method provides an explanation for each option where both definitions are closely related to the EoL variables regarding waste distribution. Therefore, the reuse of the product and its components are in a proper way taken into account.

References

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New Circularity Index (NCI)

EnelX and ICMQ

2021-2022

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Specific approach

The New Circularity Index developed by EnelX and ICMQ has the aim to measure the relevance of non-virgin materials and renewable energy consumed in a product life, calculated as a relative percentage of total material and energy flows. The NCI is applicable to products for which a function is identifiable on its whole life, according to a from cradle to grave scenario. The calculation model takes into account the amount of materials, water, energy and transports involved in the process and the produced waste; the outcomes highlight the circularity index of materials, energy, water and waste.

Input data

The input data required for the NCI calculation have to be specific for the product and calculated according to its functional unit, in a life-cycle approach.

The specific inputs are:

- functional unit according to the product category
- reference service life according to the product category and a specific RSL is the producer can justify a different scenario
- materials as raw materials and components, packaging materials, auxiliary materials for production, consumable materials in use stage, materials for maintenance and their packaging, materials for remanufacturing and their packaging
- energy as electrical energy and thermal energy consumed in production, installation, use, maintenance, decommissioning, remanufacturing and transport in all life stages
- water as water consumed in production and use
- waste as waste generated during production, maintenance, end of life and remanufacturing

Calculations

The NCI analyses the flows of material, energy, water and waste that are involved in all the stages of the product life. In each of the four categories, NCI is the relationship between the circular inputs and the total inputs involved in the product life, as described below.

Materials

$$NCI \text{ of materials} = \frac{\text{Circular materials}}{\text{Circular materials} + \text{Non - circular materials}}$$

Where:

- Circular materials = Renewable virgin materials + Recycled materials + Reused materials
- Non-Circular materials = Non-renewable virgin materials

Energy

$$NCI\ of\ energy = \frac{Circular\ energy}{Circular\ energy + Non - circular\ energy}$$

Where:

- Circular energy = Renewable electrical energy + Renewable thermal energy + Transport by electrical vehicle + Transport by train
- Non-Circular energy = Non-renewable electrical energy + Non-renewable thermal energy + Diesel + Unleaded petrol + Transport by truck + Transport by ship + Transport by aircraft

Water

$$NCI\ of\ water = \frac{Circular\ water}{Circular\ water + Non - circular\ water}$$

Where:

- Circular water = Recycled water
- Non-Circular water = Well water + Tap water

Waste

$$NCI\ of\ waste = \frac{Circular\ waste}{Circular\ waste + Non - circular\ waste}$$

Where:

- Circular waste = Waste to energy recovery + Waste for recycling + Waste for reuse
- Non-Circular waste = Waste to disposal

It is also calculated a material share and an energy share, as the material and energy contents for each year of reference service life, according to the functional unit.

Presentation of results

The "PRODUCT NCI" is a set of four specific NCIs, which represent:

- NCI of materials
- NCI of energy
- NCI of water
- NCI of waste

For the materials category, the following four values are presented:

- Quantity of Non-Circular inputs as: Non-renewable virgin materials (kg)
- Percentage of Non-Circular inputs as: Non-renewable virgin materials (% on total materials)
- Quantity of Circular inputs as: Circular materials (kg)
- Percentage of Circular inputs as: NCI of materials

The other three categories of energy, water and waste follow the same structure in results presentation.

Comprehensive level of circularity

To generate a single score resulting indicator for the circularity performance of the product, the four specific NCI results are weighted into a comprehensive level of circularity. All four NCI results are weighted the same with a factor of 0,25. As such the final single score will provide a per centage which represents the final circularity performance of the product. Depending on the per centage, the circularity performance is divided into 5 different levels.

Assessment score

New Circularity Index - EnelX/ICMQ (NCI)							
Assessment subject	Assessment criteria	Weight	Available answers				Score per criteria
Method General	Aggregating accross topics	2,5%	Yes = 1	Medium = 0,5	No = 0	Unknown = 0	0,025
	Expandability	2,5%	Yes = 1	Medium = 0,5	No = 0	Unknown = 0	0,025
	Easy / direct or very processed	5,0%	Direct = 1	Medium = 0,5	No = 0	Unknown = 0	0,05
	Helpful	5,0%	Yes = 1	Medium = 0,5	No = 0	Unknown = 0	0,05
Recycled Content	Included in the scope	5,0%	Yes = 1		No = 0	Unknown = 0	0,05
	Quantified	2,5%	Yes = 1		No = 0	Unknown = 0	0,025
	Ready for LCA	2,5%	Yes = 1		No = 0	Unknown = 0	0,025
Recyclability	Included in the scope	15,0%	Yes = 1		No = 0	Unknown = 0	0,15
	Quantified	10,0%	Yes = 1		No = 0	Unknown = 0	0,1
	Ready for LCA	5,0%	Yes = 1		No = 0	Unknown = 0	0,05
Renewables	Included in the scope	5,0%	Yes = 1		No = 0	Unknown = 0	0,05
	Quantified	2,5%	Yes = 1		No = 0	Unknown = 0	0,025
	Ready for LCA	2,5%	Yes = 1		No = 0	Unknown = 0	0,025
Quality of recycling	Included in the scope	10,0%	Yes = 1		No = 0	Unknown = 0	0
	Quantified	5,0%	Yes = 1		No = 0	Unknown = 0	0
	Ready for LCA	5,0%	Yes = 1		No = 0	Unknown = 0	0
Design for disassembly	Included in the scope	3,0%	Yes = 1		No = 0	Unknown = 0	0
	Quantified	1,0%	Yes = 1		No = 0	Unknown = 0	0
	Ready for LCA	1,0%	Yes = 1		No = 0	Unknown = 0	0
Design for low maintenance and repair	Included in the scope	3,0%	Yes = 1		No = 0	Unknown = 0	0,03
	Quantified	1,0%	Yes = 1		No = 0	Unknown = 0	0,01
	Ready for LCA	1,0%	Yes = 1		No = 0	Unknown = 0	0,01
Design for reuse	Included in the scope	3,0%	Yes = 1		No = 0	Unknown = 0	0,03
	Quantified	1,0%	Yes = 1		No = 0	Unknown = 0	0,01
	Ready for LCA	1,0%	Yes = 1		No = 0	Unknown = 0	0,01
Total score							0,75

Figure 1. Overview of assessment for the NCI.

Based on the assessment made on the NCI, the method is assigned a single score of 0.75.

Identification of gaps related to circularity information in the EPD

Based on the assessment, the NCI has a strong coherence with the EPD because was developed with the aim to become an EPD indicator. Therefore, the LCA principles and the assessment of the life-cycle stages are integrated with reference to the product functional unit and with a fully quantitative data collection. For each element inserted in the analysis, the quantity of circular and non-circular inputs have to be traced and demonstrated with useful supporting documents, as for a LCA study in EPD development. The “Quality of recycling” category is non addressed because the NCI is based on the quantities of material/energy/water/waste and their characteristics are considered with the aim to link them to the circular or non-circular category, without and judgment about the quality of the process. The “Design for disassembly” in not direct considered, even

though this category can be intended to influence the waste management in the end of life, when the quantity of waste to recycling is measured.

Reference

ICMQ (2022). Technical Manual for the calculation of the Product NCI – New Circularity Index

ICMQ (2022). NCI Tool, Demo V.0.3, 2022-04-04

ICMQ (2022). Regolamento per la certificazione dell'indice di circolarità di prodotto, Rev. 0.2, 12-05-2022

Circular Economy Indicator Prototype (CEIP)

Cayzer et al.

2017

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Specific approach

The Circular Economy Indicator Prototype (CEIP) is based on the circular economy (CE) principles developed by the Ellen McArthur Foundation (EMF) and developed to measure the product circularity over the whole life cycle of a product. As a method, the CEIP is really developed as an extension of the Kingfisher Circularity Calculator (KCC), previously created as a pilot project as part of the Material Circularity Indicator (MCI) study, also rooted in the EMF CE principles. As such, the circularity principles are central to the CEIP which includes elaborated criteria, an additional number of questions and improved structure and design to previous methods. (Cayzer et al., 2017)

The CEIP is designed to be used by manufacturers and retails companies of tangible goods with access to bill of materials (BOM) to measure and evaluate product performance in relation to CE. The users should have relatively in-depth knowledge of the product at hand, the CE model and Excel. A deeper understanding of the product specifics is seen as an advantage as it encourages the user to be more engaged with the circularity considerations of their product and possible future circularity demands. (Cayzer et al., 2017)

Input data

Answers to the questionnaire require specific information of the product characteristics as well as its relation to the concept of circularity. The information comes from manufacturers or retail companies with access to the required data. It is mainly qualitative information needed to answer these questions. However, some of the questions can require quantitative information as well. (Cayzer et al., 2017)

Calculations

The indicator is built on a questionnaire divided into five different stages of the product life cycle: design/redesign, manufacturing, commercialisation, in use, end of life. Each of these stages consist of multiple questions addressing more specific circularity variables connected to the CE principles. (Cayzer et al., 2017)

Table 3. Questions used in the CEIP.

Lifecycle Stage	Question	Variable measured: Rationale	Points	Associated CE Principles
Design/Redesign	Is the product made from recycled/reused material?	Material Selection – Use of Recovered Material. The use of reused or recycled materials reduces waste, demonstrates social responsibility and can help to ensure continuity of material supply	20	Material Selection, Cascades Thinking
	Is the product lighter than its previous version?	Material Selection – Dematerialisation. A good circular design demands less material for the same performance and quality	2	Material Selection
	Is there a complete bill of materials and substances for the product?	Material Identification – Presence of Bill of Materials. A complete bill of materials and substances provides the information required to plan for the recapture and re-use of component materials and enables the management of hazardous substances	5	Material Identification
Manufacturing	Is there a complete bill of energy for the manufacturing process?	Energy Identification – Presence of Bill of Energy. A complete bill of energy provides the information required to plan for the energy consumption and efficiency of manufacturing processes. It also contribute to the shift for using more renewable energy sources	10	Energy Identification
	Is there a complete bill of solid waste for the manufacturing process?	Manufacturing Waste Management. Waste must be avoided in a CE and it must be treated as 'food' for other processes. The waste of one process must be the resource for another process. This decreases the pressure and impacts of waste to the environment	15	Waste Management
Commercialisation	What packaging is being used?	Product Packaging. The impact of the packaging of the product or service has been reduced or eliminated with any packaging that has been used being clearly labelled to allow for effective recycling	5	Cascades Thinking, Materials, Waste
	What is the product's warranty?	Product Lifetime Extension – Warranty. Extended product guarantees that minimise the need to purchase replacement products can help to enhance our reputation for providing high quality, durable products	10	Cascades Thinking, Waste
	Is there a rental option for the product?	Product Access – Rental Schemes. Rental schemes beside acquisition enables customers to access higher quality products and materials without having to purchase the product themselves	15	Diversity
In Use	Can the usage status and identification of the product be established?	Product Lifetime Extension – Usage Status and ID. Knowing the usage status and the identification of the product contributes to plan maintenance actions before a malfunction happens. Thus, the lifetime of the product is extended	15	Cascades Thinking, Waste
	Can the product be repaired?	Product Lifetime Extension – Repair Options. Product lifetimes can be extended where products have been specifically designed for easy repair. This helps to retain custom and enhance our reputation for providing quality products and services	5	Cascades Thinking, Waste
	Can the product be reused?	Product Lifetime Extension – Reuse Options. Product lifetimes can be extended where used products have been designed to be traceable and their usage status can be easily established. Second hand markets development fosters products to find new users and extend their lifetime	10	Cascades Thinking, Waste
End of Use	Does the product reduce waste through its use?	Waste Reduction. Products that reduce waste facilitate the CE by enabling other products to become more circular	5	Waste Reduction
	What take-back scheme is available for this product?	Product Recovery – Availability of Take Back Schemes. Take-back schemes enables customers to dispose of their unwanted products and provide a mechanism for the recapture of materials and their introduction into the supply chain	15	Cascades Thinking, Materials, Waste
	Is the product separated out from other products at the end of its life?	Product Recovery – Segregation. The products recovered via take-back schemes are segregated properly and can be used to provide raw materials for the manufacture of new products. This reduces the risk of material scarcity and pricing fluctuations in the supply chain	10	Cascades Thinking, Materials, Waste
	Are the product's materials passed back into the supply chain?	Product Recovery – Product's Materials Reintroduction. Reusing or recycling a high proportion of the reclaimed material drives the development of a CE	10	Cascades Thinking, Materials, Waste

Note: Shaded questions are new; bold questions are those that have been amended from the KCC version.

Figure 1. The questionnaire including the five life cycle stages and respective questions as well as the distribution of points for each question. It also shows the relevant variables related to the CE principles for each question. Source of figure: (Cayzer et al. 2017)

To be able to transfer the answers to the questions into a quantitative form, each of the questions were rewarded with a specific number of points adding up to 152 points in total. The distribution of points was based on a literature review and interviews where a few of the life cycle stages were seen as more relevant in relation to the CE principles than others. As such, there are two of the stages that are rewarded with the majority of points, "In use" and "End of use" with 35 points each. The rest of the points are distributed between the other life cycle stages included in the questionnaire. Moreover, two of the questions are also giving the possibility to achieve bonus points lifting the inclusion of non-virgin materials or availability of BOM, see figure 2. Based on these points and the answers to the questions, each of the five life cycle stages gives an aggregated score and a total score for the circularity performance of the product. (Cayzer et al., 2017)

	LIFECYCLE	VARIABLE	QUESTION	ANSWER
Q1	Design	Material Selection - Use of Recovered Material	Is the product made from recycled/reused material?	
		<i>The use of reused or recycled materials reduces waste, demonstrates social responsibility and can help to ensure continuity of material supply.</i>	<i>Evaluate what % of the total weight of the product comes from non-virgin materials: reused (inc. remanufactured) and recycled sources.</i>	%
Q3	Design	Material Identification - Presence of Bill of Materials	Is there a complete bill of materials and substances for the product?	Yes
		<i>A complete bill of materials and substances provides the information required to plan for the recapture and re-use of component materials and enables the management of hazardous substances.</i>	<i>Assist a manufacturer with understanding of the chemicals that are present in the product so that they may be assessed for their potential to adversely impact human or environmental health.</i>	No

Figure 2. The questions which can give bonus points for the circularity performance of the product. Q1, where it is possible to include the percentage of recycled or reused material included in the product, and Q3, where it is possible to include whether there is a complete bill of materials and substances available for the product. Source of figure: (Cayzer et al. 2017)

Presentation of results

The resulting indicator is presented in an Excel format including tables showing the total product rating in a percentage, the total product ranking in text, and total points scored from the questionnaire in comparison with the total available points in the assessment. As such, this indicator is a single metric method for the product circularity of a product. However, the result for each life cycle stage in the questionnaire is also shown in another table which gives an indication on which circularity subject might need further improvement. The score for each subject is also compared to the total amount of available points in a spider diagram. The structure of the presentation of results is shown in figure 3. (Cayzer et al., 2017)

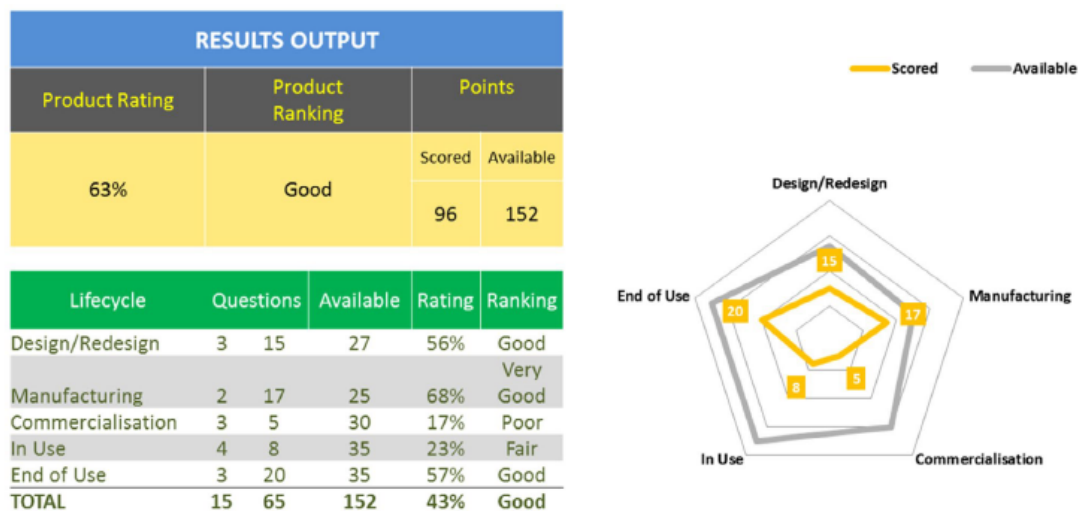


Figure 3. Presentation of results for the CEIP. Source of figure: (Cayzer et al. 2017)

Assessment score

CEIP			
Assessment subject	Assessment criteria	Weight	Score per criteria
Method General	Aggregating accross topics	2,5%	0,025
	Expandability	2,5%	0,025
	Easy / direct or very processed	5,0%	0,05
	Helpful	5,0%	0,05
Recycled Content	Included in the scope	5,0%	0,05
	Quantified	2,5%	0,025
	Ready for LCA	2,5%	0,025
Recyclability	Included in the scope	15,0%	0,15
	Quantified	10,0%	0,1
	Ready for LCA	5,0%	0
Renewables	Included in the scope	5,0%	0
	Quantified	2,5%	0
	Ready for LCA	2,5%	0
Quality of recycling	Included in the scope	10,0%	0
	Quantified	5,0%	0
	Ready for LCA	5,0%	0
Design for disassembly	Included in the scope	3,0%	0,03
	Quantified	1,0%	0,01
	Ready for LCA	1,0%	0
Design for low maintenance and repair	Included in the scope	3,0%	0,03
	Quantified	1,0%	0,01
	Ready for LCA	1,0%	0
Design for reuse	Included in the scope	3,0%	0,03
	Quantified	1,0%	0,01
	Ready for LCA	1,0%	0
		Total score	0,62

Figure 4. Overview of the assessment of the CEIP method.

Based on the assessment made on the CEIP, the method is assigned a single score of 0.62.

Identification of gaps related to circularity information in the EPD

Based on the assessment above it is possible to identify some gaps that should be filled for the method to be able to contribute with the circularity information that would be useful in an EPD. The CEIP have a clear focus on the circularity performance of a product based on defined CE principles throughout the life cycle of a product making it easy to follow through the different stages. However, the method is mainly based on qualitative information where it, for most of the cases, is not possible to derive a specific quantitative result for the product characteristics and are therefore difficult to directly translate into and LCA. Also, the method leaves out important aspects regarding the quality of the recycled material even if it clearly considers to what extent the loop is closed or not and are therefore not clearly answering the question on if the materials circled back into the manufacturing process after the use stage is able to be used for new products. Moreover, the method does not include renewables in the scope of product assessment. Nevertheless, the method delivers a straightforward, although quite basic, pathway for evaluation of the circularity performance of a product for each step along the life cycle making it easy to follow and distinguish possible future adaptation of the product for an increased positive circularity performance.

Reference

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

Resource Duration Indicator (RDI)

Franklin-Johnson et al.

2016

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Specific approach

The Resource Duration Indicator (RDI) enables managers to visualize their contribution to a more circular economy by measuring the longevity of their products. As such, this method aims at measuring the length of a products lifetime where the material is retained in the product system. By keeping the material in the product system, the resource exploitation of the material for a product can be maximized through product use, reuse, and material recycling. (Franklin-Johnson et al., 2016)

Input data

To be able to calculate the RDI indicator, product specific input data for the different stages of the life cycle is required such as:

- Temporal information for the different lifetime categories of the product in months
- End of life data relating to what is circled back in the loop and what is refurbished
- As well as what percentage is collected for recycling and for unrecovered waste.

Calculations

The calculations used for the indicator can be divided into two different categories, one used to establish the lifetime between two events (temporal calculations), and one to establish the direction of the material/product flow (directional calculations). These two calculation categories can together aid in determine the longevity of the product or material at hand.

Firstly, the temporal calculations are all measured in months and can be divided into three parts, the initial lifetime (A), the refurbished lifetime (B) and the recycled lifetime (C). A is representing the lifetime for the use of a new product. B, the refurbished lifetime is based on variables representing the percentage of returned products (w), the percentage of these product being refurbished (x) and the lifetime of the resulting refurbished product in months (U). As such, w and x are variables representing the direction of the material flows in the product system. The resulting variable B is calculating the increased lifetime of the product due to recirculated, refurbished, and reused products. The calculation for the refurbished lifetime, B, is described as follows:

$$B = B_1 + B_2$$

Where B_1 and B_2 , are representing each time the product is refurbished and are expressed as:

$$B_1 = w_1 \times x_1 \times U_1$$

$$B_2 = w_1 \times x_1 \times w_2 \times x_2 \times U_2$$

The third temporal part of the calculations is representing the recycled lifetime, C, which is representing the gained lifetime to the product due to returned and recycled products. C are representing the sum of used products being returned and recycled, C₁, and used products being returned, refurbished, returned, and recycled, C₂. As such, the contribution of the recycled lifetime for the product is considered through out the lifecycle of the product and is described as follows:

$$C = C_1 + C_2$$

Where C₁ and C₂ are calculated by following equations and where y is the percentage of recycled products and z is the percentage of unrecovered materials from the product.

$$C_1 = (A + B_1 + B_2) \times \left[\frac{(w_1 \times y_1 \times z_1)}{(1 - w_1 \times y_1 \times z_1)} \right]$$

$$C_2 = (A + B_1 + B_2) \times \left[\frac{(w_1 \times x_1 \times w_2 \times y_2 \times z_2)}{(1 - w_1 \times x_1 \times w_2 \times y_2 \times z_2)} \right]$$

As such, C is expressed in the same unit as A and B and represent the time that recycling od products and material use contribute with for the total lifetime of a product.

The resulting longevity indicator can as such be calculated as a sum of all the lifetime contributions for the product lifecycle. (Franklin-Johnson et al., 2016)

$$Longevity = A + B + C$$

Presentation of results

Based on the previously described calculation methodology of the product system, where A, B and C represent temporal variables that are common for any general product system, the resulting longevity indicator is presented as a single value with the time unit months.

Assessment score

Resource Duration Indicator (RDI) / Longivity			
Assessment subject	Assessment criteria	Weight	Score per criteria
Method General	Aggregating accross topics	2,5%	0,0125
	Expandability	2,5%	0,0125
	Easy / direct or very processed	5,0%	0,05
	Helpful	5,0%	0,05
Recycled Content	Included in the scope	5,0%	0,05
	Quantified	2,5%	0,025
	Ready for LCA	2,5%	0,025
Recyclability	Included in the scope	15,0%	0
	Quantified	10,0%	0
	Ready for LCA	5,0%	0
Renewables	Included in the scope	5,0%	0
	Quantified	2,5%	0
	Ready for LCA	2,5%	0
Quality of recycling	Included in the scope	10,0%	0
	Quantified	5,0%	0
	Ready for LCA	5,0%	0
Design for disassembly	Included in the scope	3,0%	0
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
Design for low maintenance and repair	Included in the scope	3,0%	0,03
	Quantified	1,0%	0,01
	Ready for LCA	1,0%	0,01
Design for reuse	Included in the scope	3,0%	0,03
	Quantified	1,0%	0,01
	Ready for LCA	1,0%	0,01
			0,325

Figure 1. Overview of assessment for the RDI.

Based on the assessment made on the RDI, the method is assigned a single score of 0.325.

Identification of gaps related to circularity information in the EPD

The method is clearly focused on the use phase of the product life cycle. As such the specific calculations are in a very comprehensive way taking the material flows and lifetimes for new, recycled and refurbished material/products into account. However, as the method is so focused on the use phase, it also lacks the inclusion of other important stages concerning the whole circularity measure of a product (e.g., it does not consider the input material in the new product). Nevertheless, the method clearly favors the closed loop as it is promoting to keep material and resources within the product system as long as possible, both in terms of refurbished, recycled or reused material, in order to be used as input in new products.

Reference

Franklin-Johnson, E., Figge, F., Canning, L. (2016). Resource duration as a managerial indicator for Circular Economy performance. *Journal of Cleaner Production* 133, 589–598. <https://doi.org/10.1016/j.jclepro.2016.05.023>

Recycling Indices (RIs) for Circular Economy (CE)

Van Schaik & Reuter

2016

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Presentation of results

The resulting RI for a product is then shown in a chart, see figure 2, representing a specific level of recyclability. It is as such shown in the form of a weighted average in percentage based on the product specific elements recyclability characteristics. The averages are ranging on the scale of A+++, A++, A+, A, B, C, D, E, F, and G based on the resulting percentage of product recyclability, see figure 3. (Van Schaik & Reuter, 2016)



Figure 2. The final weighted recycling indices for different products. This is an example based on different productions of LED lamps. Source of figure: (Van Schaik & Reuter, 2016)

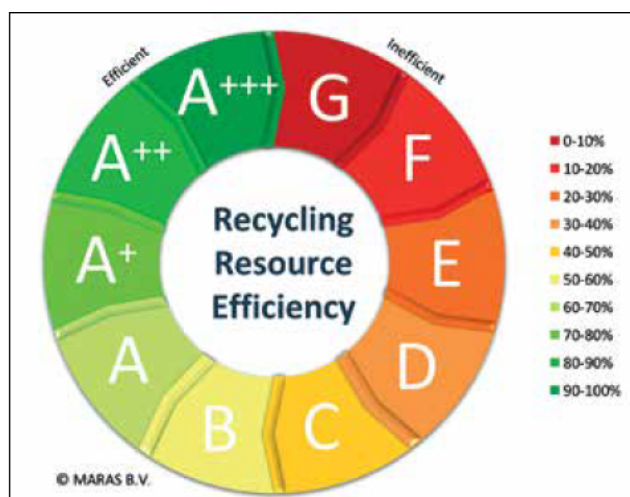


Figure 3. The scale for the weighted resulting recycling indices based on the total percentage of the weighted average of all included elements. Source of figure: (Van Schaik & Reuter, 2016)

Assessment score

Recycling Indices for Circular Economy (RIs for CE)			
Assessment subject	Assessment criteria	Weight	Score per criteria
Method General	Aggregating accross topics	2,5%	0
	Expandability	2,5%	0
	Easy / direct or very processed	5,0%	0,05
	Helpful	5,0%	0,025
Recycled Content	Included in the scope	5,0%	0
	Quantified	2,5%	0
	Ready for LCA	2,5%	0
Recyclability	Included in the scope	15,0%	0,15
	Quantified	10,0%	0,1
	Ready for LCA	5,0%	0,05
Renewables	Included in the scope	5,0%	0
	Quantified	2,5%	0
	Ready for LCA	2,5%	0
Quality of recycling	Included in the scope	10,0%	0
	Quantified	5,0%	0
	Ready for LCA	5,0%	0
Design for disassembly	Included in the scope	3,0%	0
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
Design for low maintenance and repair	Included in the scope	3,0%	0
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
Design for reuse	Included in the scope	3,0%	0
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
			0,375

Figure 4. The assessment of the RIs for CE based on defined criteria and weightings.

Based on the assessment made towards the defined criteria shown above, the RI method is reaching a score of 0,375.

Identification of gaps related to circularity information in the EPD

The RI method is quite clearly focused on one topic related to the product lifecycle and is mainly taking the recyclability of the product into account. As such, the method is lacking the inclusion of the full lifecycle of a product and does therefore not give a proper indication of the circularity potential of the product at hand. The method can therefore also not be considered to cover the main topics relating to the circular economy. Additionally, the documentation provided for the methodology does not provide a very detailed explanation of the weighted average making it difficult to understand the weighting of the result.

Reference

Van Schaik, A., Reuter, M.A. (2016). Recycling Indices Visualizing the Performance of the Circular Economy, World of Metallurgy, 69, 4.

Material based Circularity Index (CI)

Cullen J.M

2017

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Specific approach

Cullen (2017) present a material-based circularity index (CI) focusing on material losses in the lifecycle and in a closed loop system where used resources at the end of life are circled back into the first stages of the lifecycle again. As such, the indicator is mainly focusing on the end of life of the product cycle giving an indication on product circularity related to quantity and quality of material. As such, this method can be used to compare the material losses for the end of life process between different materials. In this case, the method is presented by an example of comparing four different metals. (Cullen, 2017)

Input data

The methodology for the CI requires for the first part of the calculation the amount of material input into the product and the amount of collected materials for recycling at the end-of-life stage. For the second part, the input data required is the energy required for production of the primary material as well as the energy required to recover said material. (Cullen 2017)

Calculations

The calculation method of the final CI is divided into two parts, α and β , representing the dissipative material losses (α) and a ratio for conservation of quality for recycled material (β).

Dissipative material losses, alpha

$$\alpha = \frac{\text{recovered EOL material}}{\text{total material demand}}$$

Ratio for conserving the quality of recycled material, beta

$$\beta = 1 - \frac{\text{energy required to recover material}}{\text{energy required for primary production}}$$

Based on these two ratios a final circularity index for the specific material can be calculated according to the following equation.

$$CI = \alpha\beta$$

As such, the final circularity index is an estimation of material circularity taking losses in terms of both quality and quantity related to the reprocessing of materials into consideration. (Cullen, 2017)

Presentation of results

The resulting CI is presented as a single value representing a final estimation of material circularity for a specific material. The final CI is used as an indicator for gaps between the theoretical and real circularity of a material. The theoretical circularity is reached when $CI = 1$. (Cullen, 2017)

Assessment score

Material based Circularity Index (CI)			
Assessment subject	Assessment criteria	Weight	Score per criteria
Method General	Aggregating accross topics	2,5%	0
	Expandability	2,5%	0,025
	Easy / direct or very processed	5,0%	0,05
	Helpful	5,0%	0,025
Recycled Content	Included in the scope	5,0%	0
	Quantified	2,5%	0
	Ready for LCA	2,5%	0
Recyclability	Included in the scope	15,0%	0,15
	Quantified	10,0%	0,1
	Ready for LCA	5,0%	0,05
Renewables	Included in the scope	5,0%	0
	Quantified	2,5%	0
	Ready for LCA	2,5%	0
Quality of recycling	Included in the scope	10,0%	0,1
	Quantified	5,0%	0,05
	Ready for LCA	5,0%	0,05
Design for disassembly	Included in the scope	3,0%	0
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
Design for low maintenance and repair	Included in the scope	3,0%	0
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
Design for reuse	Included in the scope	3,0%	0
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
			0,6

Figure 1. Overview of assessment for the CI.

Based on the assessment made on the CI, the method is assigned a single score of 0.6.

Identification of gaps related to circularity information in the EPD

The method is mainly focused on the aspect of material losses throughout the end of life processes and in this way, gives an approach to the recyclability of different materials. The CI indicator does in this case consider a few of the important aspects of product circularity. However, the main disadvantage with the method is that it does not consider the stages throughout the lifecycle. As such, the final circularity indicator does not include the recycled content, renewables or the design for disassembly, low maintenance and repair, nor reuse. Therefore, the method would have to cover more ground to be able to generate a more detailed result.

Reference

Cullen, J.M. (2017). Circular Economy: Theoretical Benchmark or Perpetual Motion Machine?: CE: Theoretical Benchmark or Perpetual Motion Machine? Journal of Industrial Ecology 21, 483–486. <https://doi.org/10.1111/jiec.12599>

Product-Level Circularity Metrics (PLCM)

Linder et al.

2017

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Specific Approach

The Product-Level Circularity Metrics (PLCM) method aims to enable producers and consumers to systematically contribute to an increased level of material recirculation. The method has a clear and specific focus on material recirculation and product components. The product components are referred to in terms of their economic value (estimated on the basis of a cost-based method). (Linder et al. 2017) The method covers the full value chain - from cradle to grave.

The PLCM centers exclusively on the level of circularity of the product's composition of materials and the activities required to recirculate those materials. The materials making up the components are all given different economic values depending on them being recirculated or not. (Janik and Ryszko, 2019)

Input data

The circularity metric requires specific internal company data to calculate the ratio between the economic value of recirculated components of the product and the total economic value of the product. The calculations take recirculation, repurpose, refurbishment, remanufacturing and recycling etc. into consideration and prefer so-called "tight" cycles (e.g., refurbishment and remanufacturing).

To determine the product-level circularity of the product (c), the product components are visualized as a tree by the authors (see figure X) where each component is assigned an economic and a circularity value by each node of the tree. This model allows the combination of the different components to be summarized to generate a specific circularity value for the whole product assembled by the specific components. (Linder et al. 2020) As such, the metric consists of an iterative calculation which treats the product throughout the value chain.

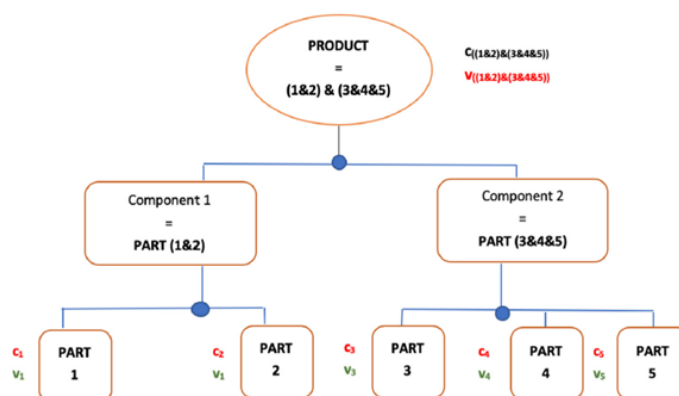


Figure 1. Visualization of the parts of the products where each part have a c-value representing the percentage of economic value for recirculated parts, and a v-value representing its economic value. Source of figure: (Linder et al., 2017)

Calculations

As such, the circularity indicator for the whole product is calculated by the ratio between the economic value of recirculated parts and the total economic value of the product according to the equation below:

$$C = \frac{\text{economic value of recirculated parts of the product}}{\text{total economic value of the product}}$$

In order to follow the product throughout the value chain the calculations are iterative, including values for each added component to the product where each component is assigned with a circulatory value (c) and total value (v). As such, the iterative process is for each step of the equation including the new values of the added components according to the equations below:

$$c_{1\&2} = c_1 \times \frac{v_1}{v_1+v_2} + c_2 \times \frac{v_2}{v_1+v_2} \quad (2)$$

$$v_{1\&2} = v_1 + v_2 \quad (3)$$

If an added part to the product is missing a circularity value equation (1) is applied where the “economic value for recirculated parts of the product” instead is referred to as “the parts of the relevant product part” and to all parts of the product. Following equations therefore show how to express this in an easier way where r_i is the economic value of the recirculated parts of the product part and n_i is the economic value for the parts that is not recirculated.

$$C_i = \frac{r_i}{r_i+n_i} \quad (4)$$

The value of r can then be derived by using the equation below:

$$r = \max [\text{cost of parts including handling costs such as procurement and logistics costs; sum of market prices for virgin materials contained in the product; secondhand market price for used material or component}] \quad (5)$$

And the value of n according to:

$$n = \text{costs of parts that have not been recirculated} \quad (7)$$

Then, the new value of v for a new product part introduced becomes the sum of both the value of the recirculated parts and the virgin parts of the added product part expressed as:

$$v_i = r_i + n_i \quad (8)$$

The metric also includes activities / work made on the product throughout the value chain. This can be divided into material and non-material work and should be prioritized according to the effect it has on the resulting circularity of the product. Material work is defined as an activity that changes the value of the product in terms of both circularity and total value. As such, this type of activity should be prioritized in the calculations as it has a larger impact on the resulting circularity indication of the product in the end than the non material work. When non material work is added to the process, for example inspection, assembly or sales, this must also be included as the total value of the product increases with that activity. However, the circularity of the product or the component does not change in this scenario. The only added value is the cost of the activity. (Linder et al. 2017)

Presentation of results

It is a single score indicator, based on the material composition of the product, including virgin, reused, recycled or remanufactured materials. The indicator is resulting in a score on the scale of 0 to 1 (or 0% to 100%) where 0 equals a product composed of only primary materials and 100 equals a product composed only by reused, recycled or remanufactured materials. (Linder et al. 2017)

Assessment score

PLCM			
Assessment subject	Assessment criteria	Weight	Score per criteria
Method General	Aggregating accross topics	2,5%	0,025
	Expandability	2,5%	0,025
	Easy / direct or very processed	5,0%	0,05
	Helpful	5,0%	0,025
Recycled Content	Included in the scope	5,0%	0,05
	Quantified	2,5%	0,025
	Ready for LCA	2,5%	0
Recyclability	Included in the scope	15,0%	0
	Quantified	10,0%	0
	Ready for LCA	5,0%	0
Renewables	Included in the scope	5,0%	0
	Quantified	2,5%	0
	Ready for LCA	2,5%	0
Quality of recycling	Included in the scope	10,0%	0
	Quantified	5,0%	0
	Ready for LCA	5,0%	0
Design for disassembly	Included in the scope	3,0%	0
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
Design for low maintenance and repair	Included in the scope	3,0%	0,03
	Quantified	1,0%	0,01
	Ready for LCA	1,0%	0,01
Design for reuse	Included in the scope	3,0%	0
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
Total score:			0,25

Figure 1. Overview of assessment of the PLCM method.

Based on the assessment made on the PLCM, the method is assigned a single score of 0.25.

Identification of gaps related to circularity information in the EPD

Based on the assessment above it is possible to identify some gaps that should be filled for the method to be able to contribute with the circularity information that would be useful in an EPD. The PLCM introduce a circularity indicator in a monetary value. The method considers some of the important blocks for circular economy and includes the whole value chain in the production part of the product. The PLCM also includes activities for the product through its lifetime, both in terms of material and non-material activities. In this way, the method considers both activities affecting the physical state of the product through the lifetime (e.g., maintenance or repair) as well as other activities linked to the product cycle (e.g., inspection and sales). However, even if the method includes these important stages, it leaves out other important steps for specifically product circularity such as, “Recyclability”, “Quality of recycling” and “Renewables” when assessing the product circularity.

References

Janik, A., Ryszko, A. (2019). Circular economy in companies: an analysis of selected indicators from a managerial perspective. *Multidisciplinary Aspects of Production Engineering* 2, 523–535. <https://doi.org/10.2478/mape-2019-0053>

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

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

Circularity Potential Indicator (CPI)

Saidani et al.

2017

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Specific Approach

The Circularity Potential Indicator (CPI) aims to fill the gap of systemic vision and operational considerations through a holistic and integrated framework offering a tool to measure, improve and monitor the circularity performance of a product. The authors present a holistic framework based on a combination of a top down and bottom up approach. The top-down approach is goal driven and based on internationally acknowledged conceptions and classifications. The bottom-up approach is data driven and primarily steered by local conceptions and appreciations from stakeholders. Both with their own advantages and disadvantages, the developers propose a combination of the two in order to tackle their shortcomings and create synergies. A combination of the approaches arguably allows for data collection that covers not only the central product features fulfilling requirements, but also markets, business models, regulations, collaborations etc which may relate to the lifecycle of the product and thus affect its circularity. (Saidani et al. 2017)

Input data

The CPI is an Excel questionnaire covering the four building blocks of the circular economy proposed by the Ellen McArthur Foundation where each block contributes to a closed loop concept. However, each building block requires support from the other blocks as well to be able to fully contribute to the closed loop. The four building blocks are:

- Circular Product Design
- New Business Model
- Reverse Cycles
- Enablers and Favourable System Conditions

Each of the four blocks are represented by a number of attributes. In turn, these attributes are assessed by answering one or a couple of multiple-choice questions in order to evaluate the extent to which the product is fulfilling the given attribute. As such, the input data can be product-, company and industry specific depending on the user objective. Depending on the qualitative data provided, it ought to be noted that the method allows for existing products to be assessed while also providing an opportunity to review products that are still in the process of being designed. (Saidani et al. 2017)

Calculations

To weigh the answers of the questions against each other, each possible answer is given a value in accordance with the Likert scale (see table X). This is one of the most recognized scales used in the design science field where each possible answer is given a quantitative value that represents the circularity performance of the product. As such, according to the Likert scale, each possible answer is given a value between 0 and 5 which is then used to calculate an unweighted average of the answers representing a value for the attributes of the building block. This is done if the attribute consists of more than one question. (Saidani et al. 2017)

Table 1. Example of the structure of the Likert scale used for the weightings of the different possible answers. Source of table: (Saidani et al., 2017)

Number of possible answers	Assigned scores to the possible answers (the higher the contribution to circularity is, the higher the score is)				
	#2	0			5
#3	0	2.5		5	
#4	0	1.67	3.33		5
#5	0	1.25	2.5	3.75	5

The values for each building block is then calculated as the sum of the unweighted averages representing each attribute and the final value of the CPI for the specific product is then calculated as the sum of all four building blocks.

Presentation of results

The questionnaire results in a number of scores: one score for each question, one score for each attribute, one score for each building block and finally a total CPI score. The total CPI score gives an indicated value for the circularity performance of the assessed product based on the averages of the building blocks and the attributes. To simplify the calculations, the method assumes that each building block and its associated 5 attributes are of equal importance for the product’s circularity.

Circularity Performance Indicator Unlock the Circularity Potential of your Product		Circularity Score of the Product = (out of 100)	13.06
BB#1 - Circular Product Design (sub-score / 25)			8.06
ATT#1 - Materials selection and combination compatibility (sub-score / 5)			3.89
Number of different materials	1 or 2	5.00	
Technical recyclability of materials combination	High	5.00	
Material contamination (coating, paints, and material mixing)	Medium	1.67	
ATT#2 - Modular product design, adaptability and flexibility			4.17
Is the product contained standardised components	Mainly	3.33	
Has the product being design with a modular mindset	Totally	5.00	
ATT#3 - Design for disassembly and easy end-of-life sorting			0.00
Handling and manoeuvrability of the product (for a single user)	Select Answer		
Number of different distinct components (regarding the size of the product)	Select Answer		
Joints and connections numbers (regarding the size and number of components)	Select Answer		
Joints and connections types	Select Answer		
Joints and connections accessibility	Select Answer		
Disassembly cost and time (regarding value of the product)	Select Answer		
Tools required for disassembly	Select Answer		
ATT#4 - Design for upgradability			0.00
Possible options of upgradability	Select Answer		
ATT#5 - Design for maintainability and longevity			0.00
Wear and tear indicator or information	Select Answer		
Possibility of maintenance and repair	Select Answer		
Accessibility, visibility, reachability and identifiability of key components	Select Answer		
BB#2 - New Business Model			5.00
ATT#6 - Design for PSS & Product-as-a-Service			5.00
Is the manufacturer currently retain ownership of the product	Yes	5.00	
ATT#7 - Leasing or rental schemes			0.00
Leasing or rental offers for the product	Select Answer		
ATT#8 - Aftersales services - Customized services related to the product			0.00
Number of services (leasing, repair, maintenance, spare parts, training)	Select Answer		

Figure 1. Picture of the presentation of results. Source of figure: (Circularity Potential Indicator (circulareconomyindicators.com))

Assessment score

CPI			
Assessment subject	Assessment criteria	Weight	Score per criteria
Method General	Aggregating accross topics	2,5%	0,025
	Expandability	2,5%	0,025
	Easy / direct or very processed	5,0%	0,05
	Helpful	5,0%	0,05
Recycled Content	Included in the scope	5,0%	0,05
	Quantified	2,5%	0
	Ready for LCA	2,5%	0
Recyclability	Included in the scope	15,0%	0,15
	Quantified	10,0%	0
	Ready for LCA	5,0%	0
Renewables	Included in the scope	5,0%	0
	Quantified	2,5%	0
	Ready for LCA	2,5%	0
Quality of recycling	Included in the scope	10,0%	0,1
	Quantified	5,0%	0
	Ready for LCA	5,0%	0
Design for disassembly	Included in the scope	3,0%	0,03
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
Design for low maintenance and repair	Included in the scope	3,0%	0,03
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
Design for reuse	Included in the scope	3,0%	0
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
		Total score:	0,51

Figure 2. Overview of the assessment of the CPI method.

Based on the assessment made on the CPI, the method is assigned a single score of 0.51.

Identification of gaps related to circularity information in the EPD

Based on the assessment above it is possible to identify some gaps that should be filled for the method to be able to contribute with the circularity information that would be useful in an EPD. Firstly, the method covers many of the most important topics related to the circular economy and vital parts for the potential product circularity. However, it does not consider the input of renewable materials nor the design for reuse. The method is also a qualitative method which means that it is not generating any quantitative information throughout the product lifecycle. Nevertheless, the method gives a good overview of the product system related to a circular economy but is lacking vital information making it difficult to look into details of the different lifecycle stages.

References

Saidani, M., Yannou, B., Leroy, Y., Cluzel, F. (2017). [Hybrid top-down and bottom-up framework to measure products' circularity performance](#). International Conference on Engineering Design, ICED 17, Aug. 2017, University of British Columbia, Vancouver, Canada.

Circularitypotentialindicator.com, *The Circularity Potential Indicator (CPI) Tool (beta version)*, Available at: [Circularity Potential Indicator \(circularpotentialindicator.com\)](https://circularpotentialindicator.com)
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End-of-Life Recycling Rates (EOL RRs)

The International Metal Study Groups, Eurometaux and EUROFER

2006

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Specific approach

The End-of-Life Recycling Rate (EoL RR) indicator is mentioned as one of the three key recycling indicators for recycling rates globally. The three indicators considered to be of most importance is The Old Scrap Ratio (OSR), The Recycling Input Rate (RIR) and the EoL RR. The indicators are presented in the context considering recycling of metals. (Tercero Espinoza & Soulier, 2017) The EoL RR indicator is presented in the context of calculating the fraction of metal that a product contains in the last stage of the lifecycle which also is collected, pre-treated, and recycled back in the loop. (Eurometaux and Eurofer, 2012) As such, the indicator is focusing on the function recycling in the end-of-life of the product lifecycle.

Input data

The specific EoL RR value is based on quantitative values of what metal is recycled in the EoL and the metal content of the product itself. (Tercero Espinoza & Soulier, 2017)

Calculations

The indicator is estimated by using following equation:

$$EoL RR_{Global} = \frac{i}{e}$$

The equation is measuring the efficiency of the process of collection, pre-treatment and recycling back in the loop for the metal. Where i is the metal recycled in the EoL stage and e is the content of metal in the product at hand. (Tercero Espinoza & Soulier, 2017)

Presentation of results

The indicator is resulting in a ratio representing the efficiency of the recycling process of metal in the product as well as the recyclability. (Tercero Espinoza & Soulier, 2017)

Assessment score

End-of-Life Recycling Rates (EOL RRs)			
Assessment subject	Assessment criteria	Weight	Score per criteria
Method General	Aggregating accross topics	2,5%	0
	Expandability	2,5%	0
	Easy / direct or very processed	5,0%	0,025
	Helpful	5,0%	0
Recycled Content	Included in the scope	5,0%	0
	Quantified	2,5%	0
	Ready for LCA	2,5%	0
Recyclability	Included in the scope	15,0%	0,15
	Quantified	10,0%	0,1
	Ready for LCA	5,0%	0,05
Renewables	Included in the scope	5,0%	0
	Quantified	2,5%	0
	Ready for LCA	2,5%	0
Quality of recycling	Included in the scope	10,0%	0
	Quantified	5,0%	0
	Ready for LCA	5,0%	0
Design for disassembly	Included in the scope	3,0%	0
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
Design for low maintenance and repair	Included in the scope	3,0%	0
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
Design for reuse	Included in the scope	3,0%	0
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
			0,325

Figure 1. Overview of the assessment of the EoL RR indicator.

Based on the assessment made of the EoL RR indicator, the method is assigned a single score of 0,325.

Identification of gaps related to circularity information in the EPD

Based on the assessment result above, the indicator is limited to the application of one of the lifecycle stages on the product level, the end of life. It is focusing on the collection of metals for recycling which is limiting the use of the indicator when applied to the full lifecycle of a product. It does not consider any design related topics for the product nor the production or usage stage in the lifecycle. As such, the lack of inclusion of a variety of variables important for the product circularity along the lifecycle is the main reason for the scoring of the method.

Reference

Tercero Espinoza. L., Soulier. M. (2017). Defining Regional Recycling Indicators for Metals. An extension of global recycling indicators to regional systems with open boundaries.

Eurometaux, Eurofer. (2012). Recycling Rates For Metals.

Reuse Potential Indicator (RPI)

Park & Chertow

2014

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Specific approach

The Reuse Potential Indicator (RPI) is aimed towards measuring the reuse potential of a specific material based on current state of knowledge of the technology development for reuse of the specific material. It can be used to evaluate the possibility to reuse a certain material without explicitly evaluating the physical characteristics of the material but instead reflects these as a function of the current development of technology. (Park & Chertow, 2014)

Input data

As the potential to reuse a material increases as the technology options increases, the RPI is dependent on time due to how it somewhat measures the evolution of the recovery process of a material. As the reusability of a material depends on the level of both material quality and technological development, the geographical boundaries also become essential for the RPI. The RPI also depends on the quantity produced of the specific material as a material with large production quantities would require an increased technological development. (Park & Chertow, 2014)

Calculations

To explain the methodology behind the RPI, it is presented by way of the example below, see Figure 1. As shown in the figure, the RPI is dependent on the quantity of material that is possible to reuse through the currently available technologies (x-axis) and on the net marginal revenue, being the profit from the material processed with the specific technology minus the cost for disposal (y-axis). However, all different technologies generate different forms of materials for different uses and to different costs. (Park & Chertow, 2014)

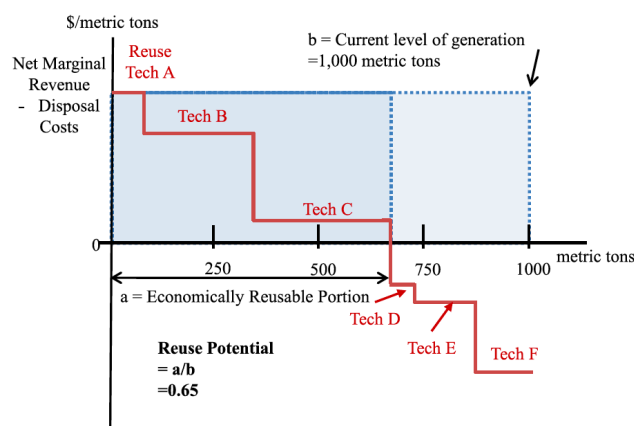


Figure 12. Reuse potential methodology. Source of figure: (Park & Chertow, 2014)

In this example, there are six types of technologies available for reusing a specific material available (A, B, C, D, E, F) and the quantity of waste material produced is assumed to be 1000 metric tons per time unit. The technology A gives the highest value on the y-axis. Technology D, E and F all deliver negative values on the y-axis and are therefore excluded from the calculation as the material recovered through these technologies is not economically beneficial. Therefore, only the material recovered by the technologies A, B and C are used to calculate the RPI. Summarized through these three technologies, there

are 650 metric tons (a) that are economically recoverable out of the original 1000 metric tons (b).

As such, the final RPI is calculated:

$$RPI = \frac{a}{b}$$

which for this example equals to 0,65. (Park & Chertow, 2014)

This material can be said to be “65% resource-like” or “35% waste-like.”

Presentation of results

The resulting RPI is presented as a single number between 0 and 1 representing the usefulness of a material or to what extent the waste material is “waste-” or “resource-like” according to Figure 2. (Park & Chertow, 2014)

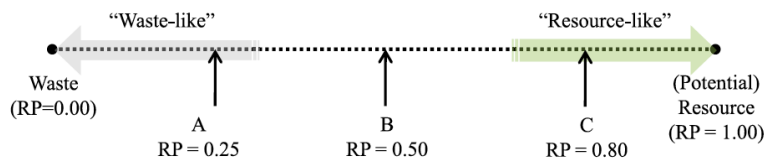


Figure 13. The RPI is expressed as a number between 0 and 1 representing the scale of reuse potential. Source of figure: (Park & Chertow, 2014)

If the RPI equals 0 none of the waste material produced is reusable, whereas an RPI value of 1 would equate that all of the waste material can be reused. (Park & Chertow, 2014)

Assessment score

RPI

Assessment subject	Assessment criteria	Weight	Score per criteria
Method General	Aggregating across topics	2,5%	0
	Expandability	2,5%	0
	Easy / direct or very processed	5,0%	0,025
	Helpful	5,0%	0,025
Recycled Content	Included in the scope	5,0%	0
	Quantified	2,5%	0
	Ready for LCA	2,5%	0
Recyclability	Included in the scope	15,0%	0,15
	Quantified	10,0%	0,1
	Ready for LCA	5,0%	0,05
Renewables	Included in the scope	5,0%	0
	Quantified	2,5%	0
	Ready for LCA	2,5%	0
Quality of recycling	Included in the scope	10,0%	0
	Quantified	5,0%	0
	Ready for LCA	5,0%	0
Design for disassembly	Included in the scope	3,0%	0
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
Design for low maintenance and repair	Included in the scope	3,0%	0
	Quantified	1,0%	0
	Ready for LCA	1,0%	0
Design for reuse	Included in the scope	3,0%	0,03
	Quantified	1,0%	0,01
	Ready for LCA	1,0%	0,01
Total score			0,4

Figure 3. Overview of assessment for the RPI.

Based on the assessment made on the RPI, the method is assigned a single score of 0,4.

Identification of gaps related to circularity information in the EPD

Based on the assessment above, the RPI presents a methodology that considers two of the subjects related to circularity topics. The indicator includes the subjects "Recyclability" and "Design for reuse". This is mainly due to the indicator being limited to the assessment of the EoL phase and specifically the recoverability of a specific material. In relation to the full lifecycle of the product, the RPI lacks a holistic circularity perspective and therefore excludes most of the assessment subjects used in this evaluation.

References

Park, J.Y., Chertow, M.R., 2014. Establishing and testing the "reuse potential" indicator for managing wastes as resources. *Journal of Environmental Management* 137, 45–53. <https://doi.org/10.1016/j.jenvman.2013.11.053>

Appendix 2

Interview Guide

This appendix is presenting the questions used for respective interview with the two green building councils. The questions for each of the interviews are based on respectively research for the council made in advance and are therefore not the same both interviews.

Questions for DGNB

Table A2.1. Interview questions for DGNB

Questions
We know that DGNB include circularity in the building assessment. Would you like to explain a little bit more in detail how, what methodologies are used to assess circularity aspects for the criteria?
Which of the methodologies for circularity used by the DGNB are focusing on quantitative respectively qualitative information?
In the CE report the MCI are clearly noted to be used, other existing methods are mentioned as well but not by name. Do you have any other specific methodology in mind that could be applicable for the DGNB?
What do you expect to see in an EPD to feed directly into the DGNB specific approach? Do you think the circularity information provided in the EPD can be limited to a specific value (quantitative)? Would it be enough for the DGNB, or should it go beyond a single number (qualitative)?

Questions for BREEAM

Table A2.2. Interview questions for BREEAM

Questions
The concept of circular economy is clearly highlighted in several chapters of the rating scheme including waste management and resource use for example. Would you like to give a more detailed explanation on how building circularity is assessed in your rating scheme?
When looking at the possibility for product circularity information to be integrated into the building assessment, what kind of information would you need on a product level to be able to assess building circularity?
And for product circularity information to be useful to you when assessing the building, what should the information look like and in what way would it best be presented? <i>(For example, qualitative or quantitative information in an EPD)</i>
Lastly, I would like to ask you to please share your thoughts on the criteria and the weightings we use to assess whether the existing methods today are contributing with the needed information?

