UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO
Centro Tecnológico
Departamento de Engenharia Ambiental

LETÍCIA ERTHAL CORDEIRO

DEVELOPMENT OF WATERWISE-BR: A CUSTOMIZABLE METHODOLOGY FOR ASSESSING WATER CIRCULARITY IN INDUSTRIAL SYSTEMS APPLIED TO A CASE STUDY IN A BRAZILIAN STEEL MILL

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Aproved on July 25,2025.

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To my family, for planting the seed of environmental awareness in me. And to all who dedicate their lives to the fight for a more just and sustainable future for the Earth, our common home.

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"This humanity refuses to recognize that the river, now in a coma, is also our grandfather; that the mountains mined in Africa or South America and transformed into merchandise elsewhere are also the grandfather, grandmother, mother, brother of some other constellation of human beings that want to go on sharing the communal home we call Earth".

Ailton Krenak

DEVELOPMENT OF WATERWISE-BR: A CUSTOMIZABLE METHODOLOGY FOR ASSESSING WATER CIRCULARITY IN INDUSTRIAL SYSTEMS APPLIED TO A CASE STUDY IN A BRAZILIAN STEEL MILL

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ABSTRACT

Faced with growing water demand, climate change, and regulatory pressures, industrial sectors are increasingly driven to enhance water use efficiency as a strategic response to sustainability challenges. The circular economy (CE) approach offers a practical framework for reducing freshwater abstraction, optimizing reuse, and reintegrating water into natural systems. However, despite rising academic interest, there is still no unified definition of the CE as of 2024, leading to fragmented indicators and methodologies that fail to capture the complexities of industrial water management. To address these limitations, this study contributed to the development of WaterWise– a customizable methodology and intellectual property of Capgemini Engineering. WaterWise-BR was customized to the Brazilian industrial landscape and had its indicators tested in a case study conducted at a domestic steel mill, using real operational data. A systematic literature review was performed to classify and critically assess prevailing circularity indicators and frameworks, drawing from ISO 59020 and foundational references. Limitations of the most comprehensive existing methodologies were examined, and selected indicators were refined to capture sector-specific complexities. The WaterWise-BR framework was then structured through integrative analysis, resulting in a modular methodology capable of evaluating diverse industrial systems. Its core output is a normalized Water Circularity Score (ranging from 0 to 1), derived from a customizable suite of indicators customized to operational and regional characteristics. The methodology encompasses all inflows and outflows, incorporating spatial data on water availability and quality, alongside information on water abstraction, consumption, and disposal. The methodology was subsequently applied in a Brazilian steel mill, proving its practical effectiveness while revealing specific opportunities for refinement. Grounded in CE principles and aligned with ISO 59020 definitions, WaterWise-BR further embeds regulatory targets and regional benchmarks into its evaluative model, thus facilitating cross-sectoral comparability and guiding water sustainability transitions in complex industrial environments.

Keywords: Circular Economy. Sustainable Water Management. ISO 59020. Methodological Framework. Industrial Sustainability.

RESUMO

Diante da crescente demanda por água, das mudanças climáticas e das pressões regulatórias, os setores industriais são cada vez mais impulsionados a aprimorar a eficiência do uso da água como resposta estratégica aos desafios de sustentabilidade. A abordagem da economia circular (EC) oferece um framework prático para reduzir a captação de água doce, otimizar o reuso e reintegrar a água aos sistemas naturais. No entanto, apesar do crescente interesse acadêmico, ainda não existe uma definição unificada de EC até 2024, o que leva a indicadores e metodologias fragmentados que não conseguem capturar as complexidades da gestão da água industrial. Para abordar essas limitações, este estudo contribuiu para o desenvolvimento do WaterWise-BR: uma metodologia personalizável e propriedade intelectual da Capgemini Engineering. Neste trabalho de graduação, o WaterWise-BR foi customizado para o cenário industrial brasileiro e teve seus indicadores testados por meio de um estudo de caso conduzido em uma siderúrgica nacional, utilizando dados operacionais reais. Uma revisão sistemática da literatura foi realizada para classificar e avaliar criticamente os indicadores e frameworks de circularidade prevalecentes, com base na ISO 59020 e em referências fundamentais. As limitações das metodologias existentes mais abrangentes foram examinadas, e indicadores selecionados foram refinados para capturar as complexidades específicas do setor. O WaterWise-BR foi então estruturado por meio de análise integrativa, resultando em uma metodologia modular capaz de avaliar diversos sistemas industriais. Seu principal resultado é uma nota de Circularidade Hídrica (variando de 0 a 1), derivado de um conjunto personalizável de indicadores ajustados às características operacionais e regionais. A metodologia abrange todos os fluxos de entrada e saída, incorporando dados espaciais sobre disponibilidade e qualidade da água, juntamente com informações sobre captação, consumo e descarte de água. A metodologia foi subsequentemente aplicada em uma siderúrgica brasileira, comprovando sua eficácia prática ao mesmo tempo em que revelou oportunidades específicas para aprimoramento. Baseado nos princípios da EC e alinhado com as definições da ISO 59020, o WaterWise-BR incorpora ainda metas regulatórias e benchmarks regionais em seu modelo avaliativo, facilitando assim a comparabilidade entre setores e orientando as transições para a sustentabilidade hídrica em ambientes industriais complexos.

Palavras-chave: Economia Circular. Gestão Sustentável da Água. ISO 59020. Framework Metodológico. Sustentabilidade Industrial.

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GLOSSARY

AGERH	The State Agency for Water Resources of Espírito Santo
CD	Circular Discharge
CE	Circular Economy
CONAMA	Brazil's National Environment Council
CS	Circular Supply
CS/TUR	Centralized supply/total use replaceability.
CWI	Circular water inflow.
CWO	Circular water outflow.
LCA	Life Cycle Assessment
MCI*	Material Circularity Indicator
MCI**	Material Circularity Indicator
OC	Onsite circulation
QD	Quality Dependent
RC	Recirculation Circularity
RHP	Rainfall harvesting potential
RWRR	Ratio (on-site or internal) water reuse or recirculation
WC	Water consumption
WCI	Water Circularity Indicator
WCM	Water Circularity Metric
WCS	Water Circularity Score
WDACE	Water discharged in accordance with CE Principles
WDAQR	Water discharged in accordance with quality requirements
WERR	Water efficiency, reuse and recycling
WF	Water footprint
WRC	Withdrawal reduction circularity
WSC	Water supply centralization
WSD	Water Stress Dependent
WT	Wastewater treatment.
WUFCS	Water use from circular sources
WUR	Water use reduction
WWICS	Water withdrawal from inflow circular sources
WWR	Water withdrawal reduction

SUMMARY

1. INTRODUCTION

Sustainable water management practices are no longer optional; they are a critical responsibility for all organizations worldwide. In Brazil, climate change is driving shifts in rainfall and decreasing the long-term mean flow across four of the country's five major regions (Brazil, 2023). Also, water demand has increased by 80% over the past two decades and is projected to rise an additional 43.5% between 2017 and 2040 (TrataBrasil, 2020). Given that the industry ranks as the third-largest water consumer nationwide (Brazil, 2024), businesses are compelled to adopt adaptive strategies to enhance resilience and reduce environmental impact.

To address this limitation, circular economy (CE) practices can be applied to ensure sustainable water management. Contrary to the linear system we still live in today, where resources are extracted, used, and then discarded, CE aims to maintain a continuous circulation by minimizing resource extraction and waste production while increasing process efficiency. That can be done by reclaiming, preserving, or enhancing their value while contributing to sustainable growth (ISO, 2024a). Despite the growing importance and rapid relevance of CE over the years (Kirchherr; Reike; Hekkert, 2017), its principles are still not extensively explored when applied to the scope of water. However, Brazil recently published in its National Circular Economy Plan 2025-2032 the goal of fostering "the circular economy in the use of water resources, promoting policies and guidelines for the reuse of water in industrial processes" (Brazil, 2025).

The principles of water circularity emphasize the integration of its natural and technical cycles. Achieving water circularity involves extracting from areas not under water stress, enhancing water use efficiency, promoting reuse, recycling wastewater, and ensuring it returns to the original water basin in the appropriate quality, preferably during the correct season, and to its original water body. This approach reduces pressure on freshwater resources, closes the water cycle, and ensures greater water availability for both human and natural systems. By aligning technical water management with natural hydrological processes, circular water practices contribute to sustainable resource use and ecosystem health (Delgado et al., 2021; ISO, 2024b; WBCSD, 2021).

Understanding the circularity degree of a system is necessary for setting and targeting achievable goals to transition from a linear to a CE. By measuring circularity, stakeholders can make informed decisions and implement more impactful actions. In that way, circularity indicators provide a clear framework, identify areas for improvement, for strategizing effectively, and assess remaining progress (Martinetti; Havas, 2021).

Camacho-Otero & Ordoñez (2017) identified a critical gap in the indicators used to measure circularity. The lack of standardization led researchers to understand differently what should be evaluated, promoting the development of circularity assessments based on different concepts, studies, and assumptions (Barros et al., 2023; Geissdoerfer et al., 2017; Kirchherr; Reike; Hekkert, 2017; Korhonen; Honkasalo; Seppälä, 2018; Sarja; Onkila; Mäkelä, 2021; Viles et al., 2020). This contributed to inconsistent analysis when comparing different assessments for identical activities or products (Camacho-Otero; Ordoñez, 2017; Miranda de Souza et al., 2021), neglecting the sector-specific nuances that influence circularity (Valls-Val; Ibáñez-Forés; Bovea, 2022). A definitive definition of CE was only established with the ISO standard released in July 2024 (ISO, 2024a).

In response to this conceptual fragmentation and lack of standardized indicators to date, this work presents the development of WaterWise-BR, a customizable methodology for assessing water circularity in industrial systems. Tailored to reflect the operational particularities, territorial dynamics, and legal frameworks of the evaluated context, WaterWise-BR was conceived to address persistent shortcomings in existing assessment models, particularly their inability to capture sector-specific circularity demands with conceptual clarity and comparative consistency. Grounded in the principles defined by ISO 59020 and structured upon a comprehensive review of established key performance indicators (KPIs), the proposed methodology consolidates best practices from prior methodologies while introducing refinements aligned with stakeholders' expectation for circularity metrics (Camacho-Otero; Ordoñez, 2017), internationally standardized circular actions (ISO, 2024b), regional water sustainability objectives (AGERH, 2024), and applicable national legislation (Brazil, 2011, 1997). Its construction followed methodological guidelines for developing high-quality and integrative circularity assessments (Patil; Van Langen; Ramakrishna, 2023), The proposed methodology supports the full assessment cycle, from initial stakeholder engagement to final report delivery. WaterWise-BR transcends conventional water circularity assessment methodologies by offering granular quantification of water inflows, internal uses, and outflow across all evaluated systems, operationalized through a robust set of KPIs. The strategic integration of these indicators provides actionable insights for multiple applications – including closing loop, risk mapping related to water dependency, valorization of internal wastewater streams, and decision support aligned with CE principles. The resulting analytical outputs empower decision-makers to identify inefficiencies, prioritize corrective actions, and strengthen system resilience, particularly in water-intensive operations and regions experiencing water stress. By converting complex water data into clear, system-specific recommendations, WaterWise-BR enhances institutional capacity for water stewardship, aligning operational performance with regulatory requirements and long-term sustainability goals.

The WaterWise methodology was originally conceived within a professional context during the author's final-year internship at Capgemini Engineering in France, where it was initially designed for general application and tested in the food sector. In the scope of this graduation project, the methodology was refined and adapted to the Brazilian industrial context, and its applicability was tested through a case study conducted at a domestic steel mill, using real operational data. In this version, more indicators were evaluated and later modified to include Brazilian legislation, industrial benchmark, and regional normatives. While implementation-specific tools, such as custom data collection instruments, advanced calculation models, and interactive dashboards, were developed to support the assessment process, they remain proprietary assets of Capgemini Engineering and are not fully disclosed herein. Nonetheless, this work provides a detailed account of the WaterWise-BR methodology, offering a comprehensive basis for future applications and academic investigations into industrial water circularity.

2. OBJECTIVES

2.1. General

Develop a customizable methodology for evaluating water circularity in industrial systems, capable of adaptation to different sectors, territorial contexts, and regulatory frameworks, with particular emphasis on applicability within Brazilian industrial sector.

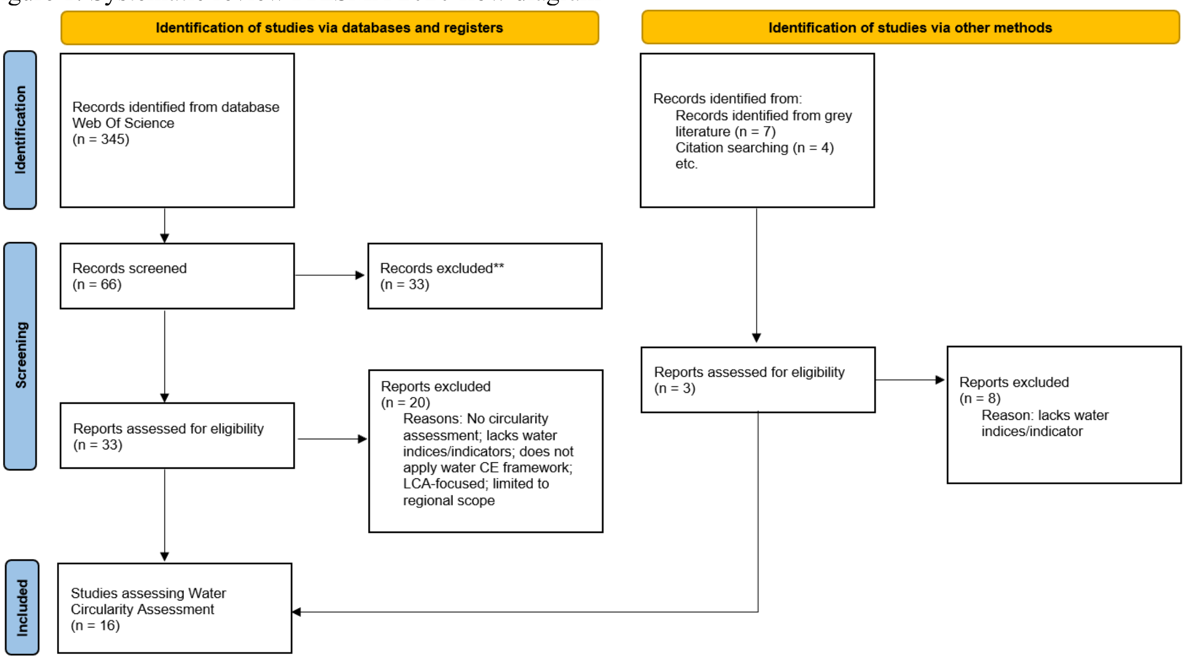
2.2. Specifics

- **i.** To conduct a systematic literature review to identify and critically analyze existing methodologies and KPIs employed in water circularity assessments;
- **ii.** To examine the Brazilian legal and normative framework related to water resource management and circular economy practices, highlighting sector-specific regulatory demands and regional sustainability targets;
- **iii.** To design a methodological framework tailored to the Brazilian industrial context, integrating conceptual foundations, technical indicators, and contextual data for comprehensive water circularity evaluation;
- **iv.** To validate the proposed methodology through a case study in a domestic steel mill, applying the framework to real operational data and analyzing its applicability and diagnostic capacity within a water-intensive industrial environment.

3. LITERATURE REVIEW

The conceptual foundation of the WaterWise-BR methodology was established through a systematic investigation of how water circularity is currently assessed within organizational contexts. A literature review was conducted using the Web Of Science database, following the structured protocol illustrated in Figure 1. The search strategy employed the following set of keywords: *((("water circularity" OR "water management" OR "water efficiency" OR "water") AND ("circular economy" OR "circularity" OR "circular transition") AND ("assessment" OR "evaluation" OR "indicators" OR "metrics")))*. This review encompassed studies published between 2014 and 2025, covering subject areas such as *Environmental Sciences Ecology, Engineering, Science Technology Other Topics, Business Economics, Food Science Technology, Development Studies, Geography, and Public Administration.* A total of 345 articles were identified and subsequently screened to inform the methodological construction, indicator selection, and contextual alignment of WaterWise-BR with industrial assessment requirements. Keywords related to sustainability weren't included. According to Geissdoerfer et al. (2017), their proximity to CE makes it difficult to define boundaries, mixing both concepts.

Figure 1: Systematic review PRISMA 2020 flow diagram



Source: Created by the author.

The review identified diverse approaches to assess water circularity. Specifically, 4 papers proposed new methodologies (Ghosh et al., 2024; Ho; Thach; Bui, 2024), while 6 introduced new indicators, indices, or novel combinations of existing indicators (Han et al., 2017; ISO, 2024b; Karkou et al., 2024; Molina-Moreno et al., 2017; Nuñez-Cacho et al., 2018; Rebolledo-Leiva et al., 2024). Additionally, 3 studies developed tools specifically designed to assess circularity (Hrouga; Michel, 2023; Nika et al., 2020; WBCSD, 2021). On the other hand, 5 papers did not propose new methodologies but instead applied existing ones (H-Hargitai; Somogyi, 2023; Lerdlattaporn et al., 2021; Rufí-Salís et al., 2021; Smol, 2022; Viles et al., 2020). H-Hargitai; Somogyi, (2023) analyzed three distinct methods in their paper. Due to the differing properties of each, they were evaluated separately in this study.

The analysis revealed that 16 of the applied methods were a quantitative evaluation, assessing water flows within a company (Ghosh et al., 2024; Han et al., 2017; H-Hargitai; Somogyi, 2023; Ho; Thach; Bui, 2024; Hrouga; Michel, 2023; ISO, 2024b; Karkou et al., 2024; Lerdlattaporn et al., 2021; Molina-Moreno et al., 2017; Nika et al., 2020; Rebolledo-Leiva et al., 2024; Rufí-Salís et al., 2021; Smol, 2022; Viles et al., 2020; WBCSD, 2021). The other 2 were qualitative assessments, calculating circularity through the answer to a questionnaire about water use and treatment within the organization (H-Hargitai; Somogyi, 2023; Nuñez-Cacho et al., 2018).

In 8 of the studies reviewed, a clear and well-defined framework for selecting indicators was lacking (Ghosh et al., 2024; Han et al., 2017; Ho; Thach; Bui, 2024; Hrouga; Michel, 2023; ISO, 2024b; Karkou et al., 2024; Lerdlattaporn et al., 2021; Nuñez-Cacho et al., 2018). Among these, 5 studies selected indicators based on the industry type without providing explicit justification for their choices (Han et al., 2017; Hrouga; Michel, 2023; ISO, 2024b; Karkou et al., 2024; Lerdlattaporn et al., 2021). In the remaining 3, the indicators were determined through a deliberative process involving an expert committee, which discussed and voted on the most relevant indicators based on their collective judgment (Ghosh et al., 2024; Ho; Thach; Bui, 2024; ISO, 2024b).

Three (3) studies were based on the "3Rs strategy", which includes Reduce, Reuse and Recycle (Molina-Moreno et al., 2017; Rebolledo-Leiva et al., 2024; Viles et al., 2020). Other 3 used the "R-strategy" (Table 1) (H-Hargitai; Somogyi, 2023; Smol, 2022; WBCSD, 2021). Different from the 3Rs, the R-strategy framework can vary from five to ten definitions of R. It englobes more circular actions and has a more holistic approach. 2 studies were based on the framework defined by Ellen MacArthur (H-Hargitai; Somogyi, 2023), where circularity aims to "Eliminate waste and pollution, circulate products and materials (at their highest value), regenerate nature". The concept is similar to "Regenerate Natural Capital, Keep Resources in

Use, and Designing out Waste Externalities", the evaluation framework adopted by (Nika et al., 2020). Finally, 1 study used the Slowing, closing, and narrowing material and energy loops framework (Rufí-Salís et al., 2021).

Table 1: The 10 Rs framework

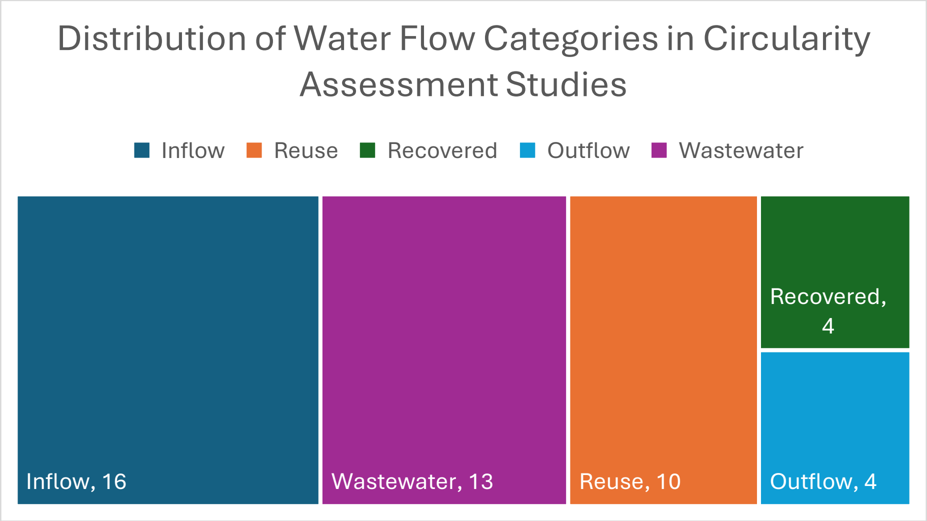
Category	10 R-strategy	Definition
Efficient use of products and manufacturing operations	R0: Refuse	Make the product redundant by abandoning its function or by offering the same ability and function in a fundamentally different product
	R1: Rethink	Rethinking the usage of products, e.g., consumers sharing products.
	R2: Reduce	Efficiently manufacturing the products, e.g., through minimizing natural resources and material usage.
Extension of product lifecycle to many lifecycles	R3: Reuse	The product is reused by another consumer while still retaining original abilities.
	R4: Repair	Repair the product to enable original abilities to properly function.
	R5: Refurbish	Refurbishing the product to its original condition.
	R6: Remanufacture	Dismantle the product and reuse parts in the manufacturing of new products (with the same abilities and functions).
	R7: Repurpose	Use discarded products or their parts in a new product (with other abilities and functions).
Maximization of material usefulness	R8: Recycle	Process the product to obtain material which can be used in the manufacturing of new products.
	R9: Recover	Incineration of material for energy recovery.

Source: Adapted from Kupfer et al., (2022)

Two studies were based on the framework defined by Ellen MacArthur (H-Hargitai; Somogyi, 2023), where circularity aims to "Eliminate waste and pollution, circulate products and materials (at their highest value), regenerate nature". The concept is similar to "Regenerate Natural Capital, Keep Resources in Use, and Designing out Waste Externalities", the evaluation framework adopted by (Nika et al., 2020). Finally, one study used the Slowing, closing, and narrowing material and energy loops framework (Rufí-Salís et al., 2021).

The systematic review identified 7 different frameworks for circularity assessment. This diversity can be attributed to the absence of a universally accepted definition of CE, leading to assessments that vary in their considerations and methodological approaches. This inconsistency demonstrates the need for a unified framework to ensure coherence in circularity evaluations across different study objects. According to Patil; Van Langen; Ramakrishna, (2023), a circularity assessment must evaluate all resource flows within a system. From the papers reviewed, that was only accomplished by quantitative evaluations. Among those, Inflow was included in all assessments (Figure 2).

Figure 2: Comparison of the number of studies assessing different water flow categories in circularity evaluations



Source: Created by the author

Wastewater was identified as a critical component, as it was evaluated in 13 out of the 16 quantitative studies, primarily due to its potential for recovering water, nutrients, and energy (Ghosh et al., 2024; Han et al., 2017; H-Hargitai; Somogyi, 2023; Ho; Thach; Bui, 2024; Hrouga; Michel, 2023; ISO, 2024b; Karkou et al., 2024; Lerdlattaporn et al., 2021; Molina-Moreno et al., 2017; Nika et al., 2020; Smol, 2022; Viles et al., 2020; WBCSD, 2021). Additionally, 10 out of 16 evaluated the reuse of resources (Han et al., 2017; H-Hargitai; Somogyi, 2023; ISO, 2024b; Karkou et al., 2024; Rufí-Salís et al., 2021; Smol, 2022; Viles et al., 2020; WBCSD, 2021). 7 studies also assessed recovered and outflow water flows (ISO, 2024b; Karkou et al., 2024; Lerdlattaporn et al., 2021; Molina-Moreno et al., 2017; Nika et al., 2020; Rebolledo-Leiva et al., 2024; WBCSD, 2021), where outflow encompasses water losses, water incorporated into products, and wastewater directed toward industrial symbiosis, in which wastewater is used as a co-product by another industry.

The primary combination of flows included inflow, reuse, and wastewater. These flows were exclusively evaluated in 4 studies (Han et al., 2017; H-Hargitai; Somogyi, 2023; Smol, 2022; Viles et al., 2020). In other 3, recover and/or outflow were also assessed (ISO, 2024b; Karkou et al., 2024; WBCSD, 2021). This reflects organizations' growing interest in understanding water consumption, improving process efficiency, and identifying opportunities within waste streams to enhance circularity. Although 14 studies assessed water inflow, only 3 integrated water stress data (ISO, 2024b; Nika et al., 2020; WBCSD, 2021). Those also included water circularity principles. Achieving circularity goes beyond reducing water consumption; its broader goal is to apply solutions with the least environmental impact. The review found that 5 out of the 18 methodologies also included Life Cycle Assessments (LCA) or Water Footprints (WF) to evaluate environmental impact (H-Hargitai; Somogyi, 2023; Ho; Thach; Bui, 2024; Rebolledo-Leiva et al., 2024; Rufí-Salís et al., 2021). Both LCA and WF are critical tools for assessing the efficiency of circular solutions, as they reveal potential impact shifts that may arise from implementing circular practices.

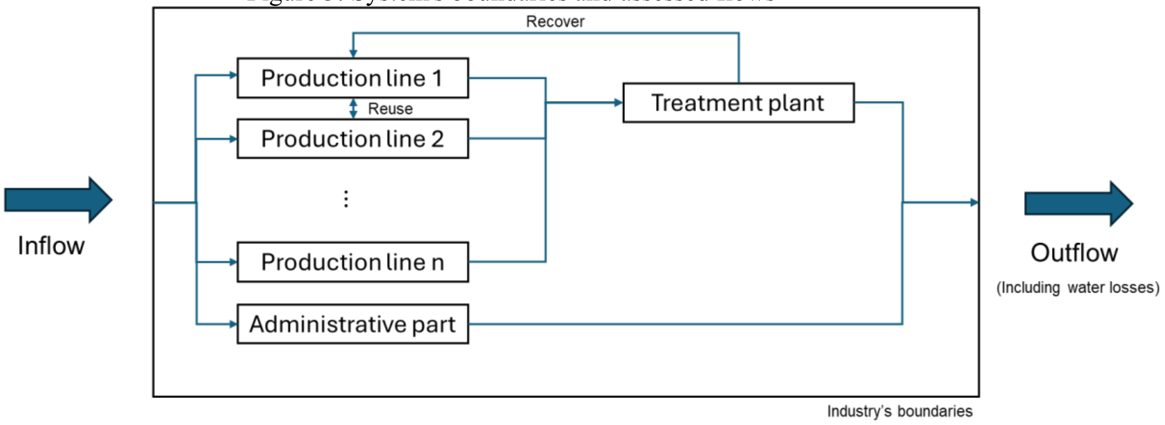
The CE encompasses environmental, economic, and social dimensions, making it a powerful tool for advancing the Sustainable Development Goals. However, only 2 studies (Rebolledo-Leiva et al., 2024; Rufí-Salís et al., 2021) incorporated environmental indicators into their circularity assessments, revealing a significant gap in the integration of these aspects.

The analysis demonstrated that water circularity assessments at the organizational level are primarily focused on on-site operations, often disconnecting them from the broader environmental and social context surrounding the organization. This narrow focus limits the potential of CE to address systemic challenges and contribute holistically to sustainability goals. To fully realize the benefits of CE, assessments should adopt a more integrated approach, considering not only the internal operations but also the external impacts and interactions with the environment and communities.

Therefore, WaterWise-BR's evaluation boundaries will encompass the industry's limits, including its geographical area. If needed, the methodology should incorporate relevant characteristics of the watershed where the industry is based at. The assessment can also be applied to a specific process, as long as it includes water sourcing and discharge. WaterWise-BR should be specific to one company site and does not extend to other units (Figure 3). Table 2 brings the definitions of key terms used.

Based on the information obtained by the systematic review, it was determined that WaterWise-BR should be capable of assessing all water flows within a system while integrating the principles of water circularity as defined by ISO 59020. The tool will employ a quantitative analysis approach, tailored and contextualized through qualitative insights specific to the industry being assessed. This combination of quantitative rigor and qualitative customization ensures that WaterWise-BR can provide a comprehensive and adaptable framework for evaluating water circularity across diverse systems and sectors.

Figure 3: System's boundaries and assessed flows



Source: Created by the author.

Table 2: Definitions of terms used in WaterWise-BR's methodology

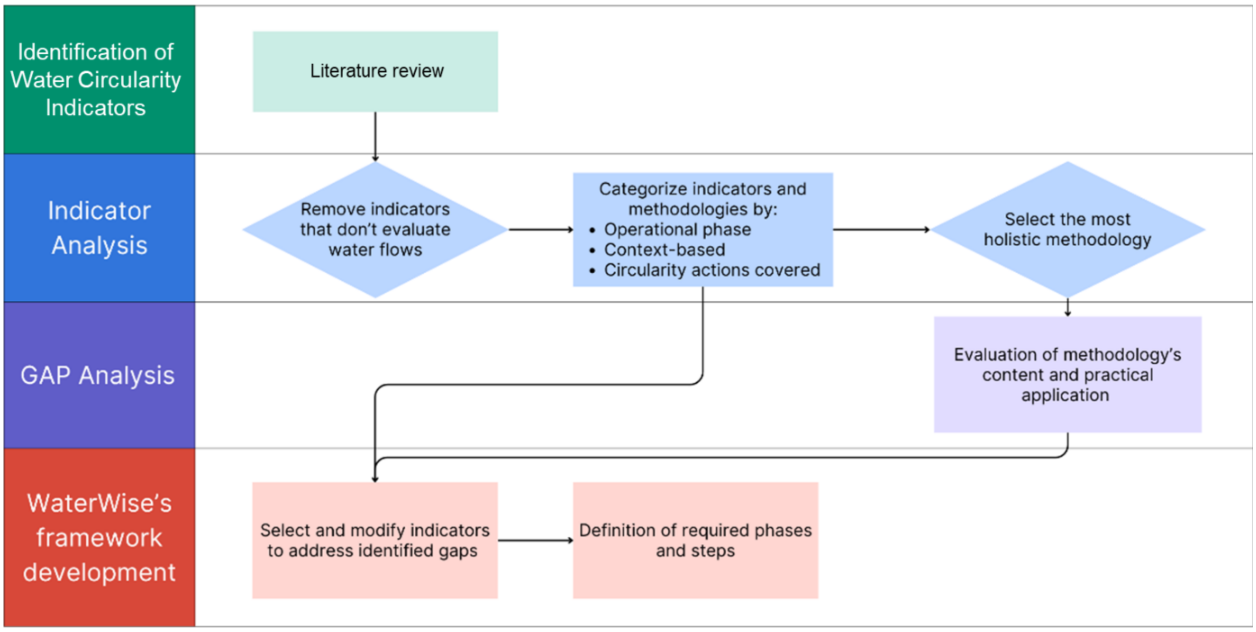
Flow	Definitions
Inflow	Water entering the company in all forms.
Outflow	Water exiting the company in all forms, including water loss.
Reused	The volume of water that is reused within the company before treatment
Recovered	The volume of water that, after treatment, is returned to be used in the company.

Source: Created by the author.

4. METHODOLOGY

The methodology was structured into four phases: literature review, indicator analysis, GAP analysis, and framework development (Figure 4). The following sections provide a detailed description of each phase.

Figure 4: Methodology's flow diagram



Source: Created by the author.

4.1. Identification and analysis of circularity indicators

To identify existing water circularity indicators, a literature review was conducted using Web of Science and ScienceDirect, with the keywords: *indicator OR score OR metric OR measur* AND *circular economy*. Additionally, grey literature was examined to identify operational indicators derived from best practices in industrial, private, and public sectors, presented in reports or designed for circular economy applications in various contexts.

Following identification, indicators were critically analyzed and classified. Those incorporating territorial characteristics, such as local water stress and wastewater quality, were designated as context-based indicators. Indicators were further grouped according to the operational phase they assessed:

- Initial phase: Indicators describing water entry into the system.
- Use phase: Indicators illustrating water utilization within the system.

- End-of-life phase: Indicators assessing water treatment or discharge.

The indices and methodologies evaluated all operational phases and thus were not assigned to a specific one. The most relevant indicators selected for WaterWise-BR should collectively:

- Analyze all operational phases, from extraction to discharge;
- Incorporate territorial information (context-based);
- Cover a broad range of circular strategies;
- Assess water flows comprehensively.

4.2. Framework gap analysis

A three-phase gap analysis was conducted to assess (1) coverage of circular actions, (2) content relevance, and (3) practical application. First, frameworks were ranked according to their inclusion of four circularity actions (ISO, 2024): adding, retaining, and recovering value, and ecosystem regeneration. Each principle was assigned a binary score (1 = included; 0 = excluded).

Next, the top-ranked framework was validated against stakeholder-derived criteria (Camacho-Otero; Ordoñez, 2017) to verify real-world applicability (Figure 5). Camacho-Otero et al. (2017)'s work follows the concepts presented in Table 3. Finally, the framework's implementation phases and procedural steps were evaluated using Patil et al., (2023) assessment guidelines to identify operational gaps and methodological strengths.

Table 3: Definitions of terms used in the GAP analysis

Concept	Description
Purpose	The aim that a circularity assessment has and the objective after implementation.
Scale	Refers to the system level at which the evaluation is addressed.
Aspects	Refers to the different features evaluated by the assessment in terms of criteria that would make a company circular.
Principles	Guiding values or ideas that support the evaluation proposal that help identify what criteria are right or wrong.

Source: Camacho-Otero (2017)

Figure 5: Components a circularity assessment should include

Component	Experts input					
Purpose	Closing the material loops	Keep resources for future generations	To know what natural resources they depend on	To identify opportunities they have from the waste stream	To make decisions that would encourage strategies toward circularity	To communicate the importance of the transition

Scale	The value chain
	Product offering and components
	Company
	Life cycle
	Business model

Aspects	Recycling	Smartness	Waste reduction	Origin of inputs	Waste generation	Material Intensity	Type of business models
	Refurbishment	Energy use	Costs	Renewability	Dependency on future materials	Repairing	Value
	Closing the material loops	Retain value	Reuse	Number of times the product is used	Remanufacturing	Hazardouness	

Principles	Closing material loops
	Systems thinking
	Resilient system
	Maximize value
	Collaboration
	Renewable energy sources
	Strong sustainability
	Positive footprint
	Future-based orientation

Source: Adapted from Camacho-Otero et al. (2017).

4.3. WaterWise-BR’s Framework Development

4.3.1. Indicators selection and modification

To address the identified gaps, a set of indicators was selected. Together, they must collectively capture the four circularity actions. To select, they were grouped by operational phase and ranked according to the number of circular actions they covered (1 = covered; 0 = not covered). Context-based indicators were mandatory for both the initial and final phases.

The top-ranked and best-suited indicators that satisfied all prerequisites were then refined to ensure that they:

- Did not reproduce the shortcomings observed in the reference framework;
- Matched the assessment scope;
- Could be aggregated;
- Conveyed the maximum amount of relevant information.

4.3.2. Phases and steps definition

To ensure the assessment’s quality, specific requirements were established for each phase of its application through critical evaluation and based on Patil RA et al. (2023) (Table 4).

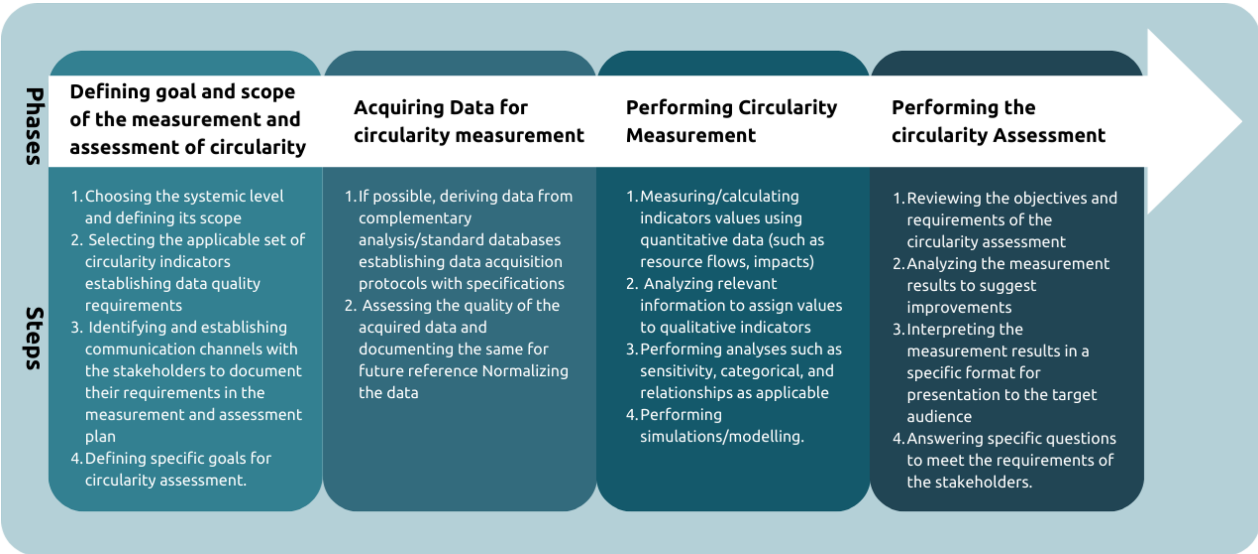
Table 4: Defined requirements for each WaterWise-BR phase

Phases	Requirements											
	Introduce the concept of water circularity to stakeholders	Create communication channels with stakeholders	Align with company purpose and define objectives	Adapt to different company sizes	Enable comparison between different circularity assessments	Assess circularity holistically at organizational level	Ensure clear and standardized data collection	Consider the use of standard data quality	Provide transparent procedure and guidance	Address both qualitative and quantitative data	Provide actionable insights for water circularity improvement	Support decision-making
Phase 1 Define Scope & Goal	✓	✓	✓	✓	✓	✓			✓			
Phase 2 Data Gathering							✓	✓	✓	✓		
Phase 3 Circularity Measurement									✓	✓		
Phase 4 Circularity Assessment											✓	✓

Source: Created by the author.

WaterWise-BR should be structured into four phases to ensure credibility and quality: (1) Defining the goal and scope of the measurement and assessment of circularity; (2) Acquiring data for circularity measurement; (3) Performing circularity measurement; and (4) Performing circularity assessment (Figure 6).

Figure 6: WaterWise-BR's phases and steps

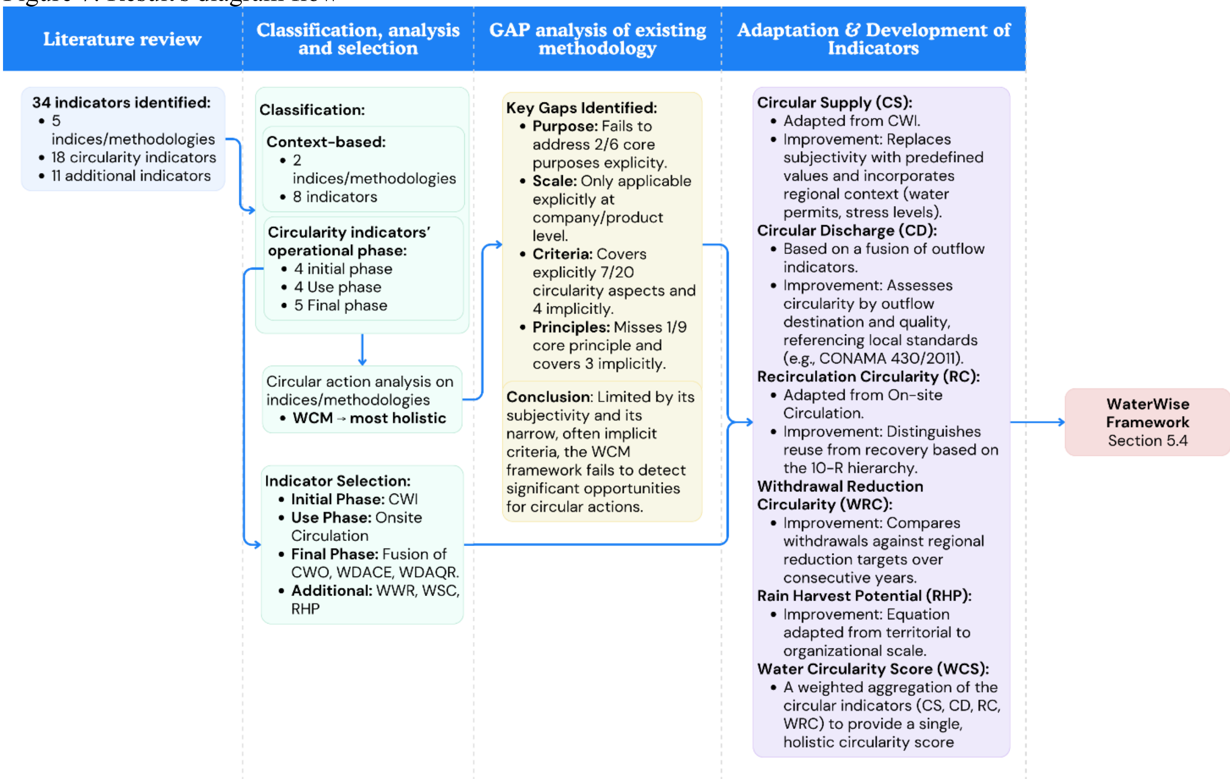


Source: Created by the author.

5. RESULTS AND DISCUSSION

The diagram below (Figure 7) summarizes the findings of this research, linking the dependent variables that led to WaterWise-BR's development. In this section, they will be presented and discussed in greater detail.

Figure 7: Result's diagram flow



Source: Created by the author

5.1. Identification and analysis of circularity indicators

The literature review identified 34 indicators: 5 circularity indices and methodologies, 18 circularity indicators, and 11 additional indicators (Table 5). Circularity indicators assess circularity in only a life cycle phase and typically address one aspect of CE. Indices aggregate circularity indicators and provide a holistic result representing overall circularity in a bigger system. Additional indicators can't assess circularity but are essential to determine and support new CE strategies by demonstrating the potential use of other sources and technologies. The scarcity of indices reflects a lack of holistic assessments, favoring failures or inefficiencies in the system to go unnoticed.

Table 5: Indicators Identified for Circularity Assessment in the Literature

Circularity Indices	**Circularity Indicators**	**Additional Indicators**
Water Circularity Indicator	Ratio (on-site or internal) water reuse or recirculation	Centralized supply replaceability to rainfall
MCI*	Circular water inflow	Centralized supply replaceability to wastewater
MCI**	Circular water outflow	Nutrient extraction from discharged water
Water Circularity Metric	Company targets related to improving water resource management	Rainfall harvesting potential
Water footprint	Number of workers in environmental remediation activities	Reliability of water supply
	Number of workers in water purification	Stormwater Potential for Water Supply - Centralized supply replaceability
	Onsite circulation	Stormwater Potential for Water Supply - Total use replaceability
	Supplier environmental criteria integration	Total use replaceability to rainfall
	Wastewater treatment	Total use replaceability to wastewater
	Water consumption	Wastewater and Stormwater Combined - Potential of total water use replaceability
	Water discharged in Accordance with CE Principles	Water Intensity
	Water discharged in accordance with quality requirement	Water loss recovery potential of total water use replaceability
	Water efficiency, reuse and recycling	Water supply centralization
	Water resource management programmes	
	Water Use from Circular Sources	
	Water use reduction	
	Water withdrawal reduction	
	Water withdrawal from inflow circular sources	

Source: Created by the author

The evaluation process did not include indicators that measure water flows. As shown in Table 6, 2 indices and 8 indicators were identified as context-based. Most of these are positioned in the final and initial phases of the water flow, respectively. In addition to measuring volumetric aspects of water consumption and discharge, they also evaluate water sources, destinations, and quality. Indicators related to the use phase are more limited in scope, focusing primarily within the boundaries of the organization.

Table 6: Operational Flows of Index and Indicators and Context-Based Classification

Indicator	Operational Phase	Context based
Water Circularity Indicator	Indice	N
MCI **	Indice	N
MCI*	Indice	N
Water Circularity Metric	Indice	Y
Water footprint	Indice	Y
Circular water inflow	Initial	Y
Water consumption	Initial	Y
Water withdrawal reduction	Initial	N
Water withdrawal from inflow circular sources	Initial	Y
Ratio (on-site or internal) water reuse or recirculation	Use	N
Onsite circulation	Use	N
Water Use from Circular Sources	Use	Y
Water use reduction	Use	N
Circular water outflow	End of life	Y
Wastewater treatment	End of life	Y
Water discharged in Accordance with CE Principles	End of life	Y
Water discharged in accordance with quality requirement	End of life	Y
Water efficiency, reuse, and recycling	End of life	N
Centralized supply replaceability to rainfall	Additional	N
Centralized supply replaceability to wastewater	Additional	N
Rainfall harvesting potential	Additional	N
Reliability of water supply	Additional	N
Stormwater Potential for Water Supply - Centralized supply replaceability	Additional	N
Stormwater Potential for Water Supply - Total use replaceability	Additional	N
Total use replaceability to rainfall	Additional	N
Total use replaceability to wastewater	Additional	N
Wastewater and Stormwater Combined - Potential of total water use replaceability	Additional	N
Water loss recovery potential of total water use replaceability	Additional	N
Water supply centralization	Additional	N

Source: Created by the author.

WCM is the methodology with more circular actions (Table 7). Its circularity score is composed of an evaluation of water inflow and outflow. WCM contains 3 additional indicators (on-site circulation, water withdrawal/use reduction) and allows the comparison of two scenarios. It stands out for its use of quantitative and qualitative data, such as water quality and availability. However, there are no standards on how that data should be acquired and evaluated. Also, the implementation may vary subjectively.

Table 7: Circular actions included in the evaluated methodologies

	Circular actions			
Indicators	**Create Added Value**	**Retain Value**	**Recover Value**	**Regenerate Ecosystems**
Water Footprint'	✓	✓	-	-
MCI'	✓	✓	-	✓
MCI''	✓	✓	-	✓
Water Circularity Metric	✓	✓	✓	✓
Water Circularity Indicator	-	✓	✓	-

Source: Created by the author.

The top-ranked indicators were chosen for inclusion in WaterWise-BR after being analyzed for every operational phase (, with the selection based on the circular actions outlined in ISO 59004 to make the methodology more robust.

Table 8), with the selection based on the circular actions outlined in ISO 59004 to make the methodology more robust.

Table 8: Circular actions included in the evaluated circularity indicators

Operational Phase	**Circularity Indicators**	**Circular actions**			
		Create Added Value	**Retain Value**	**Recover Value**	**Regenerate Ecosystems**
Initial	Water consumption	-	-	-	-
	Circular water inflow	✓	✓	✓	-
	Water withdrawal reduction	-	✓	-	✓
	Water withdrawal from inflow circular sources	✓	-	-	-
Use	Water Use from Circular Sources	-	✓	✓	-
	Onsite circulation	-	✓	✓	-
	Water use reduction	-	✓	-	✓
	Ratio (on-site or internal) water reuse or recirculation	-	✓	-	-
End of life	Water discharged in Accordance with CE Principles	✓	-	✓	✓
	Wastewater treatment	✓	-	✓	✓
	Water efficiency, reuse and recycling	✓	✓	✓	-
	Circular water outflow	✓	-	✓	✓
	Water discharged in accordance with quality requirement	✓	-	✓	✓

Source: Created by the author.

In the initial phase, the CWI received the highest score and was therefore selected. WUFCS and WUR received the best scores in the use phase. Although derived from different sources, they share similar scopes and functions. However, given their overlap with CWI, OC was judged more relevant. In the final phase, five indicators received identical scores. It was chosen to merge CWO, WDACE, and WDAQR due to their complementary scopes and capability to assess water treatment effectiveness.

The R-strategy suggests that reduction is one of the most beneficial circular actions for the environment. Therefore, WWR was judged important since it illustrates the effectiveness of strategies to reduce consumption. Its inclusion in WaterWise-BR may encourage companies to adopt it.

Additional indicators were evaluated based on their potential to support the selection of alternative solutions. WSC, RHP, and CS/TUR to Rainfall/wastewater were identified as particularly relevant for guiding organizations in defining circular economy strategies.

5.2. GAP analysis of existing methodology

Figure 8 shows WCM analysis in the light of Camacho-Otero; Ordoñez, (2017). Contrary to experts' expectations, WCM fails to address 2 out of 6 core purposes of a circularity assessment, and it is applicable only at the company level. Regarding its coverage, WCM addresses 11 out of 20 criteria, 4 of which are included implicitly. Additionally, it fails to comply with 4 of 9 circularity principles, 3 of which are implicitly included. Although it covers most assessment purposes and is suitable for evaluating companies, it fails when capturing aspects and principles. As a result, important circular actions or opportunities may remain undetected and the assessment varies subjectively.

While the WCM has the potential to collect and use diverse data type, the way they are collected is not standardized, and how the results should be used or interpreted is also not clear. The WCM's reliance on implicit rules makes the assessment subjective. For instance, its decision tree requires users to make judgment calls on vague concepts like "good water governance," a process the WCM guidance admits is uncertain and based on assumptions. This subjectivity makes it impossible to compare results between different companies. The WCM's ability to guide decisions or demonstrate tangible progress towards a circular economy is diminished by the absence of explicit and measurable criteria.

Furthermore, expanding the list of indicators and predefining circularity for qualitative data could expand the range of aspects, purposes, and principles integrated. According to Patil; Van Langen; Ramakrishna, (2023), the main limitations of WCM include the absence of clear communication channels with stakeholders and the lack of transparent, standardized methods for interpreting results. Besides that, data management should involve standardized sources, clear quality benchmarks, and techniques to transform qualitative data into quantitative metrics.

Figure 8: GAP analysis of the chosen methodology (WCM)

Component	**Experts input**					
Purpose	Close material loops	Keep resources for future generations	To know what natural resources they depend on	To identify opportunities they have from the waste stream	To make decisions that would encourage strategies toward circularity	To communicate the importance of the transition

Scale	The value chain
	Product offering and components
	Company
	Life cycle
	Business model

Criteria	**Process**		**Product**		**Others**	
	Efficient use	Renewability	Hazardouness	Recycling	Circular business model	Costs
	Energy use	Repairing	Dependency on future materials	Refurbishing	Retained value	Circulariting materials
	Material intensity	Smartness	Raw materials	Remanufacturing		
	Waste generation	Waste reduction	Reusability	Use intensity		

Principles	Closing material loops
	Systems thinking
	Resilient system
	Maximize value
	Collaboration
	Renewable energy sources
	Strong sustainability
	Positive footprint
	Future-based orientation

Included explicitly
Included implicitly
Not Included

Source: Created by the author.

5.3. Adaptation of indicators

The previously selected indicators were adapted to address identified gaps and support the development of a holistic and tailored assessment tool. Annex A shows each indicator's final equation, and description.

5.3.1. Circular Supply

Originally, CWI used a decision tree to define the source's circularity value. However, the results varied subjectively and presented challenges in cases where the source was unknown. The Circular Supply (CS) avoids this problem by having the sources' circularity previously defined (Table 9). Moreover, for extractions made directly from nature or public/third-party infrastructure, it must consider the region's water stress, and the Water Abstraction Permit given by the government, when applicable.

Table 9: Types of assessed water sources, their circularity, and definitions

Water Source	**Circularity**	**Definition**
Fossil water	0	Water that usually infiltrated millennia ago, and often under climatic conditions different from the present, and has been stored underground since that time.
Industrial Symbiosis	1	Collaborative resource sharing between industries.
Intrinsic Water	1	Water is naturally contained within materials or organisms.
Ocean	1	A vast body of saltwater.
Rainwater	1	Natural precipitation collected from the atmosphere.
Groundwater	WSD[1]	Underground layers of water-bearing rock or sediment from which groundwater can be extracted.
Lake	WSD[1]	Artificial lakes created by damming rivers to store water for various purposes.
Potable water	WSD[1]	Potable water coming from public or third part infrastructure providing water.
Reservoir	WSD[1]	Standing bodies of water often formed by natural processes like glaciation or tectonic activity.
River	WSD[1]	Natural flowing watercourse.
Unknown	WSD[1]	Source or process not identified.

Source: Created by the author.

The circularity of WSD sources must be calculated using a regional water balance index. The approach in Brazil, inspired by the European Environment Agency (EEA), was adapted by the National Water Agency (ANA) to use a drought flow for its reference. For the state of Espirito Santo, the Plano Estadual de Recursos Hídricos (Water Resources Regional Plan) (AGERH, 2018) adopts the Q90 drought flow to classify the water balance into 5 categories (Table 10). For other Brazilian regions, the water balance should be provided by their regional water resources agency. Thus, whenever the source's circularity is classified as WSD (1):

$$WSD\ Circularity = 1 - \frac{Category}{5} \quad (1)$$

[1] WSD = Water Stress Dependent

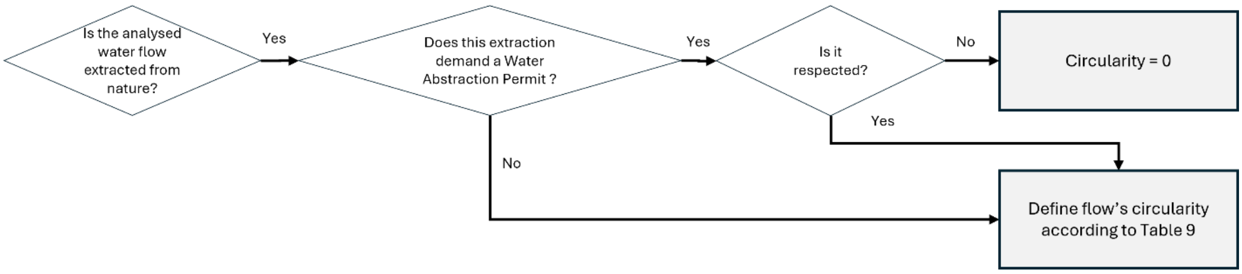
Table 10: Classification of Water Balance Scenarios and Corresponding Management Requirements

Category	Water Balance Percentage	Description
1	< 25%	Good availability condition; minimal management activity is required, and water is considered a free good that any enterprise can capture without significant consequences;
2	25% to 50%	Potentially concerning situation; management actions should be developed to address local supply issues;
3	50% to 75%	Concerning situation; management activity is essential, requiring moderate investments;
4	75% to 100%	Critical situation, demanding intense management activity and significant investments;
5	> 100%	Very critical situation, where management activities, investments, and demand reallocation are urgently needed.

Source: Adapted from (AGERH, 2018)

According to the *Politica Nacional de Recursos Hidricos* (Brazil's National Hydrological Resources Plan) (Brazil, 1997). Individuals or legal entities that extract water directly from water bodies must obtain a Water Abstraction Permit, a regulatory mechanism for water use. Various requirements, defined by each watershed committee (Brazil, 1997), related to water quality conservation and water use regulation, must be fulfilled to obtain it. If the volume of water abstracted by the industry is outside the standards, its circularity will be 0.

Figure 9: Circular Supply's flow chart to determine source's circularity



Source: Created by the author.

Therefore, CS will be calculated as in Equation 2.

$$CS = \frac{\sum_{i=1}^{n}(\text{Source's } Circularity\ i * Volume\ i)}{\sum Total\ Water\ Inflow} \quad (2)$$

The CS ranges from 0 (linear) to 1 (fully circular). A CS value below 1 indicates that a portion of the water originates from sources in water-stressed areas, is drawn from linear sources, and/or that the company is exceeding its water permit.

To formulate a strategy, the inflow data with the lowest circularity must be identified. This issue can be addressed by securing alternative water sources or by optimizing existing processes. Process optimization may involve reducing water loss or increasing water reuse and recovery rates, thereby decreasing the overall water consumption. The CS indicator has the potential to help identify vulnerabilities in the water procurement process. It enables the development of strategies to prevent production disruptions in regions susceptible to water stress, facilitates the search for more sustainable water sources, and supports the promotion of existing sustainable practices. For larger industries, this metric allows stakeholders to evaluate and compare different operational sites, leading to the creation of customized water resilience plans.

5.3.2. Circular Discharge

Based on CWO, WDACE, and WDAQR, the Circular Discharge (CD) (Equation 3) assesses Circularity based on two factors: the destination and quality of the discharged wastewater (Equation 4). Following the principle of water's circular economy, this indicator will consider the a wastewater flow circular when treated and returned to its original watershed. The quality of the water being abstracted should be equivalent to or superior to the quality of the receiving water body. WaterWise-BR will compare the quality of the water being abstracted to the outflow's for practical purposes using the same principle.

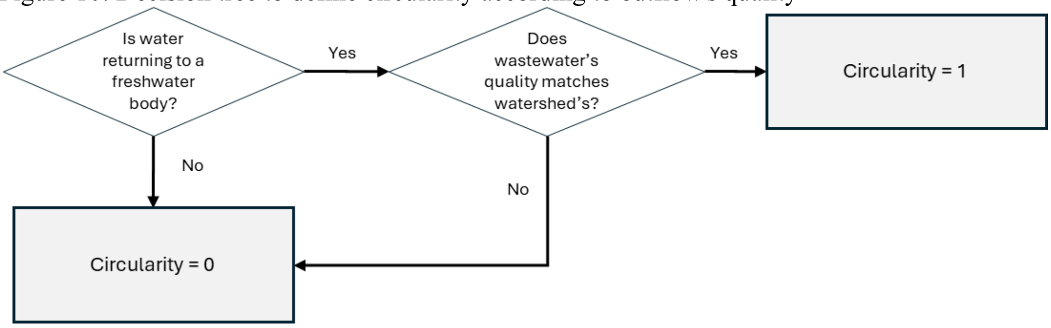
$$Circular\ Discharge = \frac{\sum_{i=1}^{n}(Circularity\ i * Volume\ i)}{\sum total\ water\ inflow} \quad (3)$$

$$Circularity\ i = \frac{Destinantion\ Factor\ i + Quality\ Factor\ i}{2} \quad (4)$$

Destination circularity was defined by answering the question: Does outflow destination "Increase water duration in human-managed water cycle within basin?" (WBCSD, 2021) For returns to nature, ISO 2024b states water should return to the watershed from which it was extracted. Therefore, WaterWise-BR considers a volume circular by comparing inflow and outflow's watersheds.

Those destinations' circularity are defined as Quality Dependent (QD) because quality needs to be assessed to determine if a flow is circular or linear. The quality factor is defined according to the criteria illustrated in Figure 10.

Figure 10: Decision tree to define circularity according to outflow's quality



Source: Created by the author.

Given that each industry generates effluents with distinct compositions, the evaluator must select and justify the most relevant quality parameters for assessment. This selection should reflect the specific pollutants of concern, and the potential environmental impacts associated with discharge. In Brazil, the evaluation process must comply with the standards established by CONAMA Resolution 430/2011 (BRASIL, 2011),any applicable state regulations and the Water Discharge Permit, if it exists. It should be noted that some permit conditions complicate direct comparison, such as when a parameter like BOD is defined by a removal efficiency (e.g., 60%). In such cases, a method must be found to standardize the permit information to compare it with the measurement and define the circularity. If the effluent fails to meet the defined quality thresholds, the flow is considered linear (circularity = 0). A value of 0 is assigned for "no" and 1 for "yes", resulting in Table 11.

The CD ranges from 0 (linear) to 1 (fully circular). A value below 1 means that at least one outflow in the system is not circular. A perfect score of 1 is rarely achieved, as all processes incur water losses that must be accounted for. Attention should be given when these losses are high enough to substantially impact on the total intake volume. A low CD value can also result from other factors, including: the production and sale of products with high embodied water content outside the region; high rates of evaporative loss; non-compliance with effluent discharge permits (regarding volume or quality); the disposal of effluent in locations that render the water unavailable for subsequent use; or the mixing of effluent with rainwater. The effectiveness of the indicator in highlighting the factors that lower the final score is directly related to the granularity and detail of the data provided, which is essential for elaborating a corrective strategy.

Table 11: Definition of different outflows' possible destination and their circularity

Destination	Circularity Discharge	Definition
Deep Well Injection	0	Disposing water by injecting it deep into the ground, typically into porous rock formations, making it unavailable for future use.
Lost	0	Water lost during the process due to leaks, spills, or other inefficiencies.
Product incorporated	0	Water that becomes part of a final product and is no longer available to use.
Stormwater Drainage Systems	0	Water discharged into systems designed to manage and convey stormwater runoff.
Evaporation	0	Water lost to the atmosphere as vapor.
Municipal Sewage System	1	Water discharged into the local public sewer system for further treatment and disposal.
Industrial Symbiosis	1	Water reused or exchanged with other industries for their processes, enhancing resource efficiency.
Energy Production	1	Water used in energy production processes.
Lake	QD[2]	Water discharged into a natural or artificial lake.
Land Application	QD[2]	Water applied to land for irrigation, fertilization, or other beneficial uses.
Ocean	QD[2]	Water discharged directly into the ocean or into a nearby water body that eventually flows into the ocean, making that volume unavailable for future use.
Reservoir	QD[2]	Water released into a reservoir for storage and future use.
River	QD[2]	Water discharged into a river or stream.
Groundwater	QD[2]	Water that infiltrates into and replenishes underground aquifers.

Source: Created by the author.

The absence of measurements for effluent discharge and process losses indicates a critical need for investment in monitoring. Without quantifying these outflows, relevant volumes of water that could be recovered or retained in the system are overlooked, as this lack of data prevents the identification of where and how losses occur, thus hindering mitigation efforts

By making these overlooked wastewater flows visible, the indicator enables targeted interventions. Its mechanism, which accounts for total water losses and the embodied water in products, promotes the adoption of eco-design principles. This encourages innovative solutions and collaborations, such as industrial symbiosis, by making the benefits of resource efficiency measurable.

[2] QD = Quality Dependent

5.3.3. Recirculation circularity

Recirculation circularity (RC), based on OC, distinguishes between reuse and recovery. While both retain water within the system, their environmental impacts differ. Recovery involves treating wastewater, which requires more water and energy. In contrast, reuse bypasses treatment, avoiding additional resource consumption.

$$RC = Reuse\ circularity * x_1 + Recover * x_2 \tag{5}$$

Where,

$$x_1 = \frac{7}{8};\ x_2 = \frac{1}{8}$$

The weights were determined according to the 10 R-Strategies, which ranks actions by importance from most to least impactful, and a corresponding score from 1 to 10 was assigned to each strategy.(Table 12). Therefore, reuse is weighted more heavily than recover to encourage industries to adopt reuse practices if they aim to achieve a high circularity score.

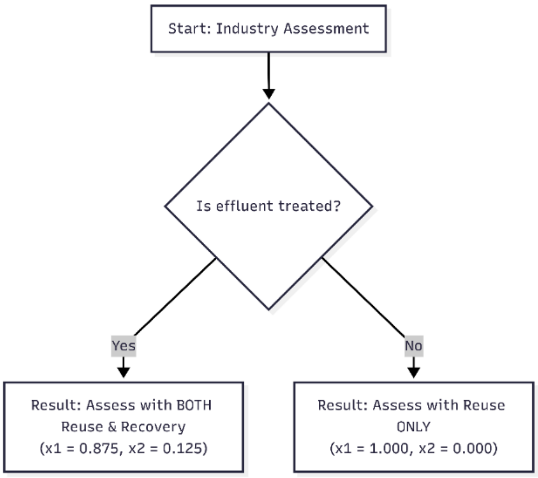
Table 12: Classification of the R-strategies by points

R-strategy	Points
R0: Refuse	10
R1: Rethink	9
R2: Reduce	8
R3: Reuse	7
R4: Repair	6
R5: Refurbish	5
R6: Remanufacture	4
R7: Repurpose	3
R8: Recycle	2
R9: Recover	1

Source: Created by the author.

Reuse is always a requirement for industry-level assessments, as water can be used for non-potable purposes in sectors of an industry. The evaluation includes recover if effluent treatment is available on-site. This leads to two possible scenarios with distinct weighting schemes as specified in Figure 11.

Figure 11: RC Indicator Composition: Industry Scope

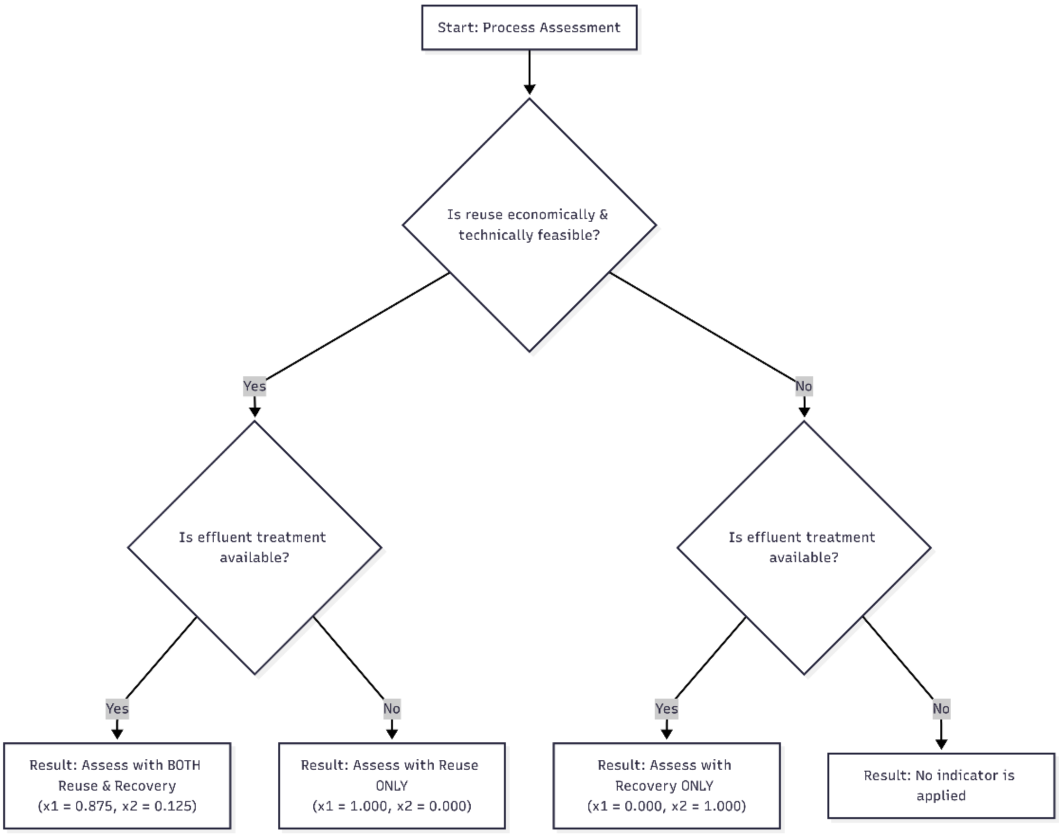


Source: Created by the author

For process-level assessments, first, the feasibility of reuse is analyzed. Reuse is only excluded if it can be technically and economically proven to be unfeasible. Following this, the availability of effluent treatment is assessed to determine if the recovery indicator should be included (

Figure 12)

Figure 12: RC Indicator Composition: Process Scope



Source: Created by the author

Brazilian industries have the potential to reach a 60% water reuse rate without substantial investments (Hespanhol, 2010). In the absence of official legislation or formal guidelines, this value will be adopted as the reference target for industries aiming to achieve 100% water recirculation circularity. The sub-indicators that are aggregated form the RC are shown in Table 13.

Table 13: Equations of the sub-indicators part of the Recirculation Circularity

Indicator	Equation
RC	$\text{RC} = Reuse\ circularity * x_1 + Recover * x_2$
% Reuse (w/o recover)	$\%\ Reuse = \frac{Water\ needed\ in\ all\ processes - Total\ water\ inflow}{Water\ needed\ in\ all\ processes} x100$
% Reuse (w/ recover)	$\%\ Reuse = \frac{Water\ needed\ in\ all\ processes - Total\ water\ inflow - Total\ wastewater\ recovered}{Water\ needed\ in\ all\ processes}$
Reuse circularity	$Reuse\ circularity = \frac{\%Reuse}{60}$
Recover	$Recover = \frac{Total\ wastewater\ recovered}{Water\ needed\ in\ all\ processes}$

Source: Created by the author.

Reuse and recover rates can be shown separately for analysis purposes; however, they won't be included in the Water Circularity Score.

When RC combines both reuse and recovery practices, due to its formulation, it is mathematically impossible for it to reach a value of 1.0. According to the %Reuse equation, the volumes of reused and recovered water are mutually exclusive, meaning a combination of both sources is required to meet the system's total water demand (ideal closed loop).

Furthermore, the Reuse circularity indicator is normalized by the equation %Reuse, which sets an ideal performance benchmark of 60% reuse to achieve the maximum score. The system reaches its highest RC value, 0.925, with the specific combination of 60% reuse and 40% recovery. Since this peak performance is less than 1.0, the final RC value must be normalized (Equation 6) before being aggregated into the WCS.

$$RC_{normalized} = \frac{RC}{0.925} \tag{6}$$

This indicator can function as an incentive: if a company focuses only on recovery and neglects reuse, its final score will be low, even if it recovers a large volume of water. Therefore, to be circular, it is essential to invest in reuse by conducting technical studies, such as analyzing the water's chemical characteristics, to identify possible opportunities, for example.

5.3.4. Withdrawal reduction circularity

The Withdrawal-Reduction-Circularity (WRC) assesses an industry's performance in reducing its total water withdrawal from external sources (both natural and public networks) over two consecutive years (Equation 7) and benchmarks it against a regional target, as there is no defined target from the National Water Resources Agency (Equation 8). In the state of Espirito Santo, industries must reduce water consumption by 25% during water crisis scenarios (AGERH, 2024).

$$WWR = \frac{Total\ water\ withdrawal,\ Y1\ - T\ water\ withdrawal,\ Y2}{Total\ water\ withdrawal,\ Y1} * 100 \quad (7)$$

$$WRC = \frac{WWR}{25} * 100 \quad (8)$$

This indicator should only be used if a company can demonstrate a reduction based on its historical data.

5.3.5. Rain harvest potential

The Rain Harvest Potential (RHP) indicator previously chosen was developed for territorial-level assessments. To calculate it for an organization, it was then used Equation 9 from (Tomaz, 2003). This is an additional indicator and will not be used to calculate the water circularity score.

$$RHP\ (m^3) = \frac{S \times C \times AAP \times \eta}{1000} \quad (9)$$

Where,

- S = Impermeable surface
- C = runoff coefficient
- AAP = annual average precipitation
- η = Performance of the system's first flush device

5.3.6. Water Circularity Score

To have a Water Circularity Score (WCS), the previously modified circularity indicators were aggregated with an arithmetic mean. Their weight was defined according to the circular actions they now encompass (Table 14).

Table 14: Relation between indicators and ISO circular actions

Indicators	ISO 59004 Circular actions				
	Added	Retain	Recover	Regenerate	Final weight
Circular Supply	✓	✓	✓		3
Circular Discharge	✓		✓	✓	3
Recirculation Circularity	✓	✓	✓		3
Withdrawal Reduction Circularity		✓		✓	2

Source: Created by the author.

Circular Supply and Circular Discharge incorporate three circular actions each and are core indicators. They will always be used because water will always enter and exit the system. The set of indicators can vary to tailor the assessment, as explained in the section 5.4.1. Recirculation Circularity assesses three, and the Water Withdrawal Circularity assesses two circular actions. They cannot always be included, as not all companies have historical data, and some processes may prohibit water reuse and recovery due to technical and/or economic reasons. Table 15 shows the different weights according to the combination of indicators.

Table 15: Weights of the indicators according to different combinations

Indicators	Weight parameter	Possibilities		
		A	B	C
Circular Supply	x_1	3	1	1
Circular Discharge	x_2	3	1	1
Recirculation Circularity	x_3	3	1	0
Withdrawal Reduction Circularity	x_4	2	0	0

Source: Created by the author.

Therefore, to calculate the Water Circularity Score, Equation 10 is applied.

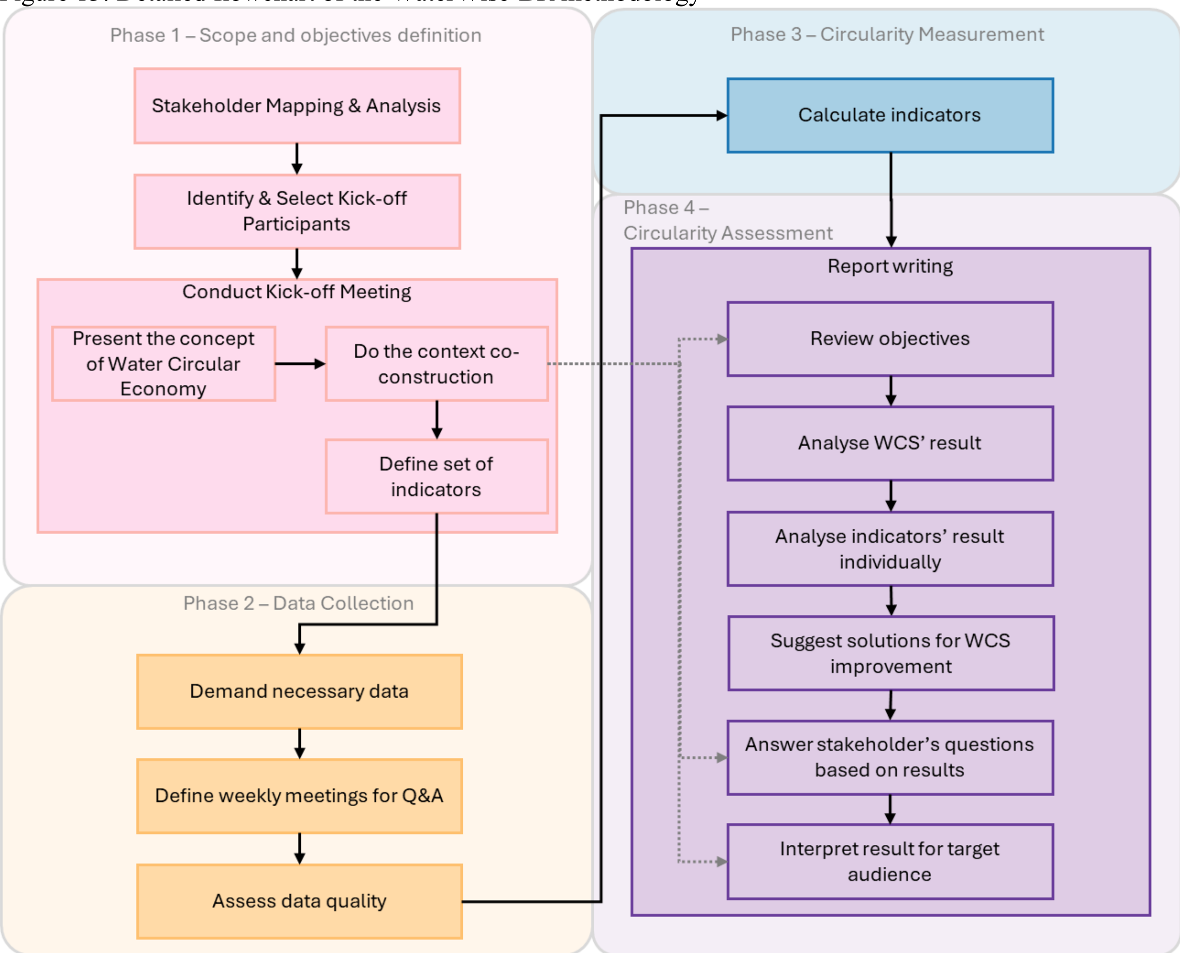
$$WCS = \frac{(x_1 \times Circular\ Inflow + x_2 \times Circular\ Outflow + x_3 \times Onsite\ Circularity + x_4 \times Withdrawal\ Reduction\ Circularity)}{x_1 + x_2 + x_3 + x_4} \quad (10)$$

The WCS ranges from 1 (fully circular) to 0 (linear). As an aggregation of four distinct indicators, the WSC provides a holistic and understandable measure of a system's overall circularity for the general public. To identify specific areas of weakness within the system contributing to a lower score, each of the four indicators must be analyzed individually.

When the WCS is affected by the industry's location in a water-stressed region and changing water sources is not feasible, options for improving the circular inflow indicator are restricted. To enhance overall circularity under these conditions, companies must optimize internal processes. This strategy focuses on maximizing water reuse and recovery while minimizing water losses to reduce overall freshwater consumption. By improving these other internal performance indicators, the negative impact of a low circular inflow caused by regional water stress can be offset.

5.4. WATERWISE-BR'S FRAMEWORK

Figure 13: Detailed flowchart of the WaterWise-BR methodology



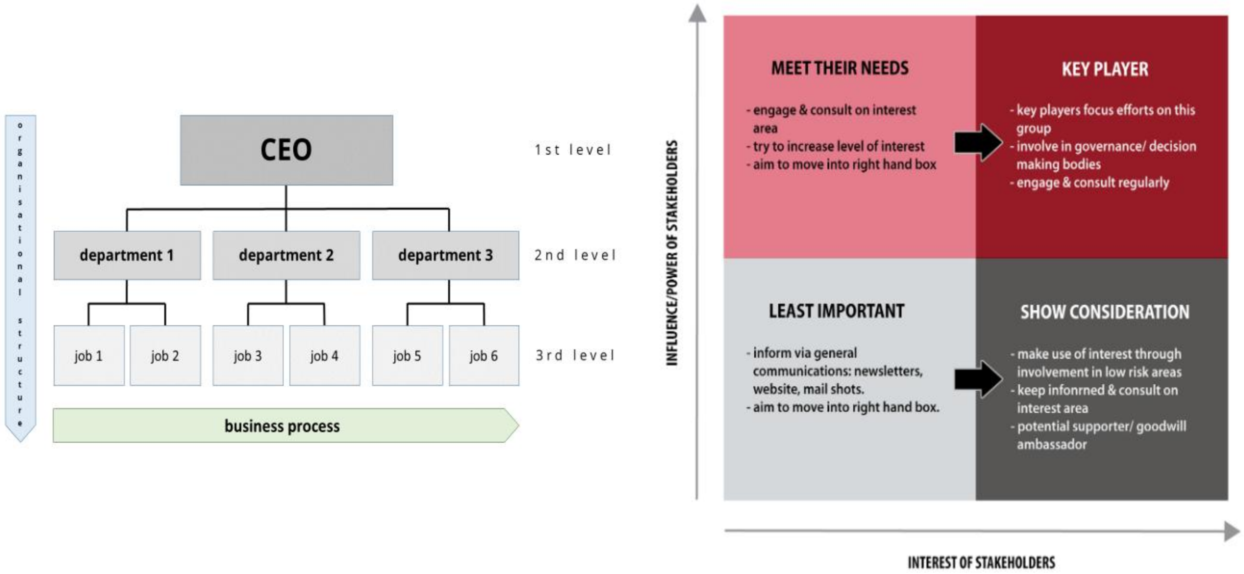
Source: Created by the author

Figure 13 details the WaterWise-BR methodology. The process begins with Phase 1 (Scope and objectives definition), with stakeholder mapping. This phase culminates in a Kick-off Meeting. During it, the presentation of the concept establishes a shared understanding of the topic, and the co-construction identifies scope, assessment's purpose(s), target audience, process/industry's characteristics, their concerns, and future strategies. Finally, with the co-construction information, the indicators are chosen. In the second phase (Data Collection) there should be a close contact with the organization to ensure full data delivery and to clarify any doubts. The methodology proceeds to Phase 3, which focuses on quantifying performance by calculating the defined indicators. The final stage, Phase 4, constitutes the comprehensive analysis. This phase involves a detailed review of objectives, analysis of indicator results both individually and aggregately, the formulation of improvement solutions, and the interpretation of findings for the target audience.

5.4.1. Phase 1: Scope and objectives definition

Key stakeholders should participate in the assessment if there is the intention to implement and develop circular strategies based on the final results. Besides helping to align expected outcomes, they are involved in decisions and can influence the group to act and invest in circular solutions (LinkedIn, 2024). Also, identifying the ones more resistant to a CE approach can help guide future workshops, final report approach, etc. Key players can be identified through mapping tools, as shown in Figure 14.

Figure 14: Organizational structure and stakeholder influence charts to assist in mapping key-actors



Source: Adapted from (Abiola, 2023; Edrawsoft, *[S.d.]*)

The assessment process is initiated with a kick-off meeting involving key stakeholders. This meeting functions as a collaborative platform for defining the assessment indicators, with its main objectives detailed in Table 16. The meeting's structure promotes open communication by contextualizing the assessment, presenting the water CE concept and its benefits, and reviewing the organization's future ambitions. This approach ensures that the selection of indicators is a well-informed and collective decision

Table 16: Kick-off's main objectives, justification, and how to implement them

Objectives	Why	How
Present the CE of water	To prevent unrealistic expectations from stakeholders, it is important to clarify the concept of water circularity, which is often misunderstood or conflated with material circularity.	Interactive presentation/workshop to encourage engagement and promote information retention.
Contextualize the importance of the assessment concerning legal frameworks, territorial recommendations, and benefits.	To engage stakeholders in actively contributing to the implementation of future solutions.	Demonstrating the benefits of becoming circular (opportunities for new investments, risk prevention)
Co-construct the general context of the company and of the assessment	Define the evaluation scope, boundaries, possible scenarios and purpose. Define target audience Support the development of actionable recommendations based on results. Foster stakeholder ownership and responsibility. Encourage stakeholder feedback, ideas, and experience sharing (Pradhan, n.d.).	Ask the previously-defined questions from annex B or more if needed
Indicators selection	To choose the most suitable set of indicators for the organization.	Table 15 and Table 17

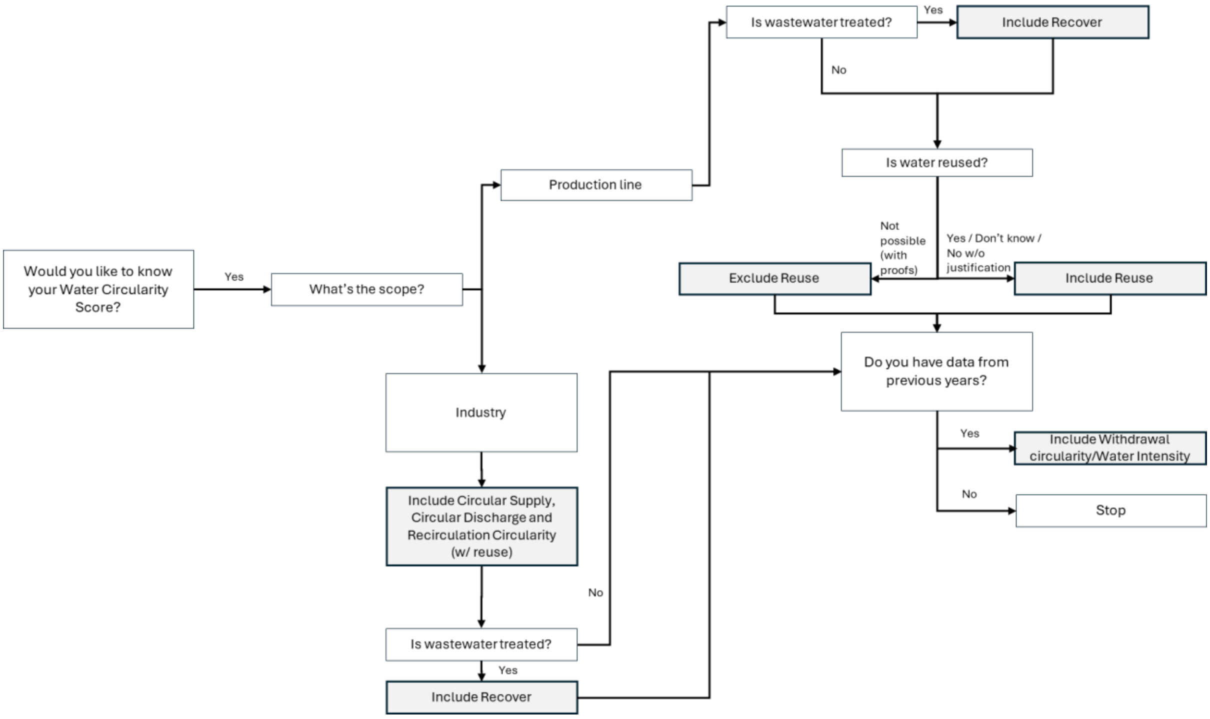
Source: Created by the author.

The co-construction phase is critical for the assessment. During it, the stakeholder must specify the scope of the evaluation. Also, information must be gathered on the company's future expansion strategies, as well as its methods for water abstraction, consumption, and effluent treatment. A key objective of WaterWise-BR is to support the search for solutions and solve problems. Therefore, it is important to understand from stakeholders which efficiency improvement strategies have been tested and failed, and what should be avoided in specific areas.

During this phase, the target audience for the assessment's results must also be defined, as it can range from the general public to potential investors. This information is relevant for structuring the final report. The outcomes of the co-construction phase will guide the report writing, ensuring that the indicators and results are interpreted to meet stakeholder expectations and serve their decision-making needs.

If the goal is to obtain the Water Circularity Score, the decision tree in Figure 15 must be used to determine its composition. Additional indicators may vary depending on the assessment's purpose, as outlined in Table 17. The table also specifies the expected outcomes and strategic applications for each assessment scenario.

Figure 15: Decision tree to define WCS' indicators set



Source: Created by the author.

If stakeholders are not focused on the WCS but have other evaluation needs, Table 17 can be used. While these indicators alone do not form a circularity score, they help meet stakeholder requirements and support the development of circularity strategies.

Table 17: Possible assessment purposes, indicators, outcomes, and strategic uses

To make decisions that would encourage strategies towards circularity	Proceed with the water circularity assessment using WaterWise's guideline			
Closing the material loops	Circular Supply Circular Discharge Recirculation Circularity Water withdrawal reduction	Total use replaceability to Centralized supply replaceability to Rainfall harvesting potential	Inflow/outflow analysis; Actual recirculation status; Consumption per produced unit and potential improvements; The potential of rainwater and wastewater harvesting and usability; Demonstrates the efficacy in the changes of water management practices from one year to the other	Circular Supply and Discharge will provide insight into the current water consumption from natural sources and the level of dependency. Recirculation Circularity will help identify opportunities to improve water reuse and recovery, as well as assess the current recirculation performance. Additional indicators will support decision-making regarding the use of water from waste streams, enabling its reintegration into the process and contributing to closing the industrial water cycle. It can be used for risk prevention: making production more resilient to the consequences of climate change and disruptions in water distribution, preventing the risk of production disruption; Find opportunities for a more circular procurement; Recycling, recovering, and using rainwater can result in cost and energy savings; Get more investors and/or participate in project call actions since reducing water consumption and increasing reuse are national goals; Can be used for communication goals and to construct a closer relationship with clients.
Keep resources for future generation	Circular Supply Circular discharge	Rainfall harvesting potential	Inflow/outflow analysis; Water sources and status Volume discharged water in comparison with inflow water The efficiency of their water treatment; Potential to harvest rain water	Evaluate where water is being discharged to determine whether the water body is being replenished as it should and, if necessary, take action to discharge it correctly. Develop a strategy to shift water supplies to more sustainable sources. Optimize the processes in case of water loss and reduce water consumption (increase water intensity). Can be used for communication goals and to construct a closer relationship with clients
To know what natural resources they depend on	Circular Supply	Water supply centralization	Water sources Water stress in the region How dependent of its suppliers the industry is	Assess the need for more sustainable suppliers or water sources from different regions. Develop a strategy to shift water supplies to more sustainable sources. It can be used for communication goals and to construct a closer relationship with clients It can be used for risk prevention: making production more resilient to the consequences of climate change and disruptions in water distribution (which can be caused by contamination in the network, water shortages in the region, etc.) - preventing the risk of production disruption; Find opportunities for a more circular procurement; Get more investors and/or participate in project call actions to become self-sufficient
To identify internal opportunities they have from waste stream	Circular Discharge Recirculation Circularity	Centralized / Decentralized supply replaceability to Total use replaceability to Rainfall harvesting potential	Reuse and Recovery status Wastewater generated and its destination / final use How dependent of its suppliers the industry is Water consummed that could be replaced by other souces Opportunity to source rainwater	Identify reuse opportunities by understanding quality thresholds and legislation for their processes. Explore opportunities to recover water from their wastewater treatment plant.
To communicate the importance of the transition	Proceed with the water circularity assessment using WaterWise's guideline			Do two evaluations: one for the present and the other for the past. Communicate the benefits of becoming more circular using measured proofs.

Source: Created by the author

5.4.2. Phase 2: Data collection

To ensure a robust and transparent analysis, the WaterWise-BR methodology utilizes a specific data collection document to record data sources and measurement details. While this document is the intellectual property of Capgemini Engineering and is not disclosed in this study, the systematic tracking of data origins is a fundamental requirement.

Regular meetings with stakeholders are important to address questions and understand their processes. These sessions enable the evaluator to identify potential causes of water loss and optimization issues. All such preliminary findings must be documented for the final report

The assessment process uses pre-gathered secondary data. To ensure objectivity, the methodology provides pre-defined sources and destinations with associated circularity values, and also guides the conversion of more detailed assessments into a circularity score in cases of high water stress.

The level of detail in the assessment results is directly dependent on the granularity of the input data. To illustrate, even if an indicator's formula requires only a single, aggregate value (such as total water volume), a more granular dataset is preferable. Such a dataset would detail all individual water inflows, specific outflows, and potential losses associated with each evaluated process.

While acquiring such detailed data can be challenging, particularly in large-scale organizations, the process of identifying information gaps is, in itself, a significant finding. These gaps highlight the specific operational areas where monitoring systems require improvement and where investment is most needed.

Once the data is obtained, its quality must be assessed. To ensure standard data quality, they must be classified as primary or secondary and evaluated depending on the collection method, reliability, and representativeness. Primary data are obtained on-site through measurement, while secondary data already exist and are collected from external sources. WaterWise-BR should ideally use secondary data from government sources. Reliability and representativeness must receive a grade from 1 to 4, according to the criteria in Table 18.

Table 18: Data quality scores and criteria description

Data Quality	Score	Criteria
Reliability	1	Verified data measured or calculated in the field.
	2	Verified data, partly based on hypotheses or unverified data from measurements (documents provided by the client or from literature).
	3	Unverified data, partly based on hypotheses or a quality estimate (performed by an expert).
	4	Roughly estimated data.
Representativeness	1	Field data (specific to the case study), laboratory data.
	2	Good geographical and/or technological representativeness of the selected process.
	3	Data related to the same process or material but referring to a different technology (e.g., a representative process available in the Ecoinvent database) .
	4	Inadequate geographical and/or technological representativeness. The data is not easily accessible, using another process as an approximation.

Source: Adapted by the author (CIRAIG, *[S.d.]*).

For a circularity assessment, data scored from 1 to 2 is considered sufficient. While score 3 data can still be used, efforts should be made to improve its reliability when possible. However, score 4 data does not meet the required reliability/accuracy standards and should be excluded from the analysis Table 19.

Table 19: Final data quality interpretation

Score	Interpretation
1	Data meets the "reliability/accuracy" criteria required for the case study
2	Data is considered sufficiently accurate/reliable for the case study.
3	Data is usable by the analysis team, but its reliability/accuracy could be improved.
4	This data does not meet the "reliability/accuracy" criteria required for the case study.

Source: Created by the author.

5.4.3. Phase 3: Performing Circularity Measurement

In this phase, the previously collected and validated data are used to quantify the organization's water circularity. The process involves calculating the individual indicator values and then aggregating them into a final WCS. These computations can be performed using standard spreadsheet software. The accuracy of the final measurement is directly dependent on the quality of the data gathered in the preceding phase.

5.4.1. Phase 4: Performing the Circularity Assessment

In the fourth and final phase, a critical analysis of the assessment results is conducted by benchmarking them against the objectives, expectations, and target audience established in Phase 1. The interpretation is guided by stakeholders' needs. Furthermore, information gathered during the collaborative context-building stage is leveraged to identify targeted solutions for enhancing the organization's circularity. The results are then presented in a format that delivers actionable and valuable recommendations to the organization.

While the Water Circularity Score provides a single value, its individual indicators should be analysed separately for a more detailed view and used as an industrial internal management tool. This deeper analysis does not change the final score but offers valuable insights. For instance, total water inflow and outflow can be compared to identify potential imbalances or unaccounted-for losses. Additionally, the percentages of water reused and recovered can be examined without their assigned weights for a direct performance comparison between different sites.

The final report must be transparent about the data, hypotheses, and calculations performed. It is essential to detail every process step, including uncertainties and data quality. By providing a transparent view of the water circularity assessment, the report will allow stakeholders to understand the context and limitations, fostering informed decisions and the implementation of more assertive circular actions.

5.5. WATERWISE-BR’S GAP ANALYSIS

A GAP evaluation (Figure 15) using the framework of Camacho-Otero & Ordoñez (2017) confirms that the WaterWise-BR methodology effectively addresses the main weaknesses of previous assessment tools. WaterWise-BR achieves a 100% alignment with the purposes identified by experts, as detailed in Table 17, which demonstrates how its indicators correspond to each of the purposes identified by Camacho-Otero (2017). It is explicitly designed as a resource stewardship and decision-making tool that also helps companies identify opportunities in waste streams, understand dependencies on natural resources, and communicate the importance of transitioning to a circular economy.

The methodology shows an alignment of 83% with the guiding principles, based on the total number of principles in the Camacho-Otero (2017) evaluation. It translates core principles like "Closing the material loops," "Systems thinking," "Strong sustainability," and "Positive Footprint" into measurable components of the assessment. The only principle not included is

"Renewable energy sources," which is consistent with the methodology's defined scope to assess water, not energy systems.

Figure 15: WaterWise-BR's methodology GAP analysis

nponent	Experts input					
pose	Close material loops	Keep resources for future generations	To know what natural resources they depend on	To identify opportunities they have from the waste stream	To make decisions that would encourage strategies toward circularity	To communicate the importance of the transition

Scale	The value chain
	Product offering and components
	Company
	Life cycle
	Business model

	Process		Product		Others	
Criteria	Efficient use	Renewability	Hazardouness	Recycling	Circular business model	Costs
	Energy use	Repairing	Dependency on future materials	Refurbishing	Retained value	Circulariting materials
	Material intensity	Smartness	Raw materials	Remanufacturing		
	Waste generation	Waste reduction	Reusability	Use intensity		

Principles	Closing material loops
	Systems thinking
	Resilient system
	Maximize value
	Collaboration
	Renewable energy sources
	Strong sustainability
	Positive footprint
	Future-based orientation

Included explicitly
Included implicitly
Not Included

Source: Created by the author

While WaterWise-BR intentionally focuses on the company and process level, its assessment is comprehensive, covering the entire water pathway from abstraction to discharge. This end-to-end analysis within a defined boundary is why the life cycle perspective is considered implicitly included. However, to prevent potential burden-shifting to other areas, using the methodology in parallel with a full LCA or WF is recommended.

WaterWise-BR explicitly quantifies recycling and value retention, integrating them into the Water Circularity Score. This provides a direct incentive for companies to implement reuse and recovery strategies, as their positive impact is reflected in the final assessment result.

WaterWise-BR also provides a method for assessing the quality of discharged water ("Hazardousness").

Compared to WCM, WaterWise-BR is enhanced by additional purposes, such as identifying value in waste streams, and is guided by new principles like collaboration and value maximization. Cost and energy use are defined as areas for future development.

In summary, WaterWise-BR remedies weaknesses of past tools by embedding core principles into its indicators and strategically defining its scope, making it a practical and applicable methodology for industrial water management.

5.6. CASE STUDY: A BRAZILIAN STEEL MILL

To test WaterWise-BR's indicators, its third phase was tested at a large scale steel industry production unit in Brazil. The unit is capable of producing several million tons of steel plates and hot-rolled coils annually. The study's scope encompassed the entire organization and evaluated data for the year 2024. The assessment utilized data on total water inflow, total water withdrawn in 2023, total water used, total wastewater recovered, and total outflow volume, all of which, except outflows, were measured by water meters. It was considered that the effluent is discharged at the limit of CONAMA 430. Table 20 resumes the results for each indicator. According to them, the organization is at the limit between linear and circular (58%) because it lacks reuse applications.

Table 20: Case-study circularity and additional indicators result

Type	Name	Result
Circular	Water Circularity score	57.71%
	Circular Supply	97.78%
	Recirculation Circularity	0.09%
	Circular Discharge	92.10%
	Withdrawal reduction	32.46%
Additional	Water supply centralization	5%
	Centralized supply replaceability to outflow	1980%
	Total supply replaceability to outflow	92%

Source: Created by the author

6. CONCLUSION

The systematic review conducted showed that previous water circularity assessments were performed using non-standardized indicators and methodologies. The concepts and scopes varied, causing a diversion in final results for the same system. Furthermore, the external environment of the organization was not considered in some cases, and the methodologies did not account for relevant aspects of certain industrial sectors due to their rigid format.

It was found during this work that Brazil's legislation, despite being robust concerning environmental protection, has few targets for reducing water consumption and increasing reuse and recovery. The National Policy on Circular Economy, despite its objective of encouraging the management of water resources using CE, is vague and does not guide how this should be done.

A water circularity assessment methodology called WaterWise-BR, customizable to the evaluated scope, was developed and tested in this study. The case study investigated proved WaterWise-BR can effectively measure water circularity in organizations, highlighting internal weaknesses. Its final results showed coherence and can be used as a management tool for decision makers when evaluated in detail.

WaterWise-BR, based on ISO 59020, reduces the problems of assessments with divergent concepts. Its indicators were adapted to incorporate a context that integrates aspects of a specific state in Brazil, standardizing the assessment for the region. The WCS, its final product, aggregates the circularity indicators and transforms them into a value that is understandable to different audiences, from decision-makers to the general public.

The WaterWise-BR methodology stands out from existing ones by instructing on communication with both stakeholders and the target audience to ensure the results culminate in the execution of circularity projects. It assists in the search for solutions to enhance circularity through the investigation carried out during the kick-off in conjunction with the results from the circularity and additional indicators. Furthermore, by comparing the quality of the captured water with that of the effluent that returns to nature and considering only the effluent with a quality greater than or equal to the captured water as circular, WaterWise-BR encourages the regeneration of nature.

WaterWise-BR not only assists in industrial optimization. Its methodology incorporates the natural and anthropological water cycle, assisting in the optimization of industrial processes and the preservation and maintenance of ecosystem services. These results can also be used in industry to compare the performance of different sites, identify risks, and outline resilience strategies.

Finally, by providing a holistic, adaptable, and data-driven framework, WaterWise-BR empowers industries to move beyond linear "take-make-dispose" water practices and transition toward a truly circular model that enhances resilience, ensures regulatory compliance, and contributes to long-term environmental and economic goals.

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Annex A

Indicator type	Indicator	Equation	Description
Circularity Indicators	**Water Circularity Score**	WCS = (x1×Circular Supply+x2×Circular Discharge+x3×Recirculation Circularity+x4×Withdrawal Circularity))/(x1+x2+x3+x4)	An aggregate score that calculates the overall water circularity of an organization by combining its performance across supply, discharge, and recirculation.
	Circular Supply	Circular Supply = ∑(Circularity i * Volume i)/(∑Total Water Inflow)	Measures the circularity of the incoming water, considering its source (linear vs. circular) and the water stress level of the region it comes from.
	Circular Discharge	Circular Outflow= ∑(Circularity i * Volume i)/(∑ total water withdrawn) Circularity i=(Destinantion Factor i +Quality Factor i)/2	Assesses the circularity of the water leaving the facility, based on its quality and its destination (e.g., returned to nature, sent to wastewater treatment).
	Recirculation circularity	RC =Reuse circularity*x1+Recover*x2 % Reuse (w/o recover) = (Water needed in all processes-Total water inflow)/(Water needed in all processes) x100 % Reuse (w/ recover)= (Water needed in all processes-Total water inflow-Total wastewater recovered)/(Water needed in all processes) Reuse circularity = (%Reuse)/60 Recover = (Total wastewater recovered)/(Water needed in all processes)	Determines how much water is recirculated within the system by measuring the percentage of water that is reused and/or recovered in internal processes.
	Withdrawn reduction circularity	WWR= (Total water withdrawal, Y1 -T water withdrawal, Y2)/(Total water withdrawal, Y1)*100 Withdrawal reduction circularity= WWR/25*100	Compares the total water withdrawn in two different years to measure progress in reducing overall water consumption.
Additional Indicators	Water supply centralization	WSC = Water volume from centralized suppliers / total water inflow	Shows the percentage of water that comes from large-scale, centralized municipal or regional suppliers.
	Rainfall harvesting potential	RHP (m^3)=(S×C×AAP×η)/1000	Calculates the potential volume of rainwater that could be collected on-site based on the facility's surface area and local rainfall data.
	Centralized supply replaceability to wastewater	(Wastewater Volume /total centralized water supply)*100	Compares the volume of wastewater generated to the volume of water taken from centralized supplies to show how much could be potentially replaced.
	Centralized supply replaceability to precipitation	(Precipitation/total centralized water supply)*100	Calculates the percentage of the centralized water supply that could potentially be replaced by collected rainwater.
	Total supply replaceability to precipitation	(Precipitation/total centralized water supply+total decentralized water supply)*100	Percentage of the total inflow that could be replaced by collected rainwater
	Total use replaceability to wastewater	Wastewater Volume/(total centralized water supply+total decentralized water supply)*100	Percentage of the total inflow that could be replaced by their total wastewater

Annex B

	Subject	Questions	Expected answer
Questions about the Company	Context	What is the main objective of this assessment?	Close the water loop, preserve resources for future generations, understand the company's water sources, identify internal opportunities based on wastewater, support strategic decision-making regarding circularity, and communicate the importance of transitioning towards CE
		What is the scope of the assessment?	Process(es) or the entire company.
		Are there any specific constraints we should take into account? (e.g., regulations, quality standards for certain processes, specific treatments, etc.)	Water used in some processes must meet specific quality standards. For example, water entering processes X and Y cannot come from reused sources as it does not meet the required criteria. However, there are no quality constraints for process Z.
	Study Results	What outcomes do you expect from this study?	What type of answers are they expecting, what type of strategies they'd like to build after having the results
		How can the results of this analysis help your company achieve future objectives? What actions or decisions do you expect to take afterward?	Here, the company should describe the strategies or actions they plan to implement based on the results.
		Are there specific areas where you are looking for recommendations or improvements?	These could be current concerns or key operational areas. This response will help guide the analysis and the improvement recommendations provided.
		Have you already implemented any circular economy initiatives? If so, which ones?	(Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover) — Can you provide concrete examples? This assesses the company's commitment to circular economy practices.
		What is the main audience for this circularity assessment?	Investors, governmental agencies, internal use for future improvements, customers.
	Production Processes	What are your strategic priorities for the coming years?	Are you planning to increase production, expand with new facilities, export to other countries, change processes to optimize production, or increase marketing efforts?
		Can you describe the main processes related to water management within your organization?	Water reuse and recovery methods, industrial symbiosis for water supply, use of alternative water sources, or procedures already in place to save water.
		Which departments or teams are involved in these processes?	The name of the process engineer – this is typically the person responsible for water management questions.
Questions on Water Management	Initial Phase	Do you know the source of the water you use? We need this information to calculate water circularity.	If the company chooses to analyze only part of its activities, it is essential to know the water source for that section. Otherwise, assumptions will need to be made. This response can also help in drafting improvement recommendations.
		If a single process was selected for the assessment:	Yes: we can calculate the circularity indicator for incoming water flows. No: either we do not use this indicator, or we estimate it based on the proportion of incoming flows.
		Do you harvest rainwater for use in your processes? If yes, how is it collected and used?	Yes/No – This is necessary to determine whether to include the rainwater harvesting potential in the circularity calculation.
		Do you extract water directly from natural sources? If yes, what extraction methods are used? Could you share your Outorga with us?	
	Usage Phase	Do you have precise measurements of water consumption for each operational step?4	Yes: This enables calculation of the water reuse indicator using the volume needed for each operation. → No: We will need to collect data on reused volumes during the assessment.
	Final Phase	Do you operate your own wastewater treatment facility?	
		a. If yes, can you describe its operation and efficiency?	They should specify its efficiency and whether part of the treated water returns to the company or is sent elsewhere for reuse.
		b. If not, how do you manage your wastewater treatment?	
	General Context	What are the main challenges you face regarding water management? Are there recurring issues or common obstacles?	This could include regulatory constraints or past attempts at solutions that were unsuccessful, which can help avoid repeating mistakes in our recommendations.
		What improvements or innovations would you like to implement in your water management practices?	This response should guide in proposing improvements and solutions that are likely to be considered and implemented.
		Is there any other important information you would like to share regarding water management in your organization?	This response could reveal additional suggestions that could be included in the recommendations, which are likely to be considered and applied in the future.