European Union Network for the Implementation and Enforcement of Environmental Law

Water Circularity Index for Products

Wastewater in Natural Environment (WiNE) project

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Introduction to IMPEL

The European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL) is an international non-profit association of the environmental authorities of the European Union (EU) Member States, and of other European authorities, namely from acceding and candidate countries of the EU and European Economic Area (EEA). The association is registered in Belgium and its legal seat is in Brussels, Belgium.

IMPEL was set up in 1992 as an informal Network of European regulators and authorities concerned with the implementation and enforcement of environmental law. The Network's objective is to create the necessary impetus in the European Community to make progress on ensuring a more effective application of environmental legislation. The core of the IMPEL activities concerns awareness raising, capacity building and exchange of information and experiences on implementation, enforcement and international enforcement collaboration, as well as promoting and supporting the practicability and enforceability of European environmental legislation.

During the previous years, IMPEL has developed into a considerable, widely known organisation, being mentioned in a number of EU legislative and policy documents, e.g. the 8th Environment Action Programme that guide European environmental policy until 2030, the EU Action Plan: "Towards a Zero Pollution for Air, Water and Soil" on Flagship 5 and the Recommendation on Minimum Criteria for Environmental Inspections.

The expertise and experience of the participants within IMPEL make the network uniquely qualified to work on both technical and regulatory aspects of EU environmental legislation.

Information on the IMPEL Network is also available through its website at: www.impel.eu

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Executive Summary

This Report is the outcome of the dedicated work of the "Wastewater in Natural Environment (WiNE)" project team. It aims to present the outcomes of 2022-2024, including the development of a key tool, the Water Circularity Index for products, which measures the circularity of certain products in terms of water use. It has the potential to significantly promote more sustainable water use under the goals of the Water Framework Directive (WFD), the Regulation (EU) for minimum requirements for water reuse and the Industrial Emissions Directive (IED). The report is designed to support decision-making processes, such as permitting within the water-food-energy nexus, by minimising the trade-offs between water demand, efficient water use, pollution reduction, and biodiversity promotion.

The 'Water Circularity Index for Product' logo was designed using an advanced AI-driven graphic design tool provided by OpenAI's DALL-E, which generates images based on textual descriptions. The design was created in response to a specific request for an ultra-minimalist and professional representation of water sustainability and recycling concepts.

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1. Introduction

1.1. Lessons learned from previous projects and project phases

Water used within installations and productions has been studied through several IMPEL Projects, namely the Project "Integrated Water Approach" (2017 & 2018) and the previous phases (2019, 2020 & 2021) of the Project Wastewater in Natural Environment (WiNE).

The "Integrated Water Approach" Project revealed that solely considering reducing water consumption by optimising processes, upgrading infrastructure, or even adopting water-saving technologies without considering the qualitative aspects could negatively and severely impact water bodies. In this project, a checklist for wastewater discharge permit writers was developed to allow the issue of permits, ensuring compliance with the Industrial Emissions Directive (IED) without jeopardising the Water Framework Directive (WFD) goals. The application to a real case study allowed a deeper understanding of the importance of the developed tool. Consequently, the need to consider both qualitative and quantitative aspects of water use was envisaged and reinforced in the Industrial Emission Directive recast (IED 2.0), namely in Article 18.

Considering the European Commission Action Plan for Circular Economy and the increasing trends in water reuse, the previous phases of the project WiNE intended to deepen the knowledge of water use in installations and/or facilities within the circular economy concept and a novel metric designated by Water Circularity Index (IC) has been devised to assess the intricacy of determinations pertaining to water balances, encompassing both the quantity and quality of water used throughout the water use cycle within installations. The index was successfully applied to facilities in seven countries, covering 14 different installations from a range of industrial activities and urban wastewater treatment plants. For one of the installations assessed (a pulp mill), the index was determined both before and after the revision of an environmental permit, in which the wastewater discharge permit had been evaluated using the aforementioned checklist.

One of the most important lessons learned from previous phases is that water circularity is often addressed through a simple integration of practices such as water reclamation and recycling. Indeed, it is possible to reduce freshwater withdrawals and minimise the environmental impact of water-intensive processes by reusing and recycling water within and across industries, cities, and communities. However, crucial trade-offs between the multiple aspects of the practices and governance decisions are often overlooked due to their commonly separated treatment. Consequently, an approach that comprehensively considers the positive and negative impacts of decisions on the water cycle is essential to deliver better permits and ensure environmental compliance within the comprehensive goals of the WFD, which are focused on achieving good qualitative and quantitative health, by involving the reduction and elimination of pollution while ensuring there is enough water to support both wildlife and human needs.

1.2. Foreword

Water circularity within the circular economy concept revolves around rethinking how water is managed, used, and reused to promote a more sustainable and regenerative system that minimises water losses and maximises resource efficiency. In a circular approach, efficient water use, recycling, and recovery methods are addressed to ensure resource protection, particularly by reducing freshwater consumption. Therefore, circular approaches can be pivotal in addressing global water scarcity, reducing pollution, and providing long-term water security.

Conversely, developing efficacious methodologies to comprehend the requisite interactions for evaluating water use while guaranteeing compliance with European environmental legislation can serve as a valuable resource for authorities and operators.

As the global demand for resources continues to rise, the need for a holistic understanding of environmental impacts becomes paramount. Therefore, despite the successful application of the Circularity Index for installations, it was noticed that several specific requirements were product-specific, where the concept of circularity in product design and resource management may emphasise the importance of sustainability and efficient resource use throughout a product's lifecycle, considering that the key components of water circularity include water efficiency, water reuse, the recovery of valuable materials, and synergies among sectors.

Thus, during 2022-2024, the project WiNE focused on the development of a circularity applied to products, considering three main types of products:

- Seasonal and/or regional products that may involve high importance for local communities, including the outermost regions of the European Union;
- Crop production;
- Products from large installations.

The Circularity Index for Products ($I_{C\ Prod}$) was developed as an additional and valuable tool for assessing compliance, focusing on freshwater usage and its implications on water scarcity. Key metrics, including the Water Exploitation Index Plus (WEI+), enable stakeholders to evaluate product impacts on local water sources, ensuring alignment with environmental regulations. Furthermore, incorporating alternative water sourcing methods, such as reclaimed or desalinated water or the promotion of agrobiodiversity (for crop production), into product strategies can also contribute to a more realistic minimisation of ecological footprints. Thus, multiple assessments connected with water use and other water-related aspects (e.g., the synergies between sectors by the use or sending to external use of secondary materials) in the product development process were intended to promote adherence to environmental compliance while fostering a shift towards a more sustainable, circular economy.

When applicable, the circularity index for products integrates the results of the circularity index for installations, allowing a comprehensive view of how water should be used to ensure compliance with water abstraction and discharge standards without endangering the status of water bodies (surface and groundwater status) according to WFD.

Accordingly, the developed index aims to encourage cooperation among several stakeholders (operators, inspective and regulatory authorities, and communities) to promote better water permits and water management solutions that support local, regional, or national water security without compromising water-related legal obligations.

By embedding water circularity principles into the broader framework of the circular economy, the current indexes aim to contribute to a transition towards a system that conserves water and enhances environmental health, resilience, and economic sustainability.

1.3. Aim of the project

This project aimed to use the results of the previous phases to find best practices on the water use cycle, including water reuse at the industrial and urban levels and develop a new tool to identify the best water management options within the process for producing specific goods ("products"), supported by the outcomes of the previous phases and knowledge taken from site visits occurred throughout the project lifetime.

The new tool (Water Circularity Index for Products), combined with the index developed in the previous project phases, aimed to improve knowledge of a more realistic transition to the circular economy by identifying and improving solutions in terms of water use efficiency, taking into account both quality and quantitative aspects, and contributing to a real reduction in water pollution.

To develop the new index, best practices in terms of water use within processes and activities, including water reuse (use of treated wastewater as an alternative water source), water quality management, sludge management, water resource use and energy balance, were assessed. The focus was on regional and seasonal products important to local communities, crop production, and goods produced in large installations.

Another project goal was using the developed index for the decision-making process (e.g., permitting) within the nexus of the water-food-energy ecosystems to avoid trade-offs by balancing the competing water needs and enhancing efficiency through optimising internal and/or external synergies (reuse, recycling, energy optimisation or promotion of landraces).

A final goal was to promote some professional training, spread knowledge, and develop a tool that contributes to compliance assurance in rural areas, as required for implementing the ECA 9-point Action Plan.

2. Development of the circularity index for products ($I_{C\ Prod}$)

2.1. Site-visits

In order to develop the new circularity index, three site visits were carried out considering three main types of products:

- Seasonal and/or regional products that may involve high importance for local communities, including the outermost regions of the European Union (Madeira site visit);
- Crop production (Murcia site visit);
- Products from large installations (Slovakia site visit).

A first site visit took place on Madeira Island (Portugal) to the sugarcane mill of Calheta (Engenho da Calheta), the water battery (Central Hidroeletrica dos Socorridos) and the sugarcane mill of Norte (Engenhos do Norte). The regional and seasonal production of rhum from sugarcane in Madeira Island served as a pertinent example for understanding how to develop a circularity index applied to products rather than installations.

A second site visit took place in the Murcia region (Spain) to the wastewater treatment plants of Los Alcazares and San Javier and the growing fields irrigated with combined water sources. The team members had the opportunity to analyse the collected data and propose specific key-factors of the circularity index for food products irrigated with reclaimed water.

Finally, a third site visit was conducted at the pulp and paper mill of Mondi SCPa.s. in Zilina (Slovakia). During this visit, the team members had the opportunity to tour the facility and gain insights about the diverse range of paper products manufactured on-site. They also learned about the technologies used and some of the environmental activities promoted by the company to foster community engagement in the preservation of the environment, as well as how water is used and how wastewater is treated in the production of both virgin and recycled pulp. In addition, the team members had the opportunity to visit the Paper Museum, where participants explored the historical evolution of paper production, which commenced in China through the recycling of fibres from discarded textiles, illustrating a "circular process".

2.2. Index development

In the context of increasing water scarcity and pollution challenges, developing a Water Circularity Index for products can provide a powerful mechanism for promoting sustainable water management. By leveraging the index's ability to evaluate and incentivise circular water practices, regulators, namely the permitting authorities, can ensure that water allocations contribute to long-term resource resilience, environmental protection, and equitable access. Aligning permitting processes with circularity objectives represents a critical advancement toward achieving sustainable water use while contributing to the goals outlined in the zero-pollution action plan.

Following the previous circularity index for installations, the criteria used for the new product index were chosen based on SMART principles, i.e.:

- **S**pecific: The index clearly explains the specific measurement intended to assess and ensures that there are no overlapping metrics included;
- **M**easurable: Consistent results can be obtained and tracked under the same conditions, regardless of who uses the index;
- **A**chievable: The index only includes realistic and feasible criteria relevant to the context;
- **R**elevant: The index ensures that the criteria are aligned with the overarching goals and priorities of the decision-making process;
- **T**ime-bound: The index specifies a particular time frame, namely the duration of the environmental, abstraction or discharge permits.

As in the previous circularity index for installations, the easily accessible and measurable factors that take into account the relationships between the water use patterns, the processes and the environmental systems were considered as inputs. These factors are described as key factors.

Subsequently, a Multicriteria Decision Analysis (MCDA) was used to provide a structured framework for comparing and prioritising alternatives for each criterion. MCDA methods offer a methodical and analytical approach to integrating multiple criteria by evaluating, scoring, and contrasting various alternatives and by integrating both qualitative and quantitative data. The index employs a simple mathematical framework to systematically score several alternatives, ensuring bias reduction and increasing final decision transparency. Additionally, it helps weigh trade-offs between conflicting objectives, such as a crop with higher natural value (e.g., landraces) but with lower economic value. This framework incorporates an importance scale based on Saaty's work, considering both positive and negative values (ranging from -9 to 9) to reflect the impact and trade-offs of different water management practices on circularity.

Thus, the index is a valuable tool for assessing and optimising water usage in specific production processes across industrial, agricultural, and urban sectors. This approach fosters the development of products that embody a higher degree of circularity.

The following paragraphs provide a detailed explanation of all the six key factors and 20 sub-key factors considered.

2.3. Key and sub-key factors

2.3.1. Freshwater consumption (water use for the product)

This main key factor (freshwater consumption) includes two sub-key factors - presented in Tables 1.1 and 1.2 - that examine the relationship between water consumption and water scarcity at the basin scale. Additionally, it looks at how scarcity is addressed in the programme of measures outlined in the River Basin

Management Plans (RBMP). This understanding helps evaluate the sustainability of the product in a specific location.

Table 1.1: Water scarcity and freshwater consumption

Key factor	Sub-key factor	Condition	Freshwater Consumption Level	Impact	Explanation
1. Freshwater consumption	1.1 Water scarcity and freshwater consumption	WEI+* > 40%	High	-9	High importance for water resources, since may contribute for its decrease
		WEI+ > 40%	Medium	-7	Medium importance for water resources, since may contribute for its decrease
		WEI+ > 40%	Low	-3	The area where the product is produced presents scarcity, and the product may still have a negative impact on water resources availability since it consumes low volumes of water
		WEI+ ≤ 40%	High	3	The area where the product is produced does not present high scarcity, but the product will may have some low impact on water resources availability since it consumes high volumes of water
		WEI+ ≤ 40%	Low	9	The area where the product is produced does not present scarcity and the product will not have a negative impact on water resources availability (i.e., a positive impact for the economy without jeopardise water resources)

*The water exploitation index plus (WEI+) compares water use against renewable water resources

To assess the freshwater consumption level the relations defined below should be considered:

- A high level when the freshwater consumption per mass unit of the final product is equal to or higher than double the mass unit of the product;
- A medium level when the freshwater consumption per mass unit of the final product is equal to or higher than the mass unit of the product but lower than its double;
- A low level when the freshwater consumption per mass unit of the final product is lower than the mass unit of the product.

Regarding crop production, the freshwater consumption level should consider the FAO considerations about water needs and the applied irrigation efficiency practices.

Table 1.2: Water scarcity and programme of measures at river basin level

Key factor	Sub-key Factor	Scarcity in RBMP Characterization	Scarcity in RBMP Program of Measures	WEI+ Condition	Impact	Explanation
1. Freshwater consumption	1.2 Water scarcity at RBMP	**No**	**No**	WEI+>40%	-9	Underestimation of risk for exploitation of water bodies
		No	**No**	WEI+≤40%	0	No input
		Yes	**No**	WEI+>40%	-5	Underestimation of risk for exploitation of water bodies
				WEI+≤40%	0	No input
		Yes	**Yes**	WEI+>40%	3	No input
				WEI+≤40%	9	Integration of risk for exploitation of water bodies

2.3.2. Use of alternative water sources (quantitative & qualitative aspects)

The subsequent tables (Table Set 2) correspond to a single key factor (Use of Alternative Water Sources) and intends to measure the impact of water sources used. The table set is divided into three levels to consider the several options for water use (alternative sources and freshwater sources), but to each case study, only one condition applies (i.e. a single table from the Table Set 2).

Table 2.1: Use of freshwater resources

Key factor	Sub-key Factor	Condition	Impact	Explanation
2. Use of alternative water sources	2.1 Freshwater resources	Only freshwater resources are used	-9	Freshwater resources are the sole source of water, which could strain local water resources
		Use of alternative sources not feasible	-3	Freshwater is the only source, but alternatives are not viable. But still, there is an impact, given the context
		Use of alternative water sources (reclaimed water and/or desalinated water)	0	Not applicable (since it is integrated into the criteria from other tables from *Table Set 2*)

Table 2.2a: Use of freshwater and reclaimed waters and/or other water sources (e.g., recovered rain waters, external water sources

Key factor	Sub-key Factor	Condition	Additional sub-condition	Impact	Explanation
2. Use of alternative water sources	2.2a Freshwater and reclaimed waters/other water sources (e.g., recovered rain waters, external water sources)	Freshwater > water reuse	If groundwater or surface water are used and the quantitative or ecological status, respectively, fails to achieve good status	-7	More freshwater is used, but some water reuse is involved, slightly reducing pressure on water resources, but the use of freshwater in areas where it's already stressed or failing exacerbates local scarcity issues
			If groundwater or surface water are used and present Good quantitative or ecological status, respectively	3	More freshwater is used, but some water reuse is involved, slightly reducing pressure on water resources, and the use of freshwater in regions where it maintains a good status, is considered neutral due to sustainability
		Freshwater = water reuse	If groundwater or surface water are used and the quantitative or ecological status, respectively, fails to achieve good status	-3	Equal use of freshwater and reused water, balancing resource use, but the use of freshwater in areas where it's already stressed or failing exacerbates local scarcity issues
			If groundwater or surface water are used and present Good quantitative or ecological status, respectively	5	Equal use of freshwater and reused water, balancing resource use. The use of freshwater in regions where it maintains a good status, is considered neutral due to sustainability
		Freshwater = water reuse & reuse as a carrier (e.g., nutrients)	If groundwater or surface water are used and the quantitative or ecological status, respectively, fails to achieve good status	3	Reused water carries additional products, enhancing sustainability, but the use of freshwater in areas where it's already stressed or failing exacerbates local scarcity issues
			If groundwater or surface water are used and present Good quantitative or ecological status, respectively	7	Reused water carries additional products, enhancing sustainability. Also, the use of freshwater in regions where it maintains a good status is considered neutral due to sustainability

Table 2.2a (cont.): Use of freshwater and reclaimed waters and/or other water sources (e.g., recovered rain waters, external water sources

Key factor	Sub-key Factor	Condition	Additional sub-condition	Impact	Explanation
2. Use of alternative water sources	2.2a Freshwater and reclaimed waters/other water sources (e.g., recovered rain waters, external water sources)	Freshwater < water reuse	If groundwater or surface water are used and the quantitative or ecological status, respectively, fails to achieve good status	3	Reuse of water exceeds freshwater use, significantly reducing demand on freshwater resources, but the use of freshwater in areas where it's already stressed or failing exacerbates local scarcity issues
			If groundwater or surface water are used and present Good quantitative or ecological status, respectively	7	Reuse of water exceeds freshwater use, significantly reducing demand on freshwater resources and the use of freshwater in regions where it maintains a good status is considered neutral due to sustainability
		Freshwater < water reuse & reuse as a carrier (e.g., nutrients)	If groundwater or surface water are used and the quantitative or ecological status, respectively, fails to achieve good status	7	Maximising sustainability by extensively using reused water, especially as a carrier for other products, but the use of freshwater in areas where it's already stressed or failing exacerbates local scarcity issues
			If groundwater and surface water are used and present Good quantitative or ecological status, respectively	9	Maximizing sustainability by extensively using reused water, especially as a carrier for other products and the use of freshwater in regions where it maintains a good status, is considered neutral due to sustainability
		Only freshwater resources (or freshwater combined with desalinated water) are used	---	0	Not applicable (since it is integrated into the other two criteria)

Table 2.2b: Use of reclaimed water, other reuse or recycled water sources (e.g., recovered rain waters, runoff, condensates

Key factor	Sub-key Factor	Condition	Additional sub-condition	Impact	Explanation
2. Use of alternative water sources	2.2b 100% reclaimed water/other reuse/recycled water sources (e.g., recovered rain waters, runoff, condensates)	Reuse as a carrier (e.g., nutrients)		9	Highly positive for reducing freshwater demand and augmentation of water reuse content (additional positive impact)
		Reuse as a carrier is not applicable	Water content is considered as not important	7	Highly positive for reducing freshwater demand, but without considering the global aspects of circularity
		Reuse not seen as carrier/no information available (e.g., nutrients)		5	Highly positive for reducing freshwater demand, but without considering the added value of water content
		Reuse with demonstrated evidence of soil salinisation or other soil contamination	Demonstrated local evidence of negative impacts on soils from water reuse practices	-9	Despite the positive impacts of reducing freshwater demand, the practice is destroying the soil's ability

Table 2.3a: Use of freshwater and desalinated waters

Key factor	Sub-key Factor	Condition	Additional sub-condition	Impact	Explanation
2. Use of alternative water sources	2.3a Freshwater and desalinated waters	Freshwater > desalinated waters	If groundwater or surface water are used and the quantitative or ecological status, respectively, fails to achieve good status	-7	Despite the use of an alternative water source (desalinated water), the use of freshwater in areas where it's already stressed or failing exacerbates local scarcity issues
			If groundwater or surface water are used and present Good quantitative or ecological status, respectively	1	Freshwater use is predominant, and its use in regions where it maintains a good status is considered neutral due to sustainability; desalination's environmental impact reduces the positive value
		Freshwater = desalinated waters	If groundwater or surface water are used and the quantitative or ecological status, respectively, fails to achieve good status	-5	Equal use of both sources; however, desalination's negative aspects slightly dampen the impact. The use of freshwater in areas where it's already stressed or failing exacerbates local scarcity issues
			If groundwater or surface water are used and present Good quantitative or ecological status, respectively	3	Equal use of both sources; however, desalination's negative aspects slightly dampen the impact. The use of freshwater in regions where it maintains a good status is considered neutral due to sustainability
		Freshwater < desalinated waters	If groundwater or surface water are used and the quantitative or ecological status, respectively, fails to achieve good status	1	Desalinated water use exceeds freshwater, positive for reducing freshwater demand but with energy/chemical products use/discharge concerns and the use of freshwater in areas where it's already stressed or failing exacerbates local scarcity issues
			If groundwater or surface water are used and present Good quantitative or ecological status, respectively	5	Desalinated water use exceeds freshwater, positive for reducing freshwater demand, but with energy/chemical products use/discharge concerns
		Only freshwater resources (or freshwater combined with reclaimed water) are used	---	0	Not applicable (since it is integrated into the other two criteria)

Table 2.3 b: Use of desalinated waters

Key factor	Sub-key Factor	Condition	Additional sub-condition	Impact	Explanation
2. Use of alternative water sources	2.3b Desalinated waters	No other water source is used		5	Desalinated water use has a positive effect on reducing freshwater demand, but with energy/chemical products use/discharge concerns
		Combined with reclaimed water & reuse as a carrier (e.g., nutrients)		7	Highly positive for reducing freshwater demand, but desalination's environmental impact reduces the positive value
		Combined with reclaimed water		5	Highly positive for reducing freshwater demand, but reuse does not incorporate the carrier possibility, and the desalination's environmental impact reduces the positive value
		Combined with freshwater	Not applicable	0	Not applicable since it is considered under table 2.3a

2.3.3. Internal use of reclaimed waters: water reuse (within the process, quantitative aspects)

It should be noted that all sub-key factors must be measurable. Therefore, the current index does not reflect different levels of internal reuse since the usual data available in permits do not include a comprehensive understanding of the various levels of internal reuse in place. For example, the current permits usually do not define percentages of implemented reuse or recycling of water, only their total or partial implementation. Subsequently, the sub-key factor, presented in Table 3, only appraises whether internal reuse is applicable.

Table 3: Internal use of reclaimed waters

Key factor	Sub-key factor	Condition	Impact	Explanation
3. Internal use of reclaimed waters	3. Use of Internal Water Reuse or Recycling, including condensate	No internal reuse or recycling	-7	The process doesn't incorporate any form of water reuse or recycling, missing opportunities for water efficiency
			-3	Water reuse/recycling seems unfeasible, or there is no information. So, it needs to be demonstrated why this practice is not used
			-1	The process doesn't incorporate any form of water reuse or recycling because previous attempts demonstrated a detrimental impact on the final product
			0	No internal reuse due to the sending wastewater to external use (or in case of crop production demonstration of water use efficiency)
		Some internal reuse or recycling	5	Some level of water reuse or recycling is promoted, contributing to resource efficiency
		Total internal reuse or recycling	9	Complete water reuse or recycling within the process, maximising water efficiency

2.3.4. Water pollutants

The presence of certain pollutants in wastewater and the use of microplastics indicate a probability of direct or indirect emissions, discharges, or losses of substances into the environment, which may negatively impact natural resources, including ecosystems. This key factor aims to measure this pressure on natural resources and is divided into five sub-key factors, which are described in detail in the Tables 4.1 to 4.5.

Table 4.1: Probability of emissions, discharges or losses of water pollutants from the product production

Key factor	Sub-key factor	Surface water status	Condition	Impact	Explanation
4. Water pollutants	4.1 Priority substances (PS), priority hazardous substances (PHS) or specific pollutants (SP) or other pollutants that could represent a specific problem (referring to permit or national legislation for ex. sulphates)	Good or higher	PS/PHS used and/or expected to be released	-7	High risk of water pollution due to the release of harmful substances.
			SP used and/or expected to be released	-5	Moderate risk of water pollution from specific pollutants.
			Partial information on use/release of PS, PHS, or SP	-1	Lack of data on pollutant usage/release.
			PS, PHS, SP not used or not expected to be released	0	Safe practices in place, no harmful pollutants expected (PS, PHS or SP are not used and are not expected to be released)
		Less than good	PS/PHS used and/or expected to be released	-9	High risk of water pollution due to the release of harmful substances.
			SP used and/or expected to be released	-7	Moderate risk of water pollution from specific pollutants.
			Partial information on use/release of PS, PHS, or SP	-3	Lack of data on pollutant usage/release.
			PS, PHS, SP not used or not expected to be released	9	Safe practices in place, no harmful pollutants expected (PS, PHS or SP are not used and are not expected to be released). Contribute to the zero-pollution action plan

Table 4.2: Probability of direct and indirect emissions of microplastics

Key factor	Sub-key factor	Condition	Impact	Explanation
4. Water pollutants	4.2 Microplastics	Used in manufacture	-7	Negative environmental impact due to the promotion of microplastic pollution (release during the life-time of product)
		Not used in manufacture	0	No direct impact from microplastics in the production process, despite the activity may release microplastics during the product life-cycle

The current limitations on microplastic monitoring do not allow the use of a more detailed sub-key factor at the current state-of-art.

Table 4.3: Characteristics of the wastewaters from the production process (pH)

Key factor	Sub-key factor	Condition	Impact	Explanation
4. Water pollutants	4.3 pH	pH < 6 or pH > 9	-7	Discharged wastewater is potentially harmful to aquatic life due to pH imbalance.
		6 ≤ pH ≤ 9	1	pH levels within acceptable range for discharge, minimal positive impact on circularity
		Not applicable	0	pH consideration is not relevant to the production process or discharge; The process does not have wastewater discharge

Table 4.4: Characteristics of the wastewaters from the production process (COD)

Key factor	Sub-key Factor	Condition	Additional sub-condition	Impact	Explanation
4. Water pollutants	4.4 Organic Matter, measured in terms of Chemical Oxygen Demand (COD) in raw wastewater	COD > 5000 mg/L O_2	No WWTP* in place	-9	Very high organic content poses a significant pollution risk
			Yes, but with non-compliance of ELV**	-7	High organic content with low treatment efficiency
			Yes, but with 1 to 2 non-compliances in the previous 12 months	-5	Medium organic content with some negative impacts due to failures in treatment compliance
			Yes, and ELV are in compliance	9	Low organic levels due to treatment effectiveness
		500 mg/L O_2 < COD ≤ 5000 mg/L O_2	No WWTP in place	-7	Very high organic content poses a significant pollution risk
			Yes, but with non-compliance of ELV	-5	High organic content with low treatment efficiency
			Yes, but with 1 to 2 non-compliances in the previous 12 months	-3	Medium organic content with some negative impacts due to failures in treatment compliance
			Yes, and ELV are in compliance	9	Low organic levels due to treatment effectiveness
		COD ≤ 500 mg/L O_2	No WWTP in place	-5	Very high organic content poses a significant pollution risk
			Yes, but with non-compliance of ELV	-3	High organic content with low treatment efficiency
			Yes, but with 1 to 2 non-compliances in the previous 12 months	-1	Medium organic content with some negative impacts due to failures in treatment compliance
			Yes, and ELV are in compliance	9	Low organic levels due to treatment effectiveness or process removal (e.g. production of chars from wastewaters or sludge)
		Not applicable		0	COD concentration so low that it is not relevant to the production process or discharge; The process does not have wastewater discharge

* WWTP: Wastewater treatment plant
** ELV: Emission Limit Value

Table 4.5: Characteristics of the wastewaters from the production process (N & P)

Key factor	Sub-key Factor	Condition	Additional sub-condition	Impact	Explanation
4. Water pollutants	4.5 Nutrients, measured in terms of Nitrogen (N_{Total}) and Phosphorous (P_{Total}) in raw wastewater	High content ($N_{Total} \geq$ 125 kg/y and/or $P_{Total} \geq$ 8 kg/y)	No WWTP* in place	-9	Very high nutrient content (N and/or P) posing a significant pollution risk
			Yes, but with non-compliance of ELV**	-7	High nutrient content (N and/or P) with environmental impact due to low treatment efficiency
			Yes, but with 1 to 2 non-compliances in the previous 12 months	-5	Medium nutrient content (N and/or P), with some negative impacts due to failures in treatment compliance
			Yes, and ELV are in compliance	9	Low nutrient content (N and/or P), due to treatment effectiveness
		Medium content (25 kg/y $\leq$ N_{Total} < 125 kg/y and/or 2 kg/y $\leq$ P_{Total} < 8 kg/y)	No WWTP in place	-7	Very high nutrient content (N and/or P) posing a significant pollution risk
			Yes, but with non-compliance of ELV	-5	High nutrient content (N and/or P) with environmental impact due to low treatment efficiency
			Yes, but with 1 to 2 non-compliances in the previous 12 months	-3	Medium nutrient content (N and/or P), with some negative impacts due to failures in treatment compliance
			Yes, and ELV are in compliance	9	Low nutrient content (N and/or P), due to treatment effectiveness
		Low content (N_{Total} < 25 kg/y and/or P_{Total} < 2 kg/y)	No WWTP in place	-5	Very high nutrient content (N and/or P) posing a significant pollution risk
			Yes, but with non-compliance of ELV	-3	High nutrient content (N and/or P) with environmental impact due to low treatment efficiency
			Yes, but with 1 to 2 non-compliances in the previous 12 months	-1	Medium nutrient content (N and/or P), with some negative impacts due to failures in treatment compliance
			Yes, and ELV are in compliance	9	Low nutrient content (N and/or P), due to treatment effectiveness
		Not applicable	Not applicable	0	N and/or P consideration is not relevant to the production process or discharge or is a crop production; The production process does not have wastewater discharge (i.e., is a dry process or is a crop production in soil without runoff)***

* WWTP: Wastewater treatment plant

** ELV: Emission Limit Value

*** Some crop production occurs in an aqueous media (hydroponic crops) with runoff production. In soils, some irrigation methods or practices may also lead to the occurrence of runoff (e.g., furrow or flood irrigation or use of water in excess regarding the crop needs)

2.3.5. Externalities: reused/recycled materials synergy

In the context of a production process, the potential for synergies between processes, industries, or even sectors can be harnessed. The production process may draw upon external inputs, such as recycled materials or recovered components (e.g., nutrients), with the objective of maintaining the circulation of resources. Conversely, the output from the production process can be directed towards other processes or industries, thereby fostering synergies that minimise the utilisation of raw materials and, directly or indirectly, freshwater. This key factor is aimed at understanding the process symbiosis, where inputs (resources and materials) and outputs (waste, byproducts or emissions) from one process can be used by another since this practice can reduce waste, improve resource efficiency, and create economic, environmental, and social benefits. Therefore, this key factor, presented in Tables 5.1 and 5.2, integrates two sub-key factors to measure the inputs and outputs of the process in terms of reused and/or recycled materials. The use of reclaimed water is excluded from the inputs since it is already addressed in the aforementioned key factor 2. Also, energy is not considered under this key factor, since measures to recover it are addressed under key factor 6.

Table 5.1: Use of reused or recycled materials, except reclaimed water (inputs to the specific production process under assessment)

Key factor	Sub-key Factor	Condition	Impact	Explanation
5. Externalities	5.1 Use (input) of reused/recycled materials, including nutrient recovery from compost/sludge or other (except water reuse)	Possible but not in place/ no information	-9	In the case of crop production, if there is no nutrient recovery, then chemical fertilisation is in place, resulting in a negative value
		Not applicable	0	The practice is not feasible, neutral impact given the context or It's already considered in the water circularity index for the installations (nutrients recovery or sludge)
		Yes, partially	5	Some level of recycling is promoted, contributing to resource efficiency. The resources are kept in the loop, minimising the consumption of fresh resources/raw materials
		Yes	9	A consistent level of recycling is promoted, contributing to resource efficiency. The resources are kept in the loop as much as possible, minimising the consumption of fresh resources/raw materials

Table 5.2: Production of materials to be reused or recycled by different processes (inside or outside of the same installation)

Key factor	Sub-key Factor	Condition	Impact	Explanation
5. Externalities	5.2 Send to external uses/activities (output) of reused/recycled water, and materials, including nutrients like compost/sludge or other	Possible but not in place/No information	-9	Promotion of end-use practices. Risk of overexploitation of natural resources
		Not applicable	0	The practice is not feasible (e.g., promotion of internal reuse, see table 4), has a neutral impact given the context or is already considered in the water circularity index for the installations (nutrients recovery or sludge). Also, when considerable and demonstrated negative environmental impacts may occur (e.g., not feasible due to high energy consumption or high CO_2 emissions), this sub-key-factor should be considered as not feasible and subsequently not applicable
		Yes, for one or more activity/use (but excluding water reuse purposes)	3	A consistent level of recycling is promoted, contributing to resource efficiency, but excludes the possibility of synergies in water reuse
		Yes, for one or more activity/use (including water reuse purposes)*	9	A consistent level of recycling is promoted, contributing to resource efficiency. The resources are kept in the loop as much as possible, minimising the consumption of fresh resources/raw materials

***** Including use of reclaimed water to suppress water needs, for heat recovery and/or components that can be used for treatment of wastewater or extracted from reclaimed waters or sludge (components recovered according to the "biorefinery" concept)

2.3.6. Additional factors

A key factor that considers additional aspects that may have a beneficial or detrimental impact on the circularity of a given product is also included. The initial consideration pertains to the matter of energy utilisation. The concepts of energy consumption and water circularity are inextricably linked, particularly in the context of sustainability and resource management. The production of energy is dependent on water, as evidenced by the use of water in thermoelectric power plants, hydropower, or cooling systems. Additionally, the extraction of raw materials for energy production, such as oil, gas, and minerals, also requires water. Concurrently, energy is necessary for the provision and treatment of water. In addition, certain energy sources may exert a greater influence on water resources due to their elevated concentration of pollutants (such as those present in fossil fuels) relative to others. The intertwining of energy and water usage gives rise to the "energy-water nexus" concept. Therefore, it becomes imperative to identify measures that can reduce or recover energy consumption within a process in order to gain insight into the overall efficiency and to ascertain the critical aspects that can promote or decrease the water circularity of a product.

The remaining factors relate to the importance of seasonal and regional products for certain local communities. These products can hold substantial economic value for these communities while promoting regional characteristics. This often enhances resilience regarding local water availability and supports the preservation of natural heritage values. s also frequently associated with crop production, and its benefits can be observed in the promotion of landraces, local varieties, and subsequently, agrobiodiversity.

The key factor “Additional factors”, described in Tables 6.1 to 6.4, is divided into five sub-key factors, of which the factor "Seasonal and non-seasonal crops" comprises two sub-key factors related to crop production.

Table 6.1: Energy sources and measures to reduce and recover energy

		Energy Recovery				
	Sub-factor	No measure taken	Not applicable to this correction factor / not possible to know	Measures to reduce energy consumption in place, but no measure to recover energy or no information available	Measures to reduce or recover energy in the process	Measures to reduce and to recover energy in the process
Energy Sources	Use of fossil sources (black)	-9	-9	-7	-5	-3
	Use of fossil and non-fossil sources	-7	-5	-3	-1	0
	Use of main non-fossil sources (grey)	-1	0	1	3	5
	Use of fossil sources and renewable energy sources	1	3	5	7	9
	Use of fossil sources and non-fossil and renewable energy sources	3	5	5	7	9
	Use of non-fossil sources and other renewable energy sources	5	7	7	9	9
	Renewable energy is the main source for water cycle (green)	7	9	9	9	9

Table 6.2a: Seasonal and non-seasonal crops (applicable only to crop production)

Key factor	Sub-key Factor	Condition	Impact	Explanation
6. Additional factors	6.2a Seasonal crops	Not seasonal crop or not a crop production	0	Not applicable
		Water-consuming product in the dry season (Apr-Sep)	-3	Freshwater consumption matches the dry period with high negative impacts on water resources. Possible acute effects from high consumption in the dry season
		Water-consuming product in the wet season (Oct-Mar)	5	The consumption of freshwater matches the wet period with low impacts over water resources

Table 6.2b: Suitability for the location (applicable only to crop production)

Key factor	Sub-key Factor	Description	Condition	Impact	Explanation
6. Additional factors	6.2b Crops suitable for the location	Is an "exotic" (not appropriate for the location) crop	Highly water consuming	-5	According to FAO, WHO or other data the crop (or its growing cycle) is not appropriate for the location (e.g., is an exotic), and the water consumption for its growth promotes overexploitation of water resources
		Is an "exotic" (not appropriate for the location) crop	Not highly water-consuming	0	According to FAO, WHO or other data, the crop (or its growing cycle) is not appropriate for the location (e.g., is an exotic), but the related water consumption does not increase the pressure over local water bodies
		Is not a crop production	Not applicable	0	
		Is a common crop in the region	It could not be an autochthonous crop, but it was introduced more than one century ago	3	Despite its not an autochthonous crop, there might be a promotion of local products
		Is an organic production	Common, autochthonous and/or not highly water-consumptive crop	5	Promotion of the use of organic fertilizers, which implies a process with nutrient recovery
		Is an autochthonous crop (local varieties)	Crop from the region	7	Promotion of local products
		Is an autochthonous crop ("landraces"**)	Crop from the region (not improved or exotic)	9	Promotion of endogenous species and agrobiodiversity***

* Local varieties often cope better with drought and other stresses, and outperform modern varieties when grown under ecological conditions.

** Crop variety that has been cultivated, selected, and conserved by farmers over generations, typically in a specific local or regional environment. These varieties are often adapted to local environmental conditions and resilient to local pests and diseases, due to the continuous selection for traits that support survival and productivity within the traditional farming systems. Traditional varieties are also referred as "landraces" and are valued for their genetic diversity, which provides a foundation for food security, crop resilience, and agricultural biodiversity.

*** The variety and variability of animals, plants and micro-organisms that are used directly or indirectly for food and agriculture, including crops, livestock, forestry and fisheries. It comprises the diversity of genetic resources (varieties, breeds) and species used for food, fodder, fibre, fuel and pharmaceuticals. It also includes the diversity of non-harvested species that support production (soil micro-organisms, predators, pollinators), and those in the wider environment that support agro-ecosystems (agricultural, pastoral, forest and aquatic) as well as the diversity of the agro-ecosystems.

Regarding the type of crop, additional information can be found on FAO website or consulted the indicative Crop Classification for the Agricultural *Census* (ICC)[1].

Table 6.3: Seasonal products (except crop production)

Key factor	Sub-key Factor	Description	Condition	Impact	Explanation
6. Additional factors	6.3 Seasonal products	The production does not occur in a specific timeframe during the year or is a crop production	Not applicable	0	No additional impacts and crop production is assessed under table 13
		The production does occur in a specific timeframe during the year, within the dry season	With no measures in place to reduce the acute effects of wastewater discharges	-7	High impacts in water bodies from a wastewater discharge concentrated in time, with no or low natural dilution/dispersion conditions
			With some measures in place to reduce some acute effects (e.g., buffer capacity where wastewater discharges can extend for more than 3 months or demonstrated treatment to prevent acute effects over receiving water bodies)	-5	The reduction in the discharged flow over time minimises impacts on water bodies
		The production does occur in a specific timeframe during the year, within the wet season	With no measures in place to reduce the acute effects of wastewater discharges	-5	The natural dilution/dispersion conditions can minimise impacts on water bodies during the wet season, but the absence of measures may have adverse effects
			With some measures in place to reduce some acute effects (e.g., buffer capacity where wastewater discharges can extend for more than 3 months)	0	No additional impacts since the natural dilution/dispersion conditions minimise impacts on water bodies during the wet season
		The production does occur in a specific timeframe during the year (dry or wet season)	With active measures in place (e.g., buffer capacity where wastewater discharges can extend for more than 6 months)	7	Actions are taken to prevent impacts on water bodies

[1] *Source:* http://www.fao.org/3/a-i4913e.pdf

Table 6.4: Regional products

Key factor	Sub-key Factor	Description	Condition	Impact	Explanation
6. Additional factors	6.4 Protected Designation of Origin (POD) / Protected Geographical Indication (PGI)/ Geographical Indication (GI) product*	Is not a product under POD or a regional product	Not applicable	0	The product does not represent an economical add due to its regionality
		Is a regional product, but with no information about its importance for the local community		3	It may create some economic advantages, but those are not clear
		Is a regional product or a POD product and with importance for the local community		5	Is an autochthonous crop and/or a POD/PGI /GI

*Geographical indications establish intellectual property rights for specific products, whose qualities are specifically linked to the area of production. Geographical indications comprise:

- PDO – protected designation of origin (food and wine)
- PGI – protected geographical indication (food and wine)
- GI – geographical indication (spirit drinks).

The EU geographical indications system protects the names of products that originate from specific regions and have specific qualities or enjoy a reputation linked to the production territory. The differences between PDO and PGI are linked primarily to how much of the product's raw materials must come from the area, or how much of the production process has to take place within the specific region. GI is specific for spirit drinks.

2.4. The Water circularity index for products ($I_{C\ Prod}$)

2.4.1. Partial Water circularity index for products ($I'_{C\ Prod}$)

The partial Water circularity for products ($I'_{C\ prod}$) is given by the sum of all the sub-key factors previously described (eq. 1), where the impacts from each sub-key factor are provided directly by the previous tables (Set 1 to Set 6). For Table Set 2, only one table (tables 2.1, 2.2 a&b and 2.3 a&b) applies to each situation under assessment.

$$I'_{C_{prod}} = \sum \left(F_{i\ Key}\right) \qquad (1)$$

Where the $F_{i\ key}$ represents the impact of each applicable sub-key factor.

The $I'_{C\ prod}$ varies from -117 to 117, and its results are prioritised in Table 7. However, not all sub-key factors apply to all types of products. Thus, for crop production, the scale varies from -87 to 100, for seasonal/regional products, it ranges from -109 to 103, and for "large" industrial products, it can go from -102 to 96.

Table 7: Partial Water circularity index for products ($I'_{C\ prod}$)

Impact of key factor	$I'_{C\ prod}$	Condition for $I_{C\ Prod}$ result	Results expression
Partial Water circularity index for products ($I'_{C\ prod}$)	$I'_{C\ prod} < -60$	High negative circularity	-9
	$-60 \leq I'_{C\ prod} < -30$	Medium negative circularity	-5
	$-30 \leq I'_{C\ prod} < 0$	Low negative circularity	-3
	$I'_{C\ prod} = 0$	Neutral circularity	0
	$0 < I'_{C\ prod} \leq 30$	Low positive circularity	3
	$30 < I'_{C\ prod} \leq 60$	Medium positive circularity	5
	$I'_{C\ prod} > 60$	High positive circularity	9

2.4.2. Correction factor from the Water circularity index for installations (I_C)

Finally, whenever applicable, the aspects directly related to the installation where the product under assessment is produced must be integrated with the partial index to correct it. Therefore, is proposed to integrate the results of the partial index ($I'_{C\ prod}$) with the results from the water circularity index developed in the previous phases of the project and applicable to installations.

According to Table 8, the circularity index for installations (I_C), developed in previous phases of the project, ranges from -4,4 to 2,6. Enlarging the scale of the I_C becomes necessary to improve the integration of results from both indexes, according to Table 9.

Table 8: Water circularity index for installations (I_C)[2]

Sub-Factor	Description	I_C	Condition for I_C result
Water circularity index for installations (I_C)	Integration of good water management practices from the installation that should be reflected in the product	$I_C < 0$	Negative circularity
		$I_C = 0$	Neutral circularity
		$0 < I_C \leq 0,85$	Low circularity
		$0,85 < I_C \leq 1,5$	Medium circularity
		$I_C > 1,5$	High circularity

Table 9: Enlarged scale for the water circularity index for installations

Sub-Factor	Description	I_C	Condition for I_C result	Results expression
Water circularity index for installations (I_C)	Integration of good water management practices from the installation that should be reflected in the product	$I_C < -2,9$	High negative circularity	-9
		$-2,9 \leq I_C < -1,47$	Medium negative circularity	-5
		$-1,47 \leq I_C < 0$	Low negative circularity	-3
		$I_C = 0$	Neutral circularity	0
		$0 < I_C \leq 0,85$	Low positive circularity	3
		$0,85 < I_C \leq 1,5$	Medium positive circularity	5
		$I_C > 1,5$	High positive circularity	9

[2] *Source:* Rebelo A., Farabegoli G. et al. (2019), Report on good practices to promote the transition to circular economy in urban and industrial water management: A new water circularity index. IMPEL report no 2019/10, 68 pages. Brussels, ISBN 978-2-931225-27-1

The final result for the circularity of the product is determined by integrating the circularity index for the installation (I_C) with the partial circularity index of the product ($I'_{C\ Prod}$) as shown in the matrix in Figure 1 and defined as follows:

			$I'_{C\ Prod}$						
			High negative circularity	**Medium negative circularity**	**Low negative circularity**	**Neutral circularity**	**Low positive circularity**	**Medium positive circularity**	**High positive circularity**
			-9	**-5**	**-3**	**0**	**3**	**5**	**9**
I_C (installation)	**High negative circularity**	**-9**	High negative circularity (-9)	High negative circularity (-9)	High negative circularity (-9)	Medium negative circularity (-5)	Low negative circularity (-3)	Low negative circularity (-3)	Neutral circularity (0)
	Medium negative circularity	**-5**	High negative circularity (-9)	Medium negative circularity (-5)	Medium negative circularity (-5)	Low negative circularity (-3)	Low negative circularity (-3)	Neutral circularity (0)	Low positive circularity (3)
	Low negative circularity	**-3**	High negative circularity (-9)	Medium negative circularity (-5)	Low negative circularity (-3)	Low negative circularity (-3)	Neutral circularity (0)	Low positive circularity (3)	Low positive circularity (3)
	Neutral circularity	**0**	Medium negative circularity (-5)	Low negative circularity (-3)	Low negative circularity (-3)	Neutral circularity (0)	Low positive circularity (3)	Low positive circularity (3)	Medium positive circularity (5)
	Low positive circularity	**3**	Low negative circularity (-3)	Low negative circularity (-3)	Neutral circularity (0)	Low positive circularity (3)	Low positive circularity (3)	Medium positive circularity (5)	High positive circularity (9)
	Medium positive circularity	**5**	Low negative circularity (-3)	Neutral circularity (0)	Low positive circularity (3)	Low positive circularity (3)	Medium positive circularity (5)	Medium positive circularity (5)	High positive circularity (9)
	High positive circularity	**9**	Neutral circularity (0)	Low positive circularity (3)	Low positive circularity (3)	Medium positive circularity (5)	High positive circularity (9)	High positive circularity (9)	High positive circularity (9)

Figure 1: Water circularity index for products ($I_{C\ Prod}$)

When the I_C is not applicable, for example, for farming products (crop production), the results from the partial circularity index ($I'_{C\ Prod}$) will be equal to the final result, i.e.:

$$I'_{C\ Prod} = I_{C\ Prod} \tag{2}$$

2.4.3. Final scale assessment

When evaluating the complete set of key factors and their associated sub-key factors, the global scale spans from -117 to 117. However, it is important to note that not all sub-key factors are relevant to the three main categories of products assessed, namely, seasonal and regional products, crops, and large installations. Consequently, an assessment was conducted considering only the applicable sub-key factors for each product type and the respective results are presented in Table 10.

Table 10: Assessment of the index scales

Sub-Key Factors		Global		Crops		Seasonal and/or regional products		Industrial products	
		Min	Max	Min	Max	Min	Max	Min	Max
1.1	**Water scarcity and freshwater consumption**	-9	9	-9	9	-9	9	-9	9
1.2	**Water scarcity at RBMP**	-9	9	-9	9	-9	9	-9	9
2	**Use of alternative water sources (table set 2)**	-9	9	-9	9	-9	9	-9	9
3	**Internal use of reclaimed waters**	-7	9	-7	9	-7	9	-7	9
4.1	**Priority substances & others**	-9	9	-9	9	-9	9	-9	9
4.2	**Microplastics**	-7	0	n.a.	n.a.	-7	0	-7	0
4.3	**WW* (pH)**	-7	1	n.a.	n.a.	-7	1	-7	1
4.4	**WW (organic matter**	-9	9	n.a.	n.a.	-9	9	-9	9
4.5	**WW (nutrients)**	-9	9	-9	9	-9	9	-9	9
5.1	**Externalities: Inputs**	-9	9	-9	9	-9	9	-9	9
5.2	**Externalities: Outputs**	-9	9	-9	9	-9	9	-9	9
6.1	**Energy (sources & measures)**	-9	9	-9	9	-9	9	-9	9
6.2a	**Seasonal crops**	-3	5	-3	5	n.a.	n.a.	n.a.	n.a.
6.2b	**Crops suitable for the location**	-7	7			-7	7		
6.3	**Seasonal products**	-5	9	-5	9	n.a.	n.a.	n.a.	n.a.
6.4	**POD / PGI / GI product**	0	5	0	5	0	5	0	5
	$I'_{C\ prod}$	Min	Max	Min	Max	Min	Max	Min	Max
	$\sum (F_{i\ Key})$	-117	+117	-87	+100	-109	+103	-102	+96

*WW: Wastewater

The assessment of the scale results reveals the following observations:

- The global scale results in a balance between positive and negative impacts;
- The scale shifts slightly towards positive values for crop products, translating a baseline circularity related to food production since a natural form of circularity is already associated with food systems. In those, nutrients are recovered and cycled back into the environment through biological processes like decomposition, excretion, and nutrient absorption, and also related to the promotion of landraces and agrobiodiversity;
- A minor deviation towards negative values can be observed for regional and seasonal products when considering microplastics. However, these uses in regional or seasonal products are less usual due to the increase in sustainable practices. Despite most situations, the sub-key factor will result in "not applicable"; specific productions where microplastics can be used may occur (e.g., local cosmetic production). When considering this sub-key factor as "not applicable", the index scale is balanced between positive and negative impacts, with a minor shift to positive (from -102 to 103), since seasonal or regional products tend to integrate local or even "old" practices aligned with the specificities of the region (e.g., local climate conditions);
- Products derived from large installations often have a higher environmental impact, and subsequently, the scale tilts to negative values. This phenomenon results from the usually elevated consumption of natural resources, including water and energy, and impacts from wastewater generated by large-scale industrial processes.

3. Application to real case scenarios

The circularity index for products was applied to five case studies encompassing three distinct product types. In the first case study (crop production), the product selected was citrus irrigated with groundwater, which was subsequently compared to the same product irrigated with reclaimed water. The data utilized for this analysis was sourced from a scientific paper published in 2022[3]. The same dataset was employed for the second case study, but this time under the hypothesis of avocados instead of oranges. For regional and seasonal products, the third case study focused on the rhum obtained from sugarcane in Madeira Island (Madeira Rhum). Regarding products from large installations, two cases were assessed, i.e., a beer produced from reclaimed waters from an urban wastewater treatment plant (case study four) and paper pulp (case study five) from an installation appraised under the previous phase of the current project (case

[3] *Source:* Moreira da Silva, M., et al. (2022). "Urban Wastewater Reuse for Citrus Irrigation in Algarve, Portugal—Environmental Benefits and Carbon Fluxes." Sustainability 14(17): 10715, available at https://www.mdpi.com/2071-1050/14/17/10715.

study A.2[4]). In Annex I, a detailed explanation of how each key factor and related key factors are applied to all case studies and variations is provided.

Table 11: Case studies results

Case Study	Partial Circularity index ($I'_{C\ Prod}$)	Condition Result	Result expression	Circularity index for installation (I_C)	Circularity index for products ($I_{C\ Prod}$)
Citrus (only irrigated with reclaimed waters)	-9	Low negative circularity	-3	---	---
Citrus (only irrigated with groundwaters)	-33	Medium negative circularity	-5	---	---
Avocados (only irrigated with reclaimed waters)	-18	Low negative circularity	-3	---	---
Avocados (only irrigated with groundwaters)	-42	Medium negative circularity	-5	---	---
Madeira Rhum (without considering only de sugarcane mill)	-18	Low negative circularity	-3	---	---
Madeira Rhum (without considering only de sugarcane mill and the sugarcane production)	-10	Low negative circularity	-3	---	---
Beer	71	High positive circularity	9	---	---
Paper pulp	29	Low positive circularity	3	1,19 (Medium positive circularity, result expression equal to 5)	5 (Medium positive circularity)

The results from the first case study indicated that the lack of information significantly affects the outcomes. Therefore, a trial was conducted under the assumption that data was available for sub-key

[4] *Source:* Rebelo A., Farabegoli G. et al. (2019), Report on good practices to promote the transition to circular economy in urban and industrial water management: A new water circularity index. IMPEL report no 2019/10, 68 pages. Brussels, ISBN 978-2-931225-27-1.

factors 3, 4.1, 5.1, 5.2, and 6.1. This availability would enable the achievement of maximum positive inputs. For this purpose, the following examples of best practices were considered:

- Sub-key 3: Collection of runoffs and blend it with irrigation waters;
- Sub-key 4.1: Presence of evidence on safe practices to prevent pesticide release to aquatic environment or organic farming
- Sub-key 5.1: Use of sludge or compost to avoid/minimise the use of chemical fertilisers;
- Sub-key 5.2: Collection of green wastes to send to compost production or animal feed
- Sub-key 6.1: Measures to reduce energy (e.g., in pumping and/or irrigation systems), such as using efficient equipment with some heat recovery, solar panels or others.

This exercise demonstrated that implementing more sustainable practices could lead to citrus with a higher circularity, namely a medium positive circularity ($I'_{C\ Prod} = 57$), quite near the high positive circularity.

A similar test can be done for the Madeira Rhum. The sugarcane plant (*Saccharum officinarum*) has been one of Madeira Island's most vital agricultural commodities since the 15th century. Currently, its primary applications include the production of cane honey and agricultural rhum, being classified as a product with protected geographical indication (PGI)[5]. In 2023, the amount of sugarcane processed for the production of Madeira Rhum alone was 7,252 tonnes, giving a production volume of 100% Madeira Rhum of 3,141 hectolitres. The largest volume of bottling is in the 'natural' Rhum category, with around 4,883 hectolitres (around 86.7 % of all Madeira Rhum bottled) In the same year, this product represented nearly five million euros (4,996.288 €) in sales, with the largest markets of Latvia and France, after Portugal. However, one of the major problems of this industry relates to the production of a large amount of organic waste, namely sugarcane bagasse. During rhum production, in addition to the bagasse, an effluent called vinasse is also produced, which has a large potential to cause negative impacts on the environment.

The bagasse results from the industrial process of sugarcane juice extraction by the mills and is currently given free of charge to farmers. This bagasse is usually incorporated into the soils, used as a substrate for the production of mushrooms or used in animal beds. These wastes are seldom also sent for energy recovery in the Solid Waste Treatment Plant of Meia Serra (incineration with energy production, and recently have been requested for use in the cosmetic and pellet industries. The vinasse is a by-product of alcohol distillation. This type of waste is a liquid effluent characterised by a high organic load. Current practices involve directly discharging into the receiving water bodies without pretreatment. Waste production from sugarcane processing is seasonal and centralised between April and May in honey mills and distillation units. Although it also presents some seasonality, the occurrence of wastes from the crop production phase is more diffuse through several fields across the island.

[5] Regulation (EC) No 110/2008 of the European Parliament and of the Council of 15 January 2008 on the definition, description, presentation, labelling and the protection of geographical indications of spirit drinks.

The reassessment of the circularity index, assuming the improvement of some current practices, such as the ones described below, would impact the sub-key factors 3, 4.3, 4.4, 4.5, 5.2, 6.1, and 6.3:

- Sub-key 3: Promotion of internal reuse (e.g., colling waters from the distillation process to minimise freshwater consumption);
- Sub-key 4.3: pH adjustment for values between 6 to 9;
- Sub-key 4.4: Implementation of a treatment process for vinasse to reduce organic load and comply with Emission Limit Values;
- Sub-key 4.5: Implementation of a treatment process for vinasse to reduce nutrient loads to ensure compliance with Emission Limit Values;
- Sub-key 5.2: Additional measures to recover some content of the vinasse, e.g., to reintegrate in other crop productions (such as banana, since it is also a crucial product for the region's economy);
- Sub-key 6.1: Additional measures to recover heat from the distillation process;
- Sub-key 6.3: Inclusion of active measures, such as creating a buffer capacity to extend the wastewater discharge period beyond the production period and minimise the possible acute effects from the short discharge period.

The final results could lead to high positive circularity despite solely considering the mill ($I_{C\ Prod}$ = 66) or integrating also the crop growth ($I_{C\ Prod}$ = 74). The higher values when considering the integration of sugarcane production into the final product circularity assessment result from the baseline circularity, as aforementioned.

4. Training session

4.1. Description

The final conference of the project was held in Larnaca, Cyprus. At this event, the practical application of the Water Circularity Index for products was presented, demonstrating its potential impact on various facilities and products. This event highlighted best practices intended to facilitate the transition to a circular economy, engaging the audience in the practical aspects of the index.

Additionally, a hands-on training session was held, allowing all participants to apply the Water Circularity Index through two trial scenarios (which were not based on real cases), empowering them with practical knowledge and skills.

In Trial A, the partial circularity index ($I'_{C\ Prod}$) value was combined with the installation results to determine the final product's circularity value. In contrast, Trial B involved a straightforward process where the value of the partial circularity index ($I'_{C\ Prod}$) was directly equal to the final product's circularity, as no corrections were made to the installation. The data used in Trial B for the installation (circularity index for the installation) was derived from a real case evaluated in the previous phase of the project (case study F)[6].

4.2. Trial A

4.2.1. Description

In the WWTP (case study F from the previous project phase), an additional step was added to use the depuration sludge. After dehydration, this sludge is further treated to produce hydrochar, which is later used as an absorbent in other facilities.

The dehydrated sludge is subjected to hydrothermal carbonisation for the production of hydrochar. The thermal process uses freshwater from surface water sources and runs at a temperature range from 200 to 230 ºC. These conditions ensure an equilibrium between energy use, the reduction of heavily contaminated effluents, and the quality of hydrocars. Therefore, despite using fossil energy for the process, active measures were also implemented to reduce energy consumption, such as using energy-efficient equipment and on-site solar production. However, no data on measures to recover energy within the hydrochar process are available.

The process uses around 2.5 litres of water per kilogram of dry sludge, producing 0,6 m^3 of effluents per ton of processed dry sludge and around 20% of solid hydrochar. To minimise water consumption, the partial recycling of effluents is previewed. In this way, only around 50% of industrial effluents return to the influent of the WWTP. Despite this plant's capacity to treat it, the effluents present a high level of nutrients, some heavy metals (including cadmium), and a pH between neutral and lightly acid (4.5 to 6.5). To minimise problems, effluents follow a neutralisation before discharge into the sewer.

According to data from the European Environment Agency, the WWTP is located in a region with a Water Index Exploitation Plus (WEI+) of 38%. The region has also faced some droughts in recent years, and the River Basin Management Plan (RBMP) in force refers to problems with increasing scarcity. Still, the respective Program of Measures (PoM) does not consider this issue. According to the RBMP, the surface water bodies that supply water for the process and receive the treated wastewater discharge present an ecological status of less than good.

The 1st Phase of Project WiNE data for Case Study F is given below.

1. The keys factors were applied to an urban wastewater treatment plant. The key operation details are:

[6] Rebelo A., Farabegoli G. et al. (2020), Report on good practices to promote the transition to circular economy in urban and industrial water management: A new water circularity index -– Addendum. IMPEL report no Addendum to 2020/13, 17 pages. Brussels, ISBN 978-2-931225-28-8.

- Load capacity (p.e.): 950 000 p.e. (1 p.e. = 60 g BOD_5 per day)
- Annual average wastewaters input: 30 000 000 m^3
- Treatment process: Mechanical-Biological-Chemical (only for phosphorous reduction)
- The sludge is passed through fermentation and stabilisation, followed by dehydration. Biogas is collected separately from the fermentation process.

2. Sub-key factors considered in the circularity index for installation (I_C):

- Measures to reduce consumption without linking impacts on the quality of wastewaters (with non-significant variation on wastewater quality, e.g., reduction on groundwater abstraction with low impacts on wastewaters);
- Compliance of Emission Limit Values with link to the WFD;
- Use of Best Available Techniques for wastewater treatment;
- Promotion of management solutions to reduce CO_2 emissions;
- Use of new technologies (go beyond BAT, with the promotion of new developments. Ex., equipment, maintenance and process improvement to reduce the microplastic release into effluent);
- Recovery of nutrients for further uses (but without influence on water bodies);
- Without promotion of integrated approach for competitive advantages;
- Minimization of sludge production, bio-thermal energy production from anaerobic digestion and reuse of treated sludge from aerobic digestion without impacts on final concentration of the wastewaters discharged.

3. Final I_C = 1,01, which results in a medium positive circularity for installation.

4.2.2. Results

Table 12: Results from the application of key factors and sub-key factors to Trial A

Key factor	Sub-Key Factor	Value	Observations
1. Freshwater consumption (water use for the product) and scarcity	1.1	3	1. WEI+ is equal to 38% (i.e., ≤ 40%); 2. A high value of water consumption: I. 2.5 L of water per kg of processed dry sludge, corresponding to 2.2 L of freshwater and 0.3 L of reused water; II. Per ton of dry sludge, only 20% of hydrochar is produced, i.e., 200 kg (0.2 kg of hydrochar per kg of dry sludge); III. 2.2 L of freshwater per 0.2 kg of hydrochar, i.e., 11 L of freshwater per kg of hydrochar.
	1.2	0	1. WEI+ is equal to 38% (i.e., ≤ 40%); 2. The River Basin Management Plan (RBMP) in force refers to problems with increasing scarcity, but the respective Program of Measures (PoM) does not consider this issue
2. Use of alternative water sources (quantitative & qualitative aspects)	2.2a	-7	1. Freshwater and reclaimed waters are used, but the volume of surface water is higher than the reclaimed water (2.2 L of freshwater per 0.3 L of reclaimed water per ton of dry sludge), so Table 2.2a is the one that applies to the case study; 2. Surface water is used, and its ecological status fails to achieve good status
3. Internal use of reclaimed waters	3	5	50% of the produced effluent is reused within the hydrochar production process, so, some internal reuse is in place
4. Water pollutants	4.1	-9	1. The hydrochar production effluents contain heavy metals such as cadmium, which is identified as priority hazardous substance (Directive 2013/39/EC) 2. Surface water is used, and its ecological status fails to achieve good status
	4.2	0	Microplastics are not used in not used in manufacture
	4.3	1	The pH is neutralised before discharge into sewer to return to the UWWTP
	4.4	9	1. Is a UWWTP, so the common COD is expected to vary between 500 to 5000 mg/L O_2 and ELV in compliance with the link to the WFD (information from case study from the project previous phase; 2. The process refers to the use of carbon from organic matter contained in sludge to produce hydrochars therefore, the level of COD in the final effluents is expected to be low
	4.5	-9	Effluents present a high level of nutrients, but no pre-treatment is foreseen before their discharge into the sewer. Only a neutralisation process is mentioned

Table 12 (cont.): Results from the application of key factors and sub-key factors to Trial A

Key factor	Sub-Key Factor	Value	Observations
5. Externalities	5.1	9	The hydrochar process is supported by the use of an input from an external process (UWWTP), so a consistent level of external inputs should be considered
	5.2	9	The hydrochars are produced to be used as absorbents in other industrial processes and/or wastewater treatment
6. Additional factors	6.1	-7	1. Use of fossil energy for the process 2. Active measures implemented to reduce energy consumption, such as using energy-efficient equipment and on-site solar production 3. No data on measures to recover energy
	6.2a	0	Not applicable (is not a crop production)
	6.2b	0	Not applicable (is not a crop production)
	6.3	0	Not applicable (is not a seasonal product)
	6.4	0	Not applicable (is not a regional product)

The results from all sub-key factors are summed to obtain the value for the partial circularity index ($I'_{C\ Prod}$), which is then integrated with the result obtained from the installation (result obtained from the previous project phase for the case study F) using the matrix described in Figure 1 to determine the final value for the product's circularity (table 11).

Table 13: Results from the application of key factors and sub-key factors to Trial A

Circularity index	Circularity index	Result	Condition Result	Result expression
Partial index for products	$I'_{C\ Prod}$	4	Low positive circularity	3
Index for installations	I_C	1,01	Medium positive circularity	5
Final index for products	$I_{C\ Prod}$	From the matrix (see figure 1)	Medium positive circularity	5

4.3. Trial B

4.3.1. Description

In trial B a wine tourism unit comprising a vineyard, a winery, and a small hotel is located in a region classified as a Protected Designation of Origin for table wine in a semi-arid zone where droughts are frequent. The complex is integrated within a "Wine Route" to promote the region and its local products.

The wastewater from the winery (wine production, bottling, and domestic sewage from personnel areas) follows a conventional secondary treatment and disinfection (UV and post-chlorination to prevent recontamination and regrowth). All of these treated wastewaters are stored and used in combination with surface waters (from a private dam) to meet the water needs of the hotel's green areas (by drip irrigation). The wastewater from the hotel is treated in a different system (compact treatment system) and discharged in a stream in compliance with the permit.

According to the self-monitoring program, the results from the last 12 months for the reclaimed waters and the hotel discharge present two non-compliances regarding COD permits and one for nitrogen. However, the treated wastewaters present a pH between 6 and 9 and a low level of nutrients.

Groundwater is the water source for the hotel and winery, and the abstracted water is treated accordingly to comply with drinking water legislation and food safety regulations.

The complex uses energy from the net (where, due to energy importation, fossil, non-fossil, and renewable energies can be used) combined with self-production (photovoltaic panels), which allows it to supply around 50% of all the energy needs. Some measures to reduce energy consumption are in place in the hotel and winery, such as light sensors, LED lamps, efficient electric equipment, etc.

For the region where the complex is located, the updated Water Index Exploitation Plus (WEI+) presents a value of 80%. Due to these specificities, scarcity is widely covered in the River Basin Management Plan (3^{rd} cycle). The respective Program of Measures (PoM) addresses specific measures to promote water use efficiency (quantitative measures), such as encouraging water reuse, reducing water consumption, reducing water losses in the systems, agriculture practices, etc. According to this Plan, both groundwater and surface water present a water status of less than good.

In wine production, all glass bottles are made from recycled glass, and the boxes are made from recycled cardboard. Part of the stems and leaves are separated and reincorporated into soils, combined with chemical fertilisers. All green wastes (from vineyards and green areas) are used to compost. The production is not organic farming, and subsequently, pesticides are used to control pests. Bagasses are recovered and sold to produce other spirit drinks and/or ethanol. All plastic, glass, metal and paper from the hotel and winery are separated and sent to be recycled.

The available data does not include information about reusing internal water streams or heat recovery. Also, according to the data, the water supplied to the crops (vineyards) does not seem to match an efficient use since irrigation practices in place seem not to consider the water in the soil during the several phases of the growing process, and no data is available for water losses in the system. Usually, the harvesting starts in August, and the irrigation stops two months before. The annual irrigation volumes per hectare are 1500 to 3000 m^3. In wine production, approximately 8 to 10 litres of water are used for every litre of wine. This includes cleaning processes, such as washing vats and equipment, as well as water needed in the winemaking process itself and for general maintenance of the winery.

4.3.2. Results

Table 14: Results from the application of key factors and sub-key factors to Trial B

Key factor	Sub-Key Factor	Value (Only considering the winery for the wine production)	Value (Considering the vineyards and winery for the wine production)	Observations
1. Freshwater consumption (water use for the product) and scarcity	1.1	-9	-9	1. WEI+ is equal to 80% (>40%) 2. There is a consumption of around 8 to 10 L of freshwater per litre of produced wined 3. The vineyards usually require high consumption, and the information presented regarding irrigation efficiency demonstrates a lack of good practices
	1.2	3	3	1. WEI+ is equal to 80% (>40%) 2. The RBMP addresses scarcity problems and presents measures for scarcity
2. Use of alternative water sources (quantitative & qualitative aspects)	2.1	-9	-9	Only freshwater is used for vineyards and for wine production, therefore Table 2.1 is the one that applies to the case study
3. Internal use of reclaimed waters	3	-7	-3	1. There is no information about internal reuse, so, there is some missing opportunities to reduce water consumption in the wine production: 2. In the vineyards, there is no information about runoffs or its recovery, which does not seem usual in vineyards 3. Lack of information on demonstration of water use efficiency in irrigation

Table 14 (cont.): Results from the application of key factors and sub-key factors to Trial B

<table>
<tr><th>Key factor</th><th>Sub-Key Factor</th><th>Value (Only considering the winery for the wine production)</th><th>Value (Considering the vineyards and winery for the wine production)</th><th>Observations</th></tr>
<tr><td rowspan="5">4. Water pollutants</td><td>4.1</td><td>-9</td><td>-9</td><td>1. Water status is less than good
2. There is a lack of information about the pollutant usage/release. However, pesticides are used in the vineyards. So, some emissions, releases or losses may occur and by the use of the precautionary principle it should be considered in both examples</td></tr>
<tr><td>4.2</td><td>0</td><td>0</td><td>There is no use of microplastics in the crop and in the wine production</td></tr>
<tr><td>4.3</td><td>1</td><td>1</td><td>1. The pH level is within the acceptable range for discharge in the winery wastewater</td></tr>
<tr><td>4.4</td><td>-5</td><td>-5</td><td>1. In the provided data there is no reference to the level of COD in the raw wastewaters and several studies in wineries indicate that COD ranges from 800 to 12800 mg/L O_2 (see ref. https://asec2023.sciforum.net/). Using the precautionary principle, it should be considered COD above 5000 mg/L O_2
2. In the last 12 months, there are two non-compliances for COD in the wastewater from the winery</td></tr>
<tr><td>4.5</td><td>-1</td><td>-1</td><td>1. Low level of nutrients
2. One non-compliance for N</td></tr>
<tr><td rowspan="2">5. Externalities</td><td>5.1</td><td>9</td><td>9</td><td>1. All glass bottles are made from recycled glass, and the boxes are made from recycled cardboard
2. Part of the stems and leaves are separated and reincorporated into soils, combined with chemical fertilisers. All green wastes (from vineyards and green areas) are used to compost.</td></tr>
<tr><td>5.2</td><td>9</td><td>9</td><td>1. Bagasses are recovered and sold to produce other spirit drinks and/or ethanol. All plastic, glass, metal and paper from the winery are separated and sent to be recycled
2. The wastewaters from the winery are used to irrigate the green areas from a tourist unit</td></tr>
</table>

Table 14 (cont.): Results from the application of key factors and sub-key factors to Trial B

Key factor	Sub-Key Factor	Value (Only considering the winery for the wine production)	Value (Considering the vineyards and winery for the wine production)	Observations
6. Additional factors	6.1	7	7	1. Due to energy importation, fossil, non-fossil, and renewable energies can be used); 2. Self-production (photovoltaic panels), which allows it to supply around 50% of all the energy needs; 3. Some measures to reduce energy consumption are in place in the hotel and winery, such as light sensors, LED lamps, efficient electric equipment, etc.
	6.2a	0*	-3	1. Is a seasonal crop 2. The harvesting starts in August, and the irrigation stops two months before (i.e., irrigation occurs in dry season from April to June) *Is not a crop production (when considering only de winery)
	6.2b	0*	3	There is no information about the grape varieties, but since is a wine region, is probable that local varieties are used, but also common varieties. Therefore, the low value is used since local varieties are usually better adapted than other crops and also may promote landraces (and agrobiodiversity), including common (see FAO) *Is not a crop production (when considering only de winery)
	6.3	7	7*	With active measures in place (wastewaters are stored to be used in irrigation blended with freshwater) *Is applicable since in this case, both vineyards and winery are considered for the production of the wine
	6.4	5	5	The region is classified as a Protected Designation of Origin for table wine

The results from all sub-key factors are summed to obtain the value for the partial circularity index ($I'_{C\,Prod}$), which, in this case, is equal to the final products' circularity since there no correction to the installation is applied.

Table 15: Results from the application of key factors and sub-key factors to Trial B

Process description	Partial Circularity index	Result ($I'_{C\ Prod}$)	Circularity index result ($I_{C\ Prod}$)	Condition Result	Result expression
Only the winery is considered for wine production	$I'_{C\ Prod\ wine\ (winery)}$	1	1	Low positive circularity	Low positive circularity
Both vineyards and the winery are considered for the wine production	$I'_{C\ Prod\ Wine\ (vineyards\ and\ winery))}$	5	5	Low positive circularity	Low positive circularity

5. Final Remarks

The exploration of water circularity within the context of the circular economy has underscored the critical importance of integrating both qualitative and quantitative aspects of water use in industrial and urban settings. Through the findings of the "Integrated Water Approach" project and the subsequent phases of the WiNE project, it has become evident that a holistic approach to water management is essential for reducing freshwater consumption while also protecting water quality and ecosystems.

The development of the Water Circularity Index (I_C) and the Circularity Index for Products ($I_{C\ Prod}$) represents significant advancements in assessing water use and its implications. These tools provide a comprehensive framework for evaluating water balances, enabling authorities and stakeholders to make informed decisions that support environmental compliance and promote sustainable practices.

Furthermore, implementing circular approaches in managing water resources addresses immediate challenges related to water scarcity and pollution and fosters long-term sustainability by encouraging collaboration across sectors and communities.

The development of the Circularity Index for Products ($I_{C\ Prod}$) serves as a tool in the permitting decision-making process. It enables a comprehensive assessment of the usage of various water sources and their implications for sustainability across different product categories. This approach aims to ensure a more holistic compliance of the various strands of environmental legislation in order to achieve the goals of the Water Framework Directive.

By concentrating on three main types of products (seasonal and regional products, crop production, and products from large installations), the index may allow to address the unique challenges and opportunities associated with each category. Seasonal and regional products, which hold significant importance for local communities and economies, may require specific approaches to resource management that consider local conditions and water availability. In the realm of crop production, understanding water efficiency and implementing effective water reuse practices are vital for enhancing agricultural sustainability. Reducing freshwater consumption while maximizing yield (e.g., through the promotion of nutrients recovery) and maintaining product quality can significantly contribute to food security and environmental health.

For products from large installations, the focus on recycling and recovery highlights the need for integrated systems that minimize waste/discharges and optimize resource use. By promoting collaboration across sectors and identifying synergies, industries can develop practices that not only ensure compliance with European legislation but also support broader circular economy goals. However, in these types of installations, the trade-offs between water quantity and quality require careful attention, as meeting specific performance targets may increase pressure over water bodies and their ecosystems, and subsequently jeopardise the zero-pollution action plan goals.

A targeted approach to water circularity that considers the specific needs and characteristics of different product types is essential for achieving both environmental compliance and resource efficiency. By leveraging tools like the Circularity Index for Products, authorities (inspection, permitting and regulators) and operators can make informed decisions that enhance water management practices, ultimately contributing to sustainable development and contribute to a long-term water resilience.

Moreover, the Circularity Index for Products can also contribute to minimise the risk of greenwashing within various industries. By providing a structured framework for evaluating several trade-offs related with water usage and other environmental compliance, the index ensures that claims of sustainability are backed by measurable data and comprehensive assessments.

In addition to the development of the $I_{C\ Prod}$, scientific dissemination actions were also carried out. The circularity index for installations was presented at the 6th Euro-Mediterranean Conference for Environmental Integration (EMCEI-2024), which took place on 15-18 May 2024 in Marrakesh (Marrocco), and the extended resume of the presentation will be published in the Conference Proceedings[7].

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Annexes

Annex I.

Table A.1: Case study – Citrus (Crop)

Key factor	Sub-Key Factor	Value	Observations	Value	Observations	Value	Observations
		Citrus only irrigated with reclaimed water		Citrus only irrigated with groundwater		Citrus only irrigated with reclaimed water with admission of best practices	
1. Freshwater consumption (water use for the product) and scarcity	1.1	-3	The region presents a WEI+ >40%*, with low freshwater consumption. Despite citrus growth requiring high water consumption, the use of reclaimed waters turns freshwater consumption into low	-9	The region presents a WEI+ >40%*, with a high freshwater consumption	-3	The region presents a WEI+ >40%*, with low freshwater consumption. Despite citrus growth requiring high water consumption, the use of reclaimed waters turns freshwater consumption into low
	1.2	3	The RBMP addresses scarcity problems and presents specific measures for it*	3	The RBMP addresses scarcity problems and presents specific measures for it*	3	The RBMP addresses scarcity problems and presents specific measures for it*
2. Use of alternative water sources (quantitative & qualitative aspects)	2	9	The study aimed to assess the irrigation with the single use off reclaimed water, and considering its nutritional value (sub-key factor 2.2b)	-9	Only freshwater resources are used (sub-key factor 2.1)	9	The study aimed to assess the irrigation with the single use off reclaimed water, and considering its nutritional value (sub-key factor 2.2b)
3. Internal use of reclaimed waters	3	-3	There is no information of the possible reuse of runoff	-3	There is no information of the possible reuse of runoff	9	E.g.: Collection of runoff and blend it with irrigation waters

*Data from RBMP of *Ribeiras do Algarve,* 3rd Cycle. Available at https://apambiente.pt/agua/3o-ciclo-de-planeamento-2022-2027.

Table A.1 (cont.): Case study – Citrus (Crop)

Key factor	Sub-Key Factor	Value	Observations	Value	Observations	Value	Observations
4. Water pollutants	4.1	-3	Groundwater in poor status* and no information is provided about the use of pesticides. The information provided on the paper is unclear regarding organic production. Thus, there is a lack of data on pollutant usage and/or release	-3	Groundwater in poor status* and no information is provided about the use of pesticides. The information provided on the paper is unclear regarding organic production. Thus, there is a lack of data on pollutant usage and/or release	9	Groundwater in poor status* but information about safe practices in place or organic farming to prevent pesticides release to aquatic environment is provided
	4.2	0	Not applicable since it is a crop production	0	Not applicable since it is a crop production	0	Not applicable since it is a crop production
	4.3	0	Not applicable (no wastewater production)	0	Not applicable (no wastewater production)	0	Not applicable (no wastewater production)
	4.4	0	Not applicable (no wastewater production)	0	Not applicable (no wastewater production)	0	Not applicable (no wastewater production)
	4.5	0	Not applicable (no wastewater production)	0	Not applicable (no wastewater production)	0	Not applicable (no wastewater production)
5. Externalities	5.1	-9	No information is provided on inputs, such as the use of sludge or compost	-9	No information is provided on inputs, such as the use of sludge or compost	9	E.g., use of sludge or compost to avoid/minimise the use of chemical fertilisers
	5.2	-9	No information provided on outputs (e.g., possible use of green wastes)	-9	No information provided on outputs (e.g., possible use of green wastes)	9	E.g., collection of green wastes to send to compost production or animal feed

*Data from RBMP of *Ribeiras do Algarve*, 3rd Cycle. Available at https://apambiente.pt/agua/3o-ciclo-de-planeamento-2022-2027.

Table A.1 (cont.): Case study – Citrus (Crop)

Key factor	Sub-Key Factor	Value	Observations	Value	Observations	Value	Observations
6. Additional factors	6.1	3	Energy from the grid (i.e., all sources due to possible energy import), but no information is provided on the recovery and/or reduction of energy (e.g., used for the irrigation system, pumping, etc.)	3	Energy from the grid (i.e., all sources due to possible energy import), but no information is provided on the recovery and/or reduction of energy (e.g., used for the irrigation system, pumping, etc.)	9	E.g., measures to reduce energy (e.g., in pumping and/or irrigation systems), such as using efficient equipment with some heat recovery, solar panels or others
	6.2a	-3	According to the article, the orchard was irrigated from March to July (so, during dry season)	-3	According to the article, the orchard was irrigated from March to July (so, during dry season)	-3	According to the article, the orchard was irrigated from March to July (so, during dry season)
	6.2b	3	Is a common crop in the region, introduced more than 500 years ago in Algarve (Portugal)	3	Is a common crop in the region, introduced more than 500 years ago in Algarve (Portugal)	3	Is a common crop in the region, introduced more than 500 years ago in Algarve (Portugal)
	6.3	0	Not applicable since it is a crop production	0	Not applicable since it is a crop production	0	Not applicable since it is a crop production
	6.4	3	Is considered a regional product (common sense), but its importance for local economy is not clear	3	Is considered a regional product (common sense), but its importance for local economy is not clear	3	Is considered a regional product (common sense), but its importance for local economy is not clear
$I'_{C\ Prod} = I_{C\ Prod}$		**-9**	**Low negative circularity (-3)**	**-33**	**Medium negative circularity (+5)**	**57**	**Medium positive circularity (5)**

Table A.2: Case study – Avocado (Crop)

Key factor	Sub-Key Factor	Value	Observations	Value	Observations
		Avocado only irrigated with reclaimed water			Avocado only irrigated with groundwater
1. Freshwater consumption (water use for the product) and scarcity	1.1	-3	The region presents a WEI+ >40%*, with low freshwater consumption. Despite citrus growth requiring high water consumption, the use of reclaimed waters turns freshwater consumption into low	-9	The region presents a WEI+ >40%*, with a high freshwater consumption
	1.2	3	The RBMP addresses scarcity problems and presents specific measures for it*	3	The RBMP addresses scarcity problems and presents specific measures for it*
2. Use of alternative water sources (quantitative & qualitative aspects)	2	9	The study aimed to assess the irrigation with the single use off reclaimed water, and considering its nutritional value (sub-key factor 2.2b)	-9	Only freshwater resources are used (sub-key factor 2.1)
3. Internal use of reclaimed waters	3	-3	There is no information of the possible reuse of runoff	-3	There is no information of the possible reuse of runoff
4. Water pollutants	4.1	-3	Groundwater in poor status* and no information is provided about the use of pesticides. The information provided on the paper is unclear regarding organic production. Thus, there is a lack of data on pollutant usage and/or release	-3	Groundwater in poor status* and no information is provided about the use of pesticides. The information provided on the paper is unclear regarding organic production. Thus, there is a lack of data on pollutant usage and/or release
	4.2	0	Not applicable since it is a crop production	0	Not applicable since it is a crop production
	4.3	0	Not applicable (no wastewater production)	0	Not applicable (no wastewater production)
	4.4	0	Not applicable (no wastewater production)	0	Not applicable (no wastewater production)
	4.5	0	Not applicable (no wastewater production)	0	Not applicable (no wastewater production)

*Data from RBMP of *Ribeiras do Algarve*, 3rd Cycle. Available at https://apambiente.pt/agua/3o-ciclo-de-planeamento-2022-2027.

Table A.2 (cont): Case study – Avocado (Crop)

Key factor	Sub-Key Factor	Value	Observations	Value	Observations
		Avocado only irrigated with reclaimed water			Avocado only irrigated with groundwater
5. Externalities	5.1	-9	No information is provided on inputs, such as the use of sludge or compost	-9	No information is provided on inputs, such as the use of sludge or compost
	5.2	-9	No information provided on outputs (e.g., possible use of green wastes)	-9	No information provided on outputs (e.g., possible use of green wastes)
6. Additional factors	6.1	3	Energy from the grid (i.e., all sources due to possible energy import), but no information is provided on the recovery and/or reduction of energy (e.g., used for the irrigation system, pumping, etc.)	3	Energy from the grid (i.e., all sources due to possible energy import), but no information is provided on the recovery and/or reduction of energy (e.g., used for the irrigation system, pumping, etc.)
	6.2a	-3	Avocados require irrigation during dry season	-3	Avocados require irrigation during dry season
	6.2b	-5	Is an “exotic” (not appropriate for the location) crop with high water consumption	-5	Is an “exotic” (not appropriate for the location) crop with high water consumption
	6.3	0	Not applicable since it is Is a crop production	0	Not applicable since it is Is a crop production
	6.4	0	Is not a regional producto despite its economic value	0	Is not a regional producto despite its economic value
$I'_{C\ Prod} = I_{C\ Prod}$		**-20**	**Low negative circularity (-3)**	**-44**	**Medium negative circularity (-5)**

Table A.3: Case study – Madeira Rhum (Seasonal & Regional Product)

Key factor	Sub-Key Factor	Value	Observations	Value	Observations
		Citrus only irrigated with reclaimed water		Citrus only irrigated with groundwater	
1. Freshwater consumption (water use for the product) and scarcity	1.1	3	The region presents a WEI+ ≤ 40%*, and there is a high freshwater consumption (in the rhum production)	3	The region presents a WEI+ ≤ 40%*, and there is a high freshwater consumption (in the rhum production and in the sugarcane production)
	1.2	9	The RBMP addresses scarcity problems and presents specific measures for it*	9	The RBMP addresses scarcity problems and presents specific measures for it*
2. Use of alternative water sources (quantitative & qualitative aspects)	2.1	-9	Only freshwater resources are used	-9	Only freshwater resources are used in the whole process
3. Internal use of reclaimed waters	3	-9	No internal reuse practices in place, missing opportunities for water efficiency	-9	No internal reuse practices in place, missing opportunities for water efficiency
4. Water pollutants	4.1	0	Priority substances, Priority hazardous substances & other pollutants or specific pollutants are not used and are not expected to be released	0	Priority substances, Priority hazardous substances & other pollutants or specific pollutants are not used and are not expected to be released
	4.2	0	Not used in beverage production	0	Not used in beverage production
	4.3	-7	Not applicable (no wastewater production)	-7	pH very low (<4); Discharged wastewater (from the mill) is potentially harmful to aquatic life due to pH imbalance
	4.4	-9	No WWTP and very high organic content (COD>40000 mg/L)	-9	No WWTP (in the mill) and very high organic content (COD>40000 mg/L)
	4.5	-9	No WWTP and possible high level of nutrients	-9	No WWTP (in the mill) and possible high level of nutrients
5. Externalities	5.1	5	Use of some recycled material, like glass (partially; Other options could be in place)	5	Use of some recycled material, like glass (partially; Other options could be in place)
	5.2	3	Recycling of packages (collection of metal, cardboard, etc) & Bagasse is used as fertilizer in crops (e.g., mushrooms, sugarcane), But no use/content recover is proposed for the vinasse	3	Recycling of packages (collection of metal, cardboard, etc) & Bagasse is used as fertilizer in crops (e.g., mushrooms, sugarcane), But no use/content recover is proposed for the vinasse

*Data from RBMP *Arquipélago da Madeira (PGRH-Madeira)*: 2022-2027. Available https://www.madeira.gov.pt/dram.

Table A.3 (cont.): Case study – Madeira Rhum (Seasonal & Regional Product)

Key factor	Sub-Key Factor	Value	Observations	Value	Observations
6. Additional factors	6.1	7	Hydroelectric power but no recover/reduction measure seems to be in place, despite being possible (e.g., heat recover from distillation process)	7	Hydroelectric power but no recover/reduction measure seems to be in place, despite being possible (e.g., heat recover from distillation process)
	6.2a	0	Is not a crop production, since this exercise only include the mill	5	Irrigation of sugarcane occurs in the wet season (and the sugarcane production is considered in the assessment)
	6.2b	0	Is not a crop production, since this exercise only include the mill	3	Is a common crop introduced in the XV century in Madeira (and the sugarcane production is considered in the assessment)
	6.3	-7	Rhum is produced between April and May and no measures are in place to reduce the impacts from wastewater (vinasse)	-7	Rhum is produced between April and May and no measures are in place to reduce the impacts from wastewater (vinasse)
	6.4	5	Is a regional product (PGI)* with importance for local community	5	Is a regional product (PGI)* with importance for local community
$I'_{C\ Prod} = I_{C\ Prod}$		**-18**	**Low negative circularity (-3)**	**-10**	**Low negative circularity (-3)**

*Protected geographical indication

Table A.4: Case study – Madeira Rhum (Seasonal & Regional Product), assuming best practices

Key factor	Sub-Key Factor	Value	Observations	Value	Observations
		Citrus only irrigated with reclaimed water		Citrus only irrigated with groundwater	
1. Freshwater consumption (water use for the product) and scarcity	1.1	3	The region presents a WEI+ ≤ 40%*, and there is a high freshwater consumption (in the rhum production)	3	The region presents a WEI+ ≤ 40%*, and there is a high freshwater consumption (in the rhum production and in the sugarcane production)
	1.2	9	The RBMP addresses scarcity problems and presents specific measures for it*	9	The RBMP addresses scarcity problems and presents specific measures for it*
2. Use of alternative water sources (quantitative & qualitative aspects)	2.1	-9	Only freshwater resources are used	-9	Only freshwater resources are used in the whole process
3. Internal use of reclaimed waters	3	9	E.g.: Promotion of internal reuse (e.g., colling waters from the distillation process to minimise freshwater consumption)	9	E.g.: Promotion of internal reuse (e.g., colling waters from the distillation process to minimise freshwater consumption)
4. Water pollutants	4.1	0	Priority substances, Priority hazardous substances & other pollutants or specific pollutants are not used and are not expected to be released	0	Priority substances, Priority hazardous substances & other pollutants or specific pollutants are not used and are not expected to be released
	4.2	0	Not used in beverage production	0	Not used in beverage production
	4.3	1	E.g.: pH adjustment for values between 6 to 9	1	E.g.: pH adjustment for values between 6 to 9
	4.4	9	E.g.: Implementation of a treatment process for vinasse to reduce organic load and comply with Emission Limit Values	9	E.g.: Implementation of a treatment process for vinasse to reduce organic load and comply with Emission Limit Values
	4.5	9	E.g.: Implementation of a treatment process for vinasse to reduce nutrient loads to ensure compliance with Emission Limit Values	9	E.g.: Implementation of a treatment process for vinasse to reduce nutrient loads to ensure compliance with Emission Limit Values
5. Externalities	5.1	5	Use of some recycled material, like glass (partially; Other options could be in place)	5	Use of some recycled material, like glass (partially; Other options could be in place)
	5.2	9	E.g.: Additional measures to recover some content of the vinasse, e.g., to reintegrate in other crop productions (such as banana, since it is also a crucial product for the region's economy)	9	E.g.: Additional measures to recover some content of the vinasse, e.g., to reintegrate in other crop productions (such as banana, since it is also a crucial product for the region's economy)

*Data from RBMP *Arquipélago da Madeira (PGRH-Madeira)*: 2022-2027. Available https://www.madeira.gov.pt/dram.

Table A.4 (cont.): Case study – Madeira Rhum (Seasonal & Regional Product), assuming best practices

Key factor	Sub-Key Factor	Value	Observations	Value	Observations
6. Additional factors	6.1	9	E.g.: Additional measures to recover heat from the distillation process	9	E.g.: Additional measures to recover heat from the distillation process
	6.2a	0	Is not a crop production, since this exercise only include the mill	5	Irrigation of sugarcane occurs in the wet season (and the sugarcane production is considered in the assessment)
	6.2b	0	Is not a crop production, since this exercise only include the mill	3	Is a common crop introduced in the XV century in Madeira (and the sugarcane production is considered in the assessment)
	6.3	7	Inclusion of active measures, such as creating a buffer capacity to extend the wastewater discharge period beyond the production period and minimise the possible acute effects from the short discharge period	7	Inclusion of active measures, such as creating a buffer capacity to extend the wastewater discharge period beyond the production period and minimise the possible acute effects from the short discharge period
	6.4	5	Is a regional product (PGI)* with importance for local community	5	Is a regional product (PGI)* with importance for local community
$I'_{C\ Prod} = I_{C\ Prod}$		**66**	**High positive circularity**	**74**	**High positive circularity**

*Protected geographical indication

Table A.5: Case study – Beer (product from large installation)

Key factor	Sub-Key Factor	Value	Observations
1. Freshwater consumption (water use for the product) and scarcity	1.1	9	The region presents a WEI+ ≤ 40%* and low freshwater consumption due to the use of reclaimed waters for all process
	1.2	9	The RBMP addresses scarcity problems and presents specific measures for it*
2. Use of alternative water sources (quantitative & qualitative aspects)	2.2b	7	Only uses reclaimed water, but water content is considered as not important
3. Internal use of reclaimed waters	3	9	From the beer process, all water is reused
4. Water pollutants	4.1	-9	Surface waters in status less than good; The raw water is urban wastewater with some Priority substances and Priority hazardous substances (ex. Nonylphenols), and no evidence that there are none in the beer
	4.2	0	Not used in beverage production
	4.3	1	Data from reclaimed water shows pH in the range 6 to 9
	4.4	9	Reclaimed water from a treated UWWTP in compliance
	4.5	9	Reclaimed water from a treated UWWP in compliance
5. Externalities	5.1	9	A consistent level of recycling is promoted in the beer production process (used of recycled materials, like glass, cardboard, etc.)
	5.2	9	All wastewater from beer process goes WWTP, where part is reused for the irrigation of green areas
6. Additional factors	6.1	9	Energy from the grid (all sources due to possible importation of energy) and measures in place to be energy neutral (UWWTP)
	6.2a	0	Is not a crop production
	6.2b	0	Is not a crop production
	6.3	0	Is not a seasonal product
	6.4	0	Is not a regional product; No additional importance for the local economy
$I'_{C\ Prod} = I_{C\ Prod}$		**71**	**High positive circularity (9)**

*Data from RBMP of *Tejo e Ribeiras do Oeste*, 3rd Cycle. Available at https://apambiente.pt/agua/3o-ciclo-de-planeamento-2022-2027.

Table A.6: Case study – Paper pulp (product from large installation)

Key factor	Sub-Key Factor	Value	Observations
1. Freshwater consumption (water use for the product) and scarcity	1.1	3	The region presents a WEI+ ≤ 40%* and high freshwater consumption
	1.2	9	The RBMP addresses scarcity problems and presents specific measures for it*
2. Use of alternative water sources (quantitative & qualitative aspects)	2.2a	-7	Surface water with status less than good and high consumption of freshwater face to reclaimed water
3. Internal use of reclaimed waters	3	5	Some internal reuse
4. Water pollutants	4.1	-9	The discharge permit includes some of these parameters (priority substances and others)
	4.2	0	No use of microplastics is expected
	4.3	1	Data from reclaimed water shows pH in the range 6 to 9
	4.4	-5	High COD with some non-compliances
	4.5	9	Medium content in nutrients & in compliance
5. Externalities	5.1	5	Yes (recycled fibbers) but with lack of information on a consistent level of promotion of externalities
	5.2	9	Yes, according permit
6. Additional factors	6.1	9	Energy from the grid (all sources due to possible importation of energy) and measures to reduce and recover in place
	6.2a	0	Is not a crop production
	6.2b	0	Is not a crop production
	6.3	0	Is not a seasonal product
	6.4	0	Is not a regional product; No additional importance from the product for the local economy
$I'_{C\ Prod}$		**29**	**Low positive circularity (3)**
I_C(installation)**		**1,19**	**Medium positive circularity (5)**
$I_{C\ Prod}$		**See figure 1**	**Medium positive circularity (5)**

*Data from RBMP of *Tejo e Ribeiras do Oeste*, 3rd Cycle. Available at https://apambiente.pt/agua/3o-ciclo-de-planeamento-2022-2027.

** Case study A.2 from the previous project phase.