Water Circularity Indexes: Tools to improve water reuse approaches

International Workshop on Water Treatment and Reuse, Yixing, China

19 May 2025

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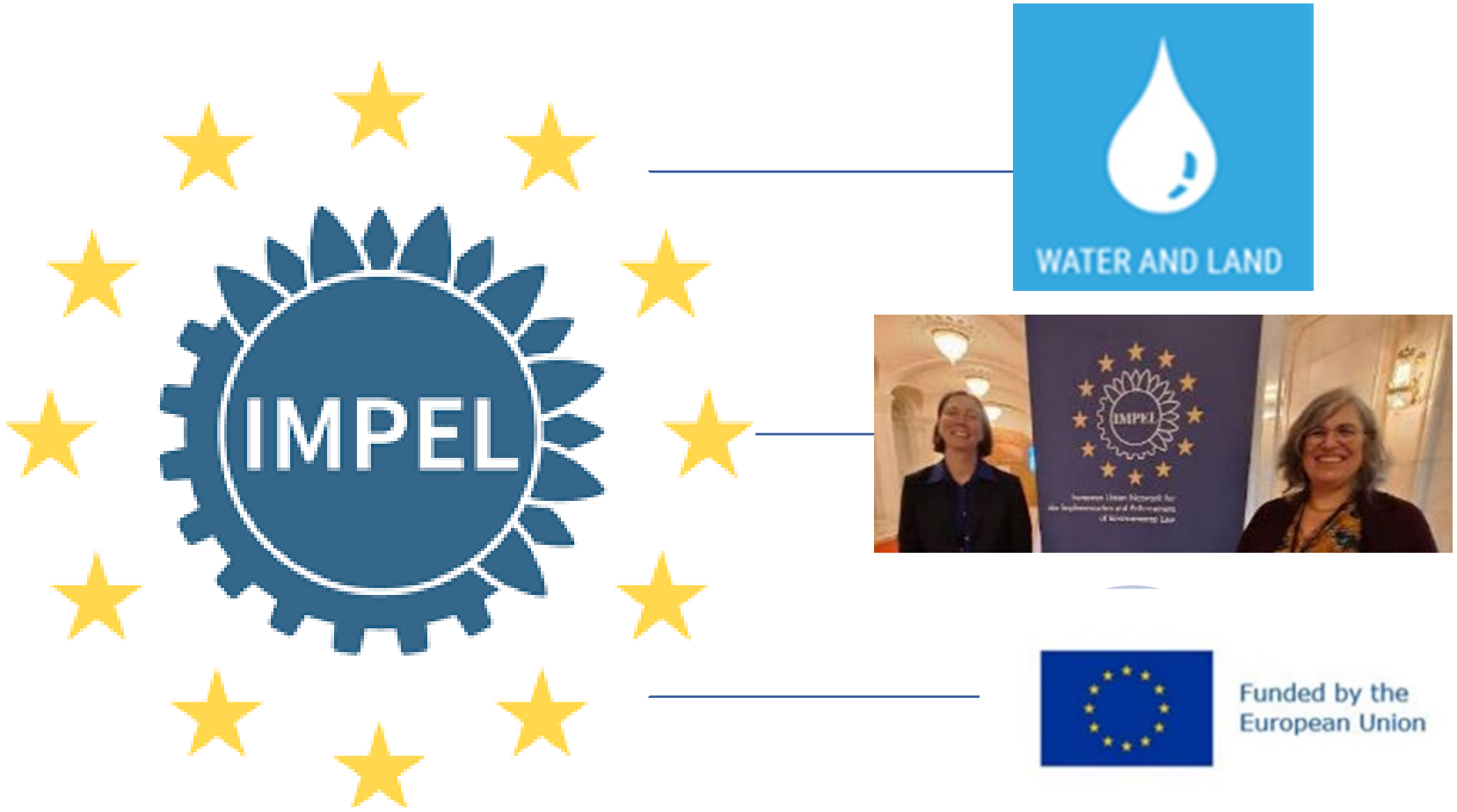
Project: Wastewater in Natural Environment (WiNE)



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About

- The European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL)
- An international non-profit organisation of **environmental authorities**
- Founded in **1992.** Legal seat in Brussels; website: https://www.impel.eu
- **59 members authorities** from **38 European countries** including all EU MS
- **>1250 involved experts**

The objective of IMPEL is to create the necessary impetus to make progress on ensuring a more effective implementation of environmental legislation

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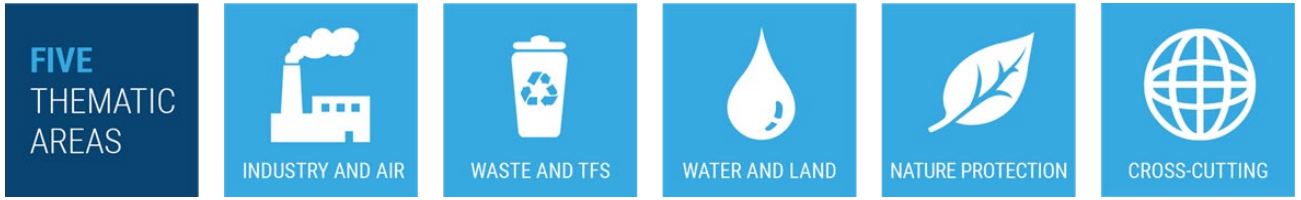
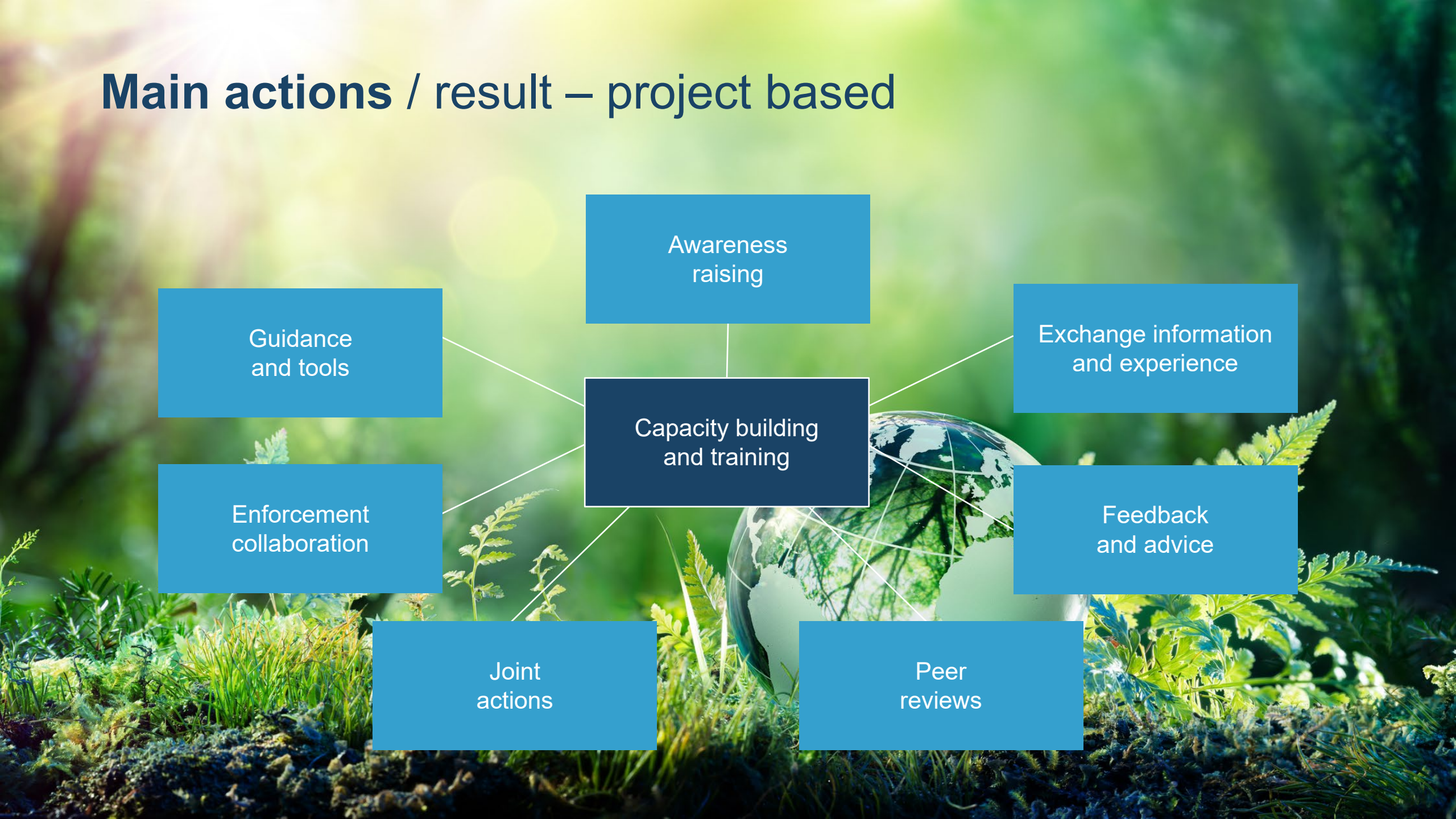


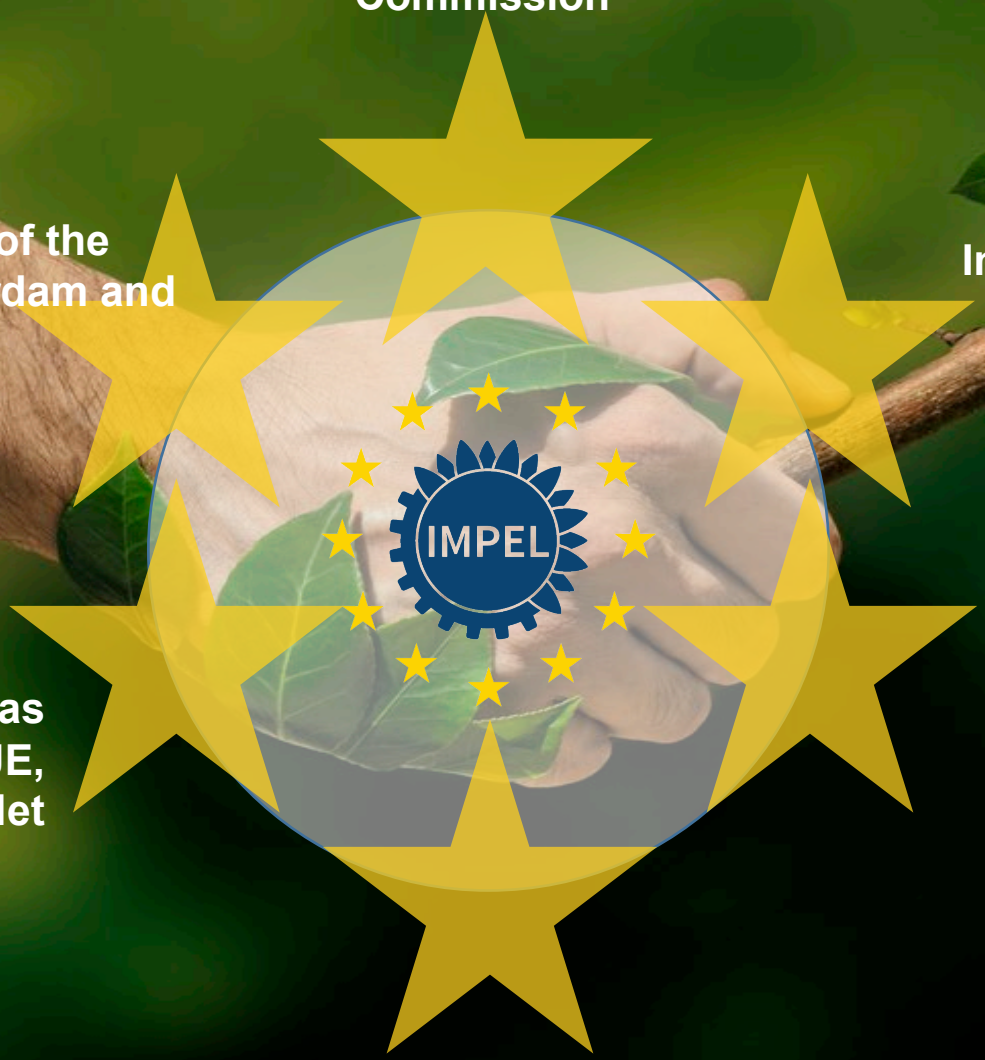
Water and Land

- **Focus on practical implementation and enforcement of directives preventing quality and quantity degradation of water resources and soils:**
  - Water Framework Directive
  - Nitrates Directive
  - Marine Strategy directives
- **Key areas:**
  - Permitting - inspection in water and land areas
  - Water Management
  - Agriculture
- **Projects:**
  https://www.impel.eu/en/expert-teams/water-and-land

Main actions / result – project based



Environmental law partners



European Commission

Secretariats of the Basel, Rotterdam and Stockholm Conventions

Institutional funders

Other networks such as EUFJE, ENPE, ENVICrimeNet

Europol, Interpol, Eurojust etc.

Member organisations

Background information
(Former IMPEL Project: Integrated Water Approach)

- Use of less water per unit of produced material
- Energy savings
- Reduction of CO_2 emissions (reduction of pumping)

Reduce of freshwater consumption

Water resources

- Reduce the water bodies over-exploitation
- Promote water resources replenishment

- Concentration of pollutants in wastewaters
- May promote short and long negative impacts on water bodies (acute and chronic effects on ecosystems)

Consequences

Water resources

- Reduction of natural values (ecosystem lost)
- Increase of CO_2 emissions (oxidation of organic matter/algae blooms)
- Can compromise the water status

IED: Industrial Emissions Directive
WFD: Water Framework Directive

Background information (Former IMPEL Project: Integrated Water Approach)

USUAL APPROACHES

Water use efficiency: Usually only looks at quantitative aspects

Simplistic approaches to promote water reuse without linking to impacts on water bodies

Compliance of IED (Best Available Technologies) without link to WFD goals (Water Body Good Status)

NEEDS

Use of an integrated approach to water use under industrial and urban cycle, at local and catchment scale

Deepen the understanding of the principles of circular economy in the water use cycle

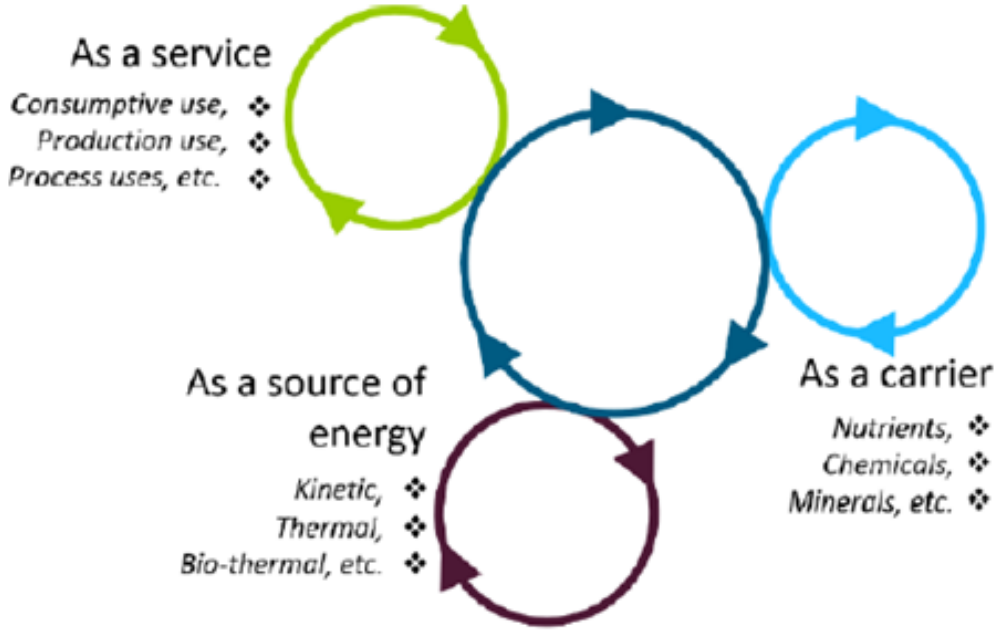
Introduction (Water Circularity)

Classic approach:

- **Water use efficiency, namely the quantitative aspects through the reduction of consumptions and losses**
- **Rain waters recovery**
- **Water reuse**
- **Use of sludge from wastewater treatment plants and manure as a source of organic matter and nutrients, and/or use for energy production**

To achieve a real transition, the above factors cannot be seen as individual indicators but instead, they should be linked with the several possible processes

It is very important to look at several trade-offs and synergies between decisions on process and environment!



Development of a circularity index for water able to measure important trade-offs and synergies results

Under the IMPEL Project "Wastewater in Natural Environment" (WiNE) 2019-2021

Methodology: Development of the Index

SMART criteria: Easily accessible and measurable factors (key factors) that take into account the relationships between the water use patterns, the processes and the environmental systems were considered as inputs

S **SPECIFIC**	The index accurately describes what is intended to be measured and does not include multiple measurements
M **MEASURABLE**	Regardless of who uses the index, consistent results can be obtained and tracked under the same conditions
A **ACHIEVABLE**	Collecting data for the index is simple, straightforward, and cost-effective
R **RELEVANT**	The index is closely connected with each respective input, output or outcome
T **TIME-BOUND**	The index includes a specific time frame, i.e., the validity of the environmental/ discharge permit

Development of the Index: Key Factors

- **11 key Factors distributed by 3 levels of Importance:**

High

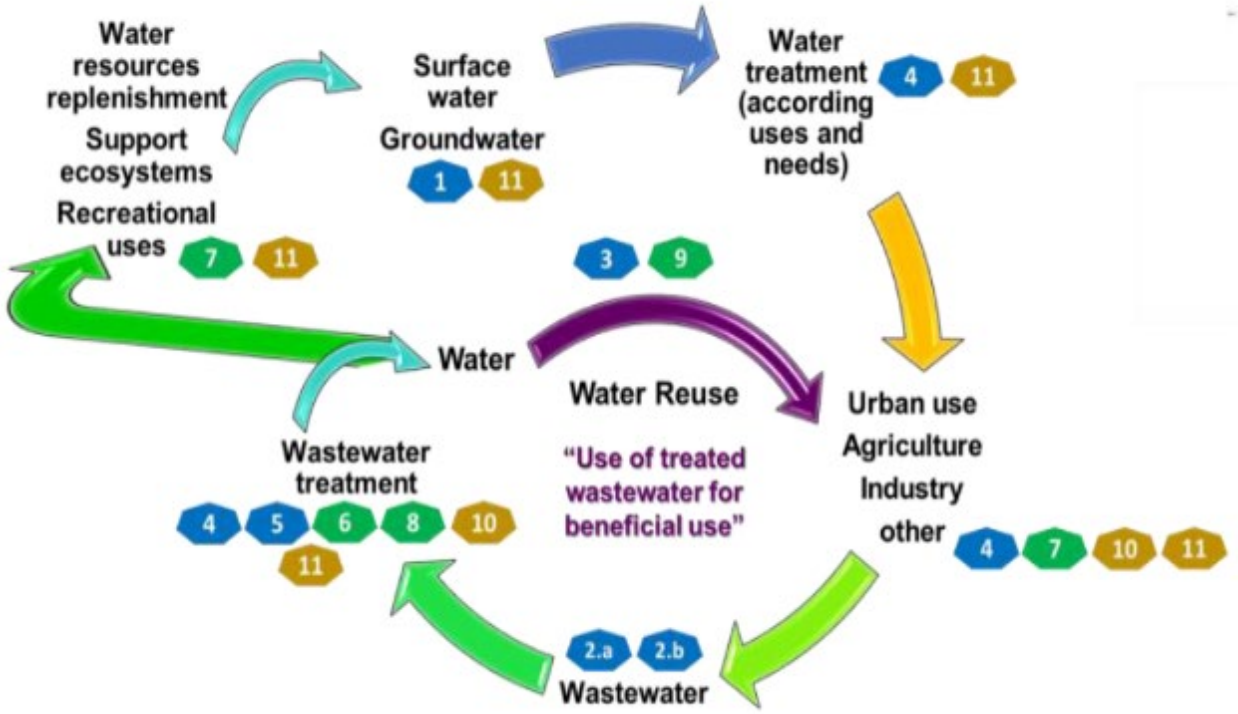
1. Freshwater consumption
2. Wastewater discharges:
   a. Non-IED installations
   b. IED installations
3. Water reuse
4. Best management practice and technologies
5. Priority substances (PS), priority hazardous substances (PHS) and other pollutants (OP) and specific pollutants (SP)

Medium

6. Microplastics and/or compounds of emergent concern
7. Biodiversity
8. Recovery of nutrients
9. Internal industrial symbiosis

Low

10. Sludge
11. Voluntary and incentive instruments



- **The Water Circularity Index (I_C) was developed to endorse the transition to the circular economy**
- **Tool to measure the circularity of a certain process or installation**

Water Circularity Index (I_c)

- **For each key factor are applicable sub-key factors with positive or negative values (from -9 to 9), i.e., Positive & Negative Impacts**

1	Freshwater consumption	9	
	Measures to reduce consumption without linking the impacts on the quality of wastewaters and contributing directly to its degradation		-9,00
	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)		1,00
	Measures to reduce consumption with measures to reduce possible effects of effluents concentration		4,00
	Reducing abstraction directly from water body (ex. Rainwater collection and reuse) promoting replenishment		4,00

3	Water Reuse	9	
	Promotion of water reuse with negative impacts on final concentration of the wastewaters discharged with negative impact on surface water		-6,00
	Promotion of water reuse with negative impacts on final concentration of the wastewaters discharged and no impact on groundwater abstraction		-3,00
	Promotion of water reuse without negative impacts on final concentration of the wastewaters discharged		3,00
	Promotion of water reuse with positive impacts on final concentration of the wastewaters discharged		6,00

7	Biodiversity	5	
	Promotion of water reuse with negative impacts on biodiversity (water quality and quantity index)		-5,00
	Promotion of water reuse without negative impacts on biodiversity (water quality and quantity index)		2,00
	Promotion of water reuse with positive impacts on biodiversity (water quality and quantity index)		3,00

10	Sludge	1	
	Minimization of sludge production, bio-thermal energy production from anaerobic digestion and reuse of treated sludge from aerobic digestion with impacts on final concentration of the wastewaters discharged		-1,00
	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		1,00

$$I_c = \frac{\sum(f_{i\ s\text{-}key} \times f_{i\ w})}{N_f}$$ **INDEX**

$$f_{i\ w} = \frac{\left|f_{i\ s\text{-}key_{+++,++or+}}\right|}{F_{key_{+++,\ ++or+}} \times n_{s\text{-}key\ app_{+++,++or+}}}$$ **WEIGHTING FACTOR**

$$N_f = \frac{n_{F_{key+++}} \times 9 + n_{F_{key++}} \times 5 + n_{F_{key+}} \times 1}{5 \times 9 + 4 \times 5 + 2 \times 1} = \frac{9n_{F_{key+++}} + 5n_{F_{key++}} + n_{F_{key+}}}{67}$$

NORMALIZATION FACTOR

	Ic <0	Negative Circularity: Negative inputs for the circular economy (negative impacts for water bodies)
	Ic = 0	No inputs for circular economy
	0 < Ic ≤ 0,85	Low Circularity: Low level of inputs for circular economy
	0,85 < Ic ≤ 1,5	Medium Circularity: Medium level of inputs for circular economy
	Ic > 1,5	High Circularity: High level of inputs for circular economy

I_c Scale: -4,4 to 2,6

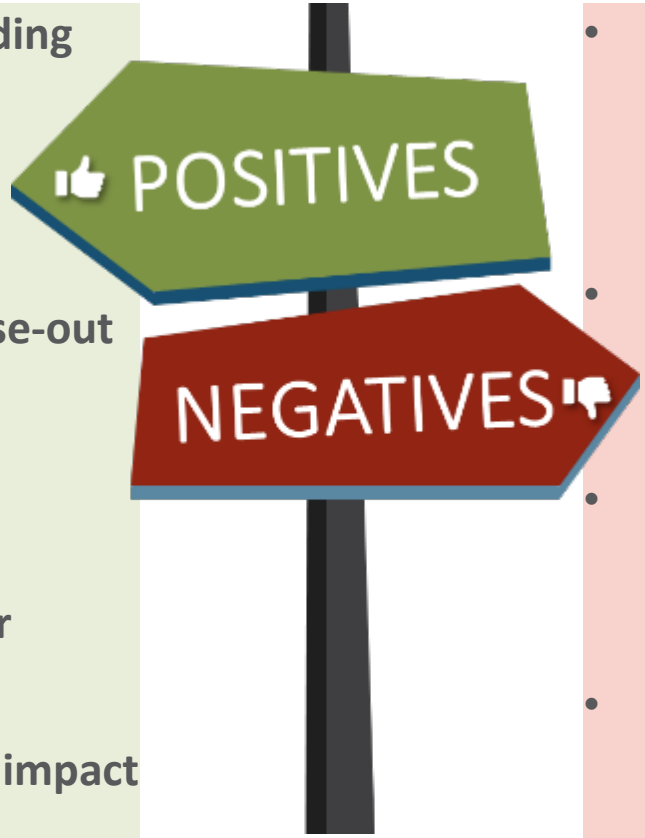
Results

Case study	IED	Non IED	Description	I_C	Circularity
A1	X		Pulp mill before permit review	-1,24	Negative
A2	X		Pulp mill after permit review	1,19	Medium
A3		X	Urban wastewater treatment plant (UWWTP)	1,91	High
B1	X		Pulp and paper industry	0,35	Low
B2	X		Biorefinery	2,13	High
B3	X		Oil refinery	-1,01	Negative
C1		X	UWWTP with industrial connections	3,48	High
C2	X		Company cleaning and shredders plastic barrels	1,46	Medium
D1	X		Pulp and paper industry and urban wastewater	1,39	Medium
D2	X		Fertilizer production plant	1,00	Medium
D3	X		Large smelter	2,94	High
E1	X		Pulp and paper industry	0,52	Low
E2	X		Brewery	1,09	Medium
F		X	UWWTP	1,01	Medium
G	X		Sugar beet factory	0,07	Low

- **Application to 14 installations (15 case studies) in 7 EU Countries**
- **Case studies A1 & A2: Same installation before and after a permit review**
- **Results distribution:**

Results: High circularity vs Negative Circularity

- Emission Limit Values compliance according WFD criteria
- Use of new technologies
- Consideration of Priority Hazardous Substances and measures to cease, phase-out emissions, discharges and losses
- Promotion of water reuse with positive impacts on biodiversity
- Promotion of an integrated approach for competitive advantages
- Reduction of sludge production with no impact on final effluent concentration
- Adoption of voluntary and incentive instruments



- Measures to reduce water consumption with a negative impact on wastewater quality and which directly contribute to the degradation of the receiving environment
- Compliance of Best Available Techniques - Associated Emission Level (BAT-AEL in IED installations) with no link to WFD
- Promotion of water reuse with negative impacts on final concentration of discharges with negative impacts on surface water
- Without removal of nutrients and with consequent visible negative effects on the water bodies
- Without adoption of voluntary and incentive instruments

Developments: Circularity Index for Product ($I_{C\ prod}$)

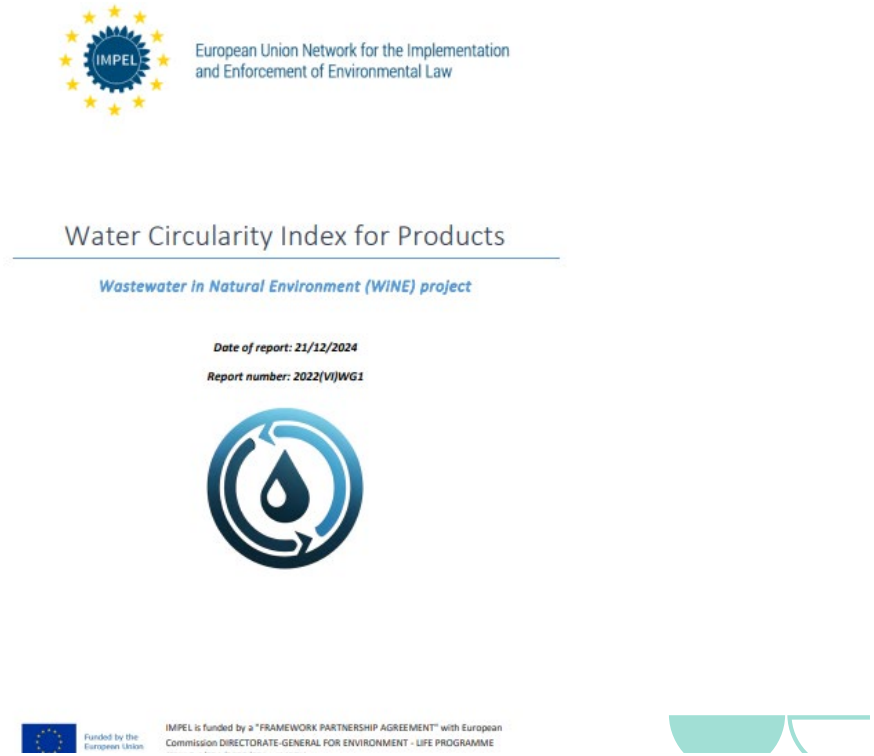
- Improvement of the Water Circularity Index to be applied to product (the previous one is only applied at the installation level)
  I. Local and/or seasonal products with significant impact in terms of water use, but important for the local communities' economy
  II. Crops production (with water reuse)
  III. Products from critical activities/facilities with high pressure over water bodies (IED)

WATER CIRCULARITY INDEX PRODUCT

The logo for the 'Water Circularity Index for Product' 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.

Circularity Index for Product ($I_{C\ prod}$)

Impact of key factor	$I'_{C\ prod}$	Condition for $I_{C\ Prod}$ result	Results expression
Partial Water circularity index for products ($I'_{C\ prod}$) $I'_{C_{prod}} = \sum (F_{i\ Key})$	$I'_{C\ prod} < -60$	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



https://www.impel.eu/en/topic/water-and-land/water-pollution/projects/wastewater-in-natural-environment-wi-ne

			$I'_{C\ Prod}$						
			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)

WATER CIRCULARITY INDEX FOR PRODUCT

KEY-FACTORS

Freshwater consumption (water use for the product)	Use of alternative water sources (quantitative & qualitative aspects)	Internal use of reclaimed waters: water reuse (within the process, quantitative aspects)
Water pollutants	Externalities (reused/recycled materials synergies)	Additional factors (energy, seasonality, crop characteristics)

Scales & Metrics

	Sub-Key Factors	Global		Crops		Sea./Reg. prod		Industrial prod.	
		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	Protected Designation Origins (DPO) product	0	5	0	5	0	5	0	5

WATER CIRCULARITY INDEX FOR PRODUCT

Example 1

sustainability

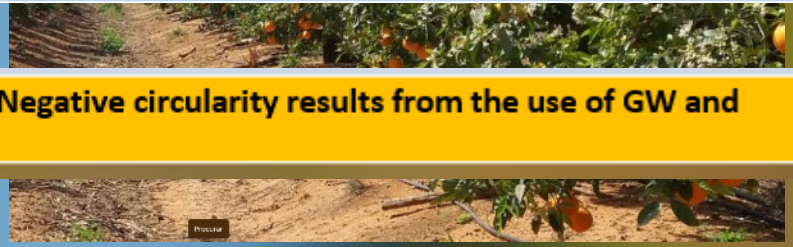
MDPI

Article

Urban Wastewater Reuse for Citrus Irrigation in Algarve, Portugal—Environmental Benefits and Carbon Fluxes

Manuela Moreira da Silva [1,2,3], Flávia C. Resende [1], Bárbara Freitas [4], Jaime Aníbal [1,2], António Martins [5] and Amílcar Duarte [4,6,*]

$I'_{c\ prod}$	-9	Expression: Low negative circularity (-3) | Negative circularity results from lack of information
$I'_{c\ prod}$	57	Expression: Medium positive circularity (5), due to the consumption of water in dry season



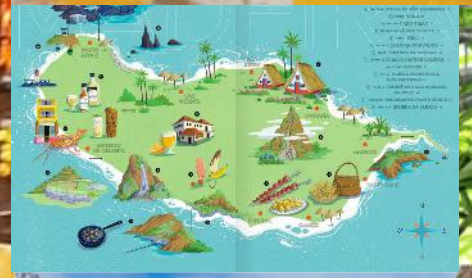
$I'_{c\ prod}$	-33	Expression: Medium negative circularity (-5) | Negative circularity results from the use of GW and lack of information

Example 1

Citrus (orange) production

- **Use of 100% Reclaimed water (as the aim of the study)**
- **Use of 100% GW (current practice)**

Example 2



Sugarcane Production: Wastes and By-Products

The sugarcane (*Saccharum officinarum*) is one of the most important crops in the History of Madeira Island.

The production of sugarcane in Madeira Island dates back to the 15th century, having contributed inexorably to the economic, social and cultural development of the Region through trade and sugar exports. Currently, sugarcane is mainly used in the production of cane honey and sugarcane rum (agricultural rum).

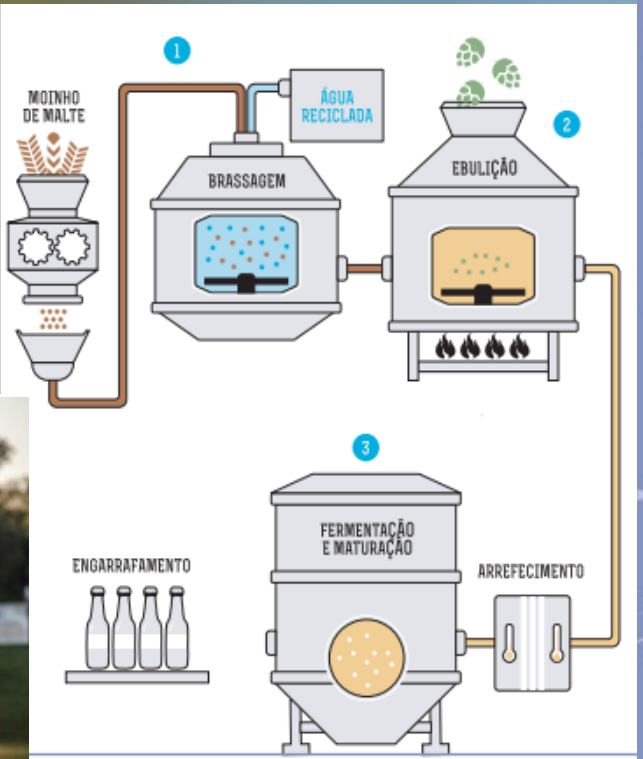
$I'_{c\,prod}$	-18	-10	Expression: Low negative circularity (-3) | Negative circularity results from the impacts of wastewater and the absence of measures to reduce/recover it
$I'_{c\,prod}$	66	74	Expression: High positive circularity (9) is possible to achieve

Possible if a WWTP is installed and with measures to recover content from vinasses

Mashing
The malt is previously milled and mixed with water under controlled operating conditions (time, temperature, pH) allowing the starch to be converted into simple sugars

Boiling
Hops are added to the wort and brought to the boil to gain flavour and aroma. The mixture is then cooled

Fermentation
For this phase, it is necessary to add yeasts that will transform the simple sugars into alcohol and carbon dioxide

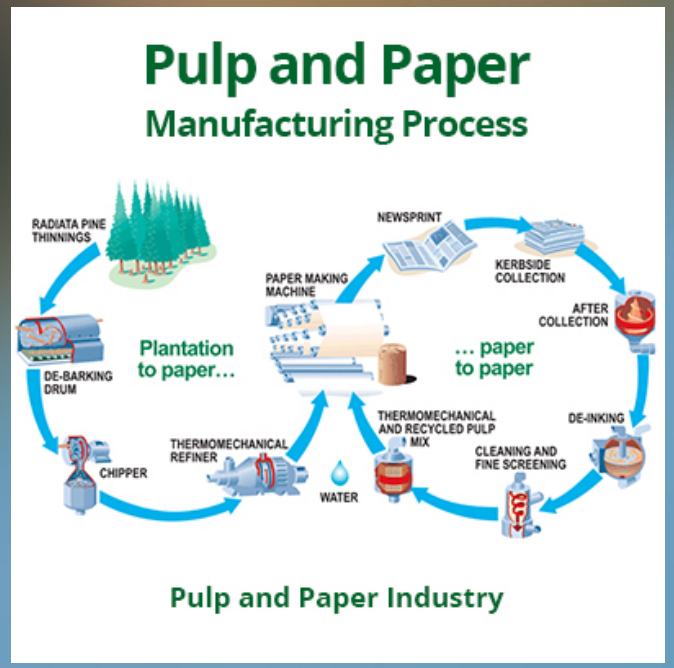


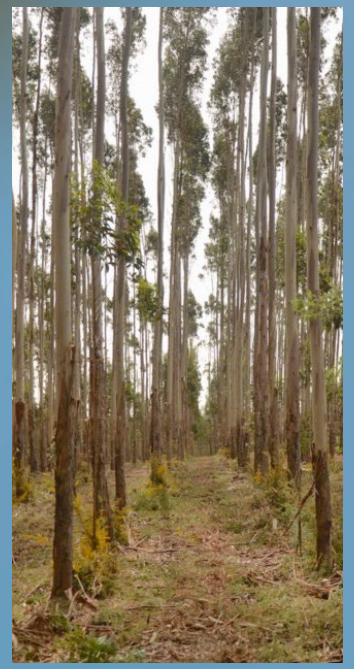
Example 3

Parâmetro	*Resultado*	*VP**	*Unidades*
Det. de Microorganismos viáveis a 22ºC	< 15	---	ufc / mL
Det. de Microorganismos viáveis a 37ºC	< 35	---	ufc / mL
Detec. e Quant. de Bactérias Coliformes	0	0	ufc / 100 mL
Detec. e Quant. de Escherichia Coli.	0	0	ufc / 100 mL
Detec. e Quant. de Enterococos intestinais	0	0	ufc / 100 mL
Pesq. e Quant. de Clostridium perfringens	0	0	ufc / 100 mL
Staphylococcus coagulase positva	<10	<= 1 x10^2	ufc/g

WATER CIRCULARITY INDEX FOR PRODUCT

Example 5





Case study	IED Installation	NON IED Installation	Description of WWTP	Ic
A 1	X		Pulp mill before permit review	-1,24
A 2	X		Pulp mill after permit review	1,19

Final Remarks

- Circular approaches can play a pivotal role in addressing global water scarcity, reducing pollution, and ensuring long-term water security
- The developed water use indexes allow for assessing the impact of integrated approaches and confirm water circularity promotion based on best management options
- The index for installations enabled the measurement of the positive impacts resulting from the integration of environmental legislation, as opposed to mere compliance with individual directives
- The study for installations found that implementing efficient water use, including water reuse solutions, can help understand the cumulative impact on water use efficiency, in terms of quantity and quality for several ranges of installations

Final Remarks

The index for products by a multicriteria analysis enables the measurement of important tradeoffs in water management, including the suitability for location by considering the water scarcity (or in the case of crop production, its specific characteristics)

The application of the index for product to real case studies demonstrated its suitability in identifying areas needing improvement in circularity, particularly for seasonal or regional products and crop production

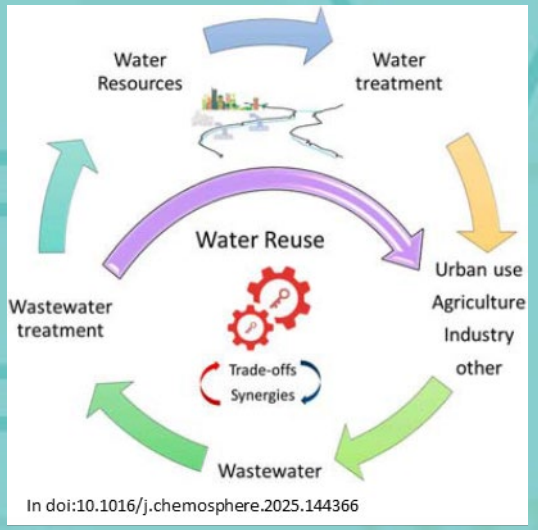
The development of these indexes represents significant advancements in assessing water use and its implications

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

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

By providing a structured framework for evaluating several trade-offs related to water usage and other environmental compliance, the indexes ensure that claims of sustainability are backed by measurable data and comprehensive assessments (may be used to prevent greenwashing activities)

Additional information about the Indexes



IMPEL Website:
https://www.impel.eu/en/topic/water-and-land/water-pollution/projects/wastewater-in-natural-environment-wine/outputs#reports

Rebelo, A., & Farabegoli, G. (2025). **Water circularity index: A novel approach for authorities and operators**. Chemosphere, 377, 144366. https://doi.org/https://doi.org/10.1016/j.chemosphere.2025.144366

Thank you for your attention!

Wastewater in Natural (WiNE) Environment 2022-2024