

Assessment of Water Reuse Technologies and Concepts - Technical aspects (KPI/KUOI)



TECHNISCHE
UNIVERSITÄT
DARMSTADT

WavE Online Seminar

Assesment of Water Reuse Technolgies and Concepts

31 March 2021



Member of
German Water
Partnership

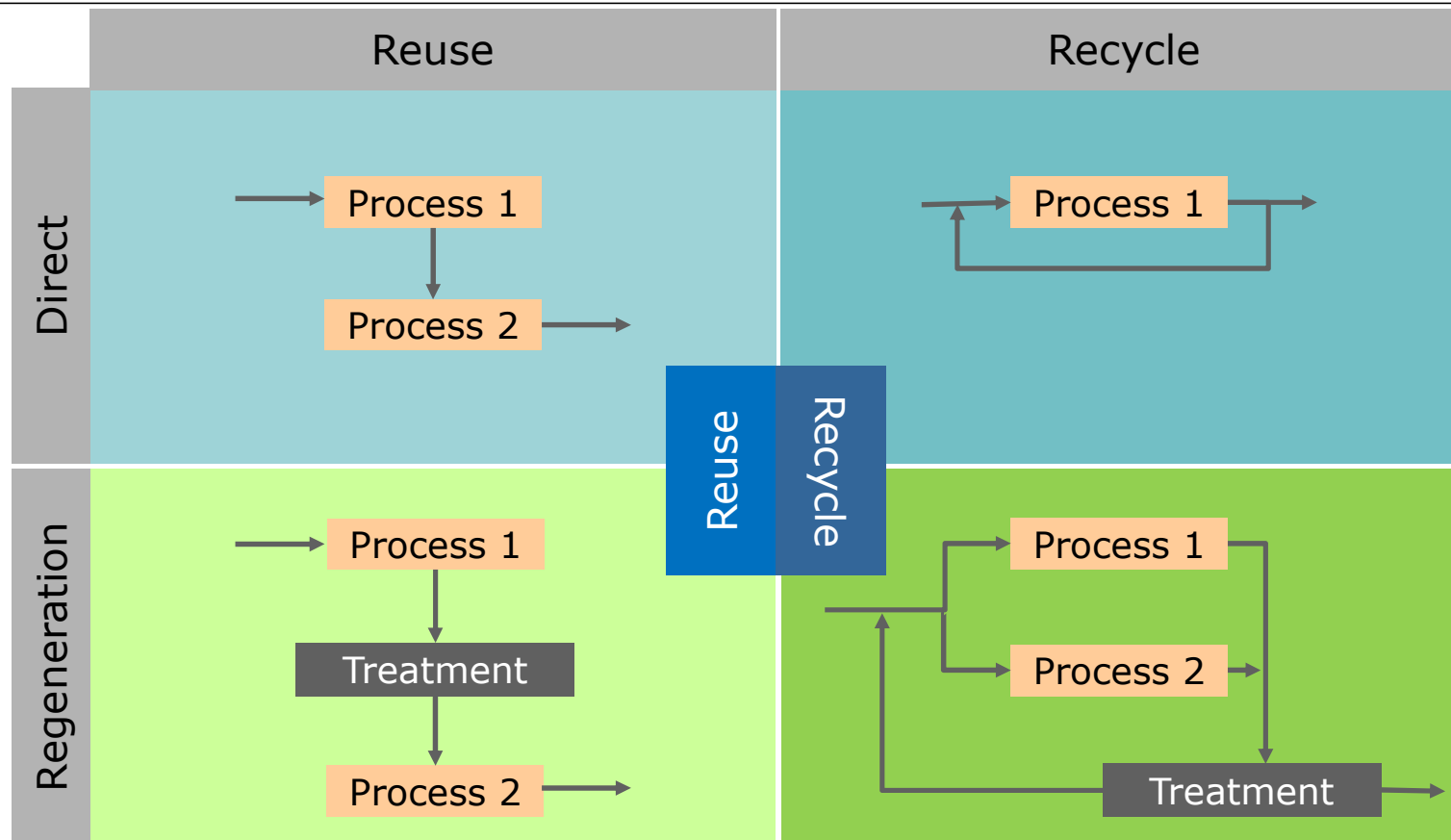


IWAR

Technological comparison:
Technical requirements and
key performance indicators

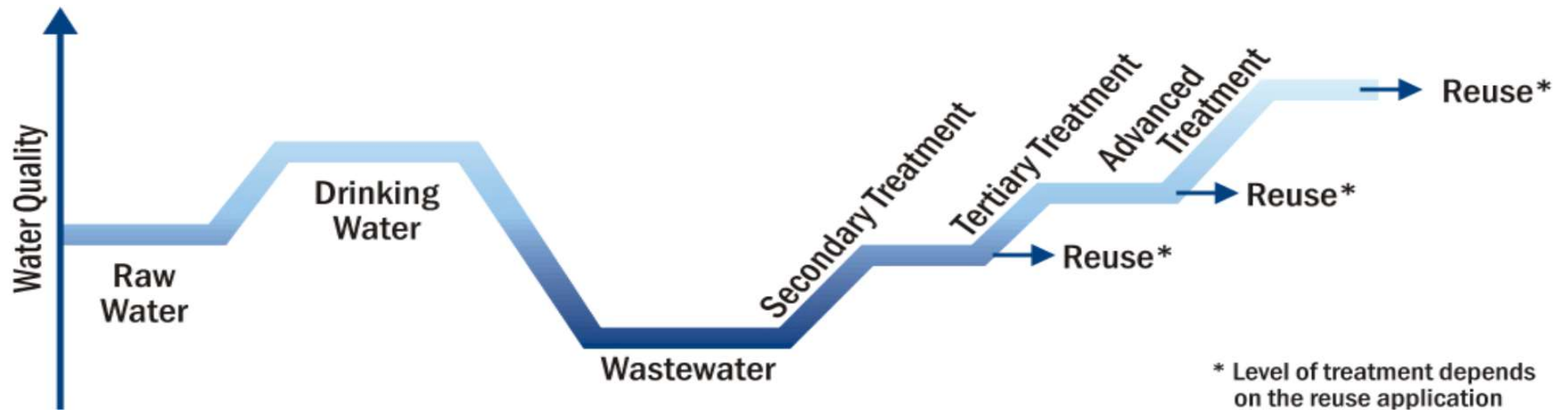
Validation:
Comparison of assessment methods and
inclusion of other, non-technical assessment criteria
(economic, environmental, social).

Definition Reuse / Recycle

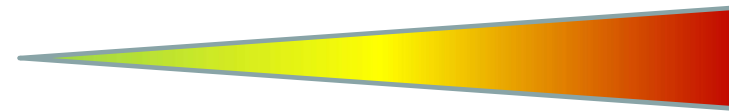


(Wang und Smith, 1994)

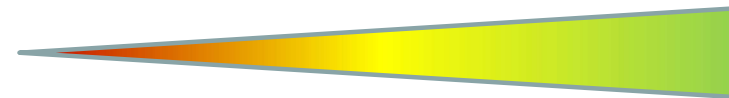
Treatment: Fit for Purpose Water



Effort



Acceptability



Treatment Technologies

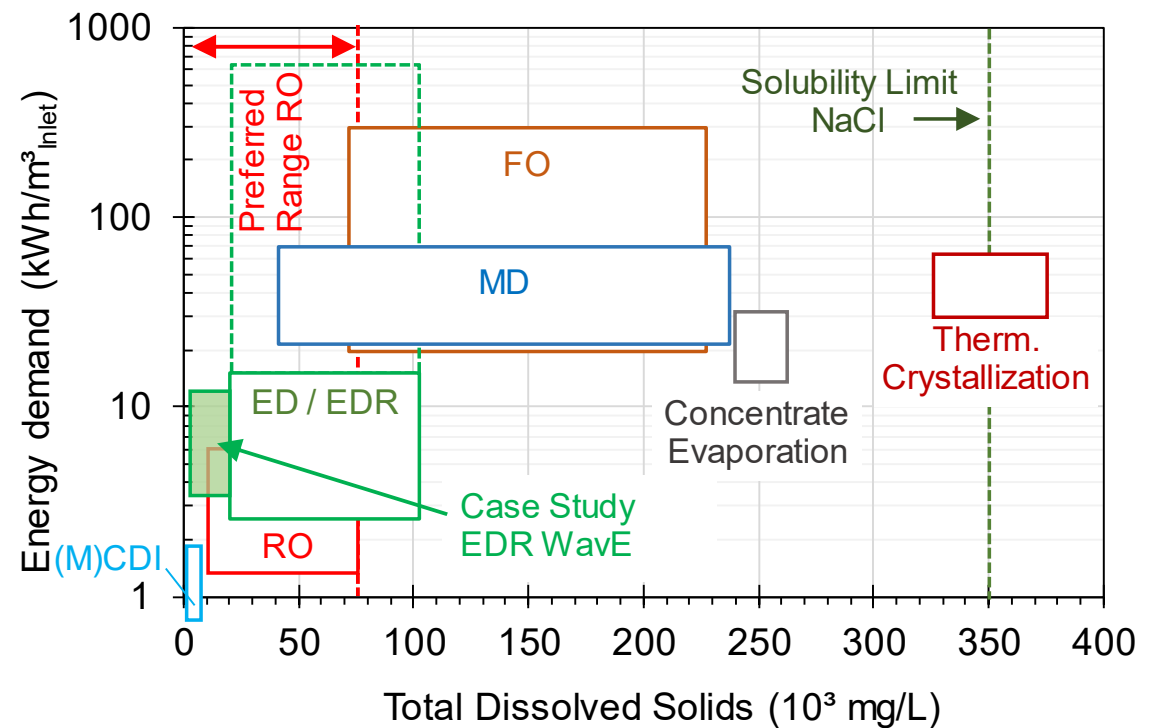
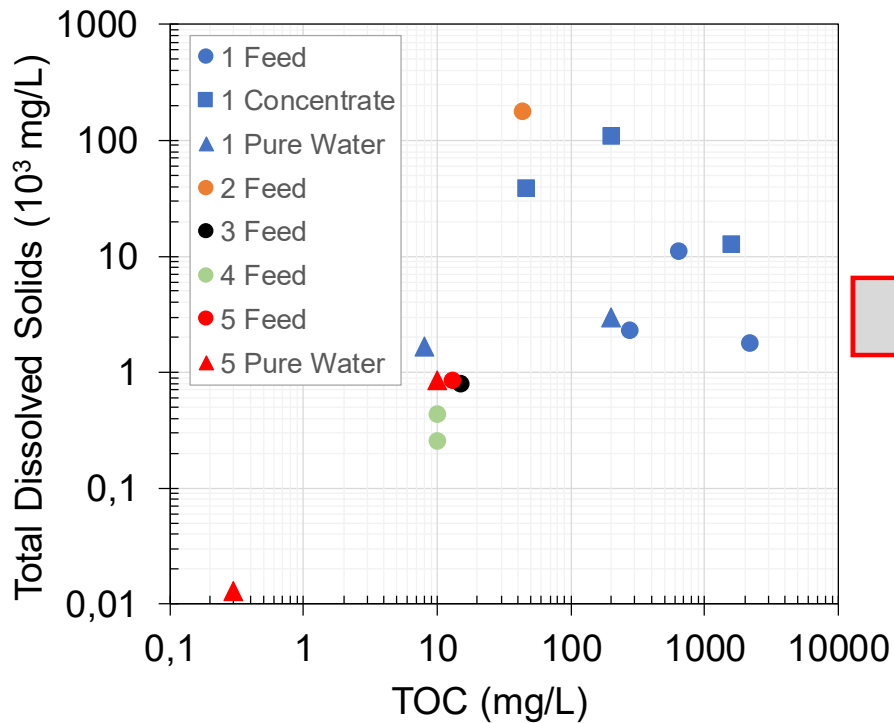
	Solids	Heavy Metals	SO ₄ , PO ₄	CN, Cr ⁶⁺ , NO _x	Ions	Gas	Dye	FOG	Organics	AOX
Ion Exchange		partly suitable	partly suitable	partly suitable	partly suitable				partly suitable	
Oxidation (AOP)				partly suitable			partly suitable	pos. side effect	partly suitable	partly suitable
Detoxification				partly suitable						
Precipitation	partly suitable	partly suitable	partly suitable		partly suitable		pos. side effect	partly suitable	pos. side effect	pos. side effect
Electrolysis		partly suitable	partly suitable		partly suitable					
Adsorption (AC)							pos. side effect	pos. side effect	partly suitable	partly suitable
Sedimentation	partly suitable	pos. side effect	pos. side effect					partly suitable		
Flotation	partly suitable	partly suitable				partly suitable		partly suitable		
Centrifugation	partly suitable	partly suitable						partly suitable		
Depth Filtration	partly suitable	partly suitable					pos. side effect	pos. side effect		
Microfiltration	partly suitable							pos. side effect		

	Solids	Heavy Metals	SO ₄ , PO ₄	CN, Cr ⁶⁺ , NO _x	Ions	Gas	Dye	FOG	Organics	AOX
Ultrafiltration	partly suitable						partly suitable	partly suitable	pos. side effect	pos. side effect
Nanofiltration	partly suitable	partly suitable	partly suitable	partly suitable	partly suitable	partly suitable	partly suitable		partly suitable	partly suitable
Reverse Osmosis	pos. side effect	partly suitable	partly suitable	partly suitable	partly suitable	partly suitable			partly suitable	partly suitable
Electrodialysis	pos. side effect	partly suitable	partly suitable		partly suitable					
Extraction	pos. side effect						partly suitable	partly suitable		
Distillation / Rekt.	pos. side effect	pos. side effect	pos. side effect		pos. side effect		partly suitable	partly suitable	pos. side effect	pos. side effect
Thermolysis / Hydrol.	pos. side effect						partly suitable	partly suitable	partly suitable	partly suitable
Evaporation	pos. side effect	partly suitable	partly suitable		partly suitable		pos. side effect		pos. side effect	pos. side effect
Stripping						partly suitable				

Contamination	■ solid	■ inorganic	■ organic
Process	■ chemical	■ physical	■ thermal
Suitability	■ suitable	■ partly suitable	■ pos. side effect
	 unsuitable		

Rosenwinkel et. al. (Hrsg.) (2020)

Water Composition / Technology - Nexus



Key Unit Operation Indicators vs. Key Performance Indicators

Key Unit Operation Indicator (KUOI)	Key Performance Indicator (KPI)
KUOIs are used to define boundary conditions and reasonable application limits for technology selection.	KPIs are used to compare the performance of the technologies (benchmarking) in a specific application.
<ul style="list-style-type: none">• Technology readiness Level	<ul style="list-style-type: none">• Treatment performance
<ul style="list-style-type: none">• Complexity	<ul style="list-style-type: none">• Energy demand
<ul style="list-style-type: none">• Wastewater composition	<ul style="list-style-type: none">• Residue production
<ul style="list-style-type: none">• Technological application limits	<ul style="list-style-type: none">• Input of auxiliary substances / chemicals
	<ul style="list-style-type: none">• Size and footprint
	<ul style="list-style-type: none">• Maintenance requirements

Key Unit Operation Indicators (KUOI)

Technology status	Technology Readiness Level – TRL (1-9)
Complexity	<p>Operating stress – Normalized Shift Position (?)</p> <p>Man hours/m³ clean water produced</p> <p>Man hours/year (> TRL 6)</p> <p>DVGW 1000 – technical effort, safety management (TWA)</p> <p>Robustness (Scale 1-10)</p> <p>Training level of supervising personnel (low – medium - high)</p>
Substantial Application Limits	<ul style="list-style-type: none"> • Inlet concentrations (mg/L) • Maximum inlet concentration (mg/L) • Typical product concentration (mg/L) • Typical volumetric feed flow rate (m³/h) • Typical clean water yield (m³/h) • Typical retention (%) • Interfering substances
Technical Application Limits	<ul style="list-style-type: none"> • Variation of influent load and concentrations allowed over time • Flexibility start-up/shut-down and changeover time (dynamic modification capability) • Temperature

Key Performance Indicators (KPI)

Substantial KPI	$(c_0 - c_e)$ Elimination	Unit
Sum Parameters	<ul style="list-style-type: none"> • COD / TOC / DOC • Alkalinity • Conductivity • TSS • TDS 	(mg/L – mg/L) % (mmol/L – mmol/l) % (mS/cm – mS/cm) % (mg/L – mg/L) % (mg/L – mg/L) %
Single Parameters	<ul style="list-style-type: none"> • Nitrogen • Phosphorus • Chloride • Sulfate • Nitrate • Heavy metals • Hydrocarbons (Oil) 	(mg/L – mg/L) % (mg/L – mg/L) % (mg/L – mg/L) % (mg/L – mg/L) % (mg/L – mg/L) % (mg/L – mg/L) % (mg/L – mg/L) %
Hygienic Parameters	<ul style="list-style-type: none"> • CFU (colony forming unit) • Relevant Microorganisms, e.g. Legionella 	(CFU/100 mL - CFU/100 mL) log (CFU/100 mL - CFU/100 mL) log

Key Performance Indicators (KPI)

Energy Demand	Specific Energy Demand	
	<ul style="list-style-type: none"> Energy index Energy type (electricity, heat, primary energy) 	kWh/m ³ product water, kWh/kg
Residuals	Specific Load	
	<ul style="list-style-type: none"> Type (solid, liquid, gaseous) Disposal quantity 	m ³ /m ³ product water, kg/m ³ product water
Auxiliaries / Chemicals	Specific input / Dosage	
	<ul style="list-style-type: none"> e.g. acid, lye, antiscalant Maintenance and cleaning chemicals 	kg active ingredient/m ³ product water
Footprint	Volume / area consumption	
	<ul style="list-style-type: none"> Reactor size Space requirements, building volume 	m ³ /(m ³ /h) m ² /(m ³ /h)
Maintenance	Man hours	
	<ul style="list-style-type: none"> Personnel deployment per operating time Maintenance per operation time 	h/a, h/m ³ , h/kg

KPI: Energy demand

Treatment goal : reuse and recycling of process water

Technology	KUOI Feed TDS [mg/L]	KPI Energy demand [kWh/m ³ Feed]
(M)CDI	500 - 2000	0,5 - 2
ED(R)	1000 - 5000	2 - 8
RO	1000 - 10000	1 - 6

Modified KPI: Energy demand

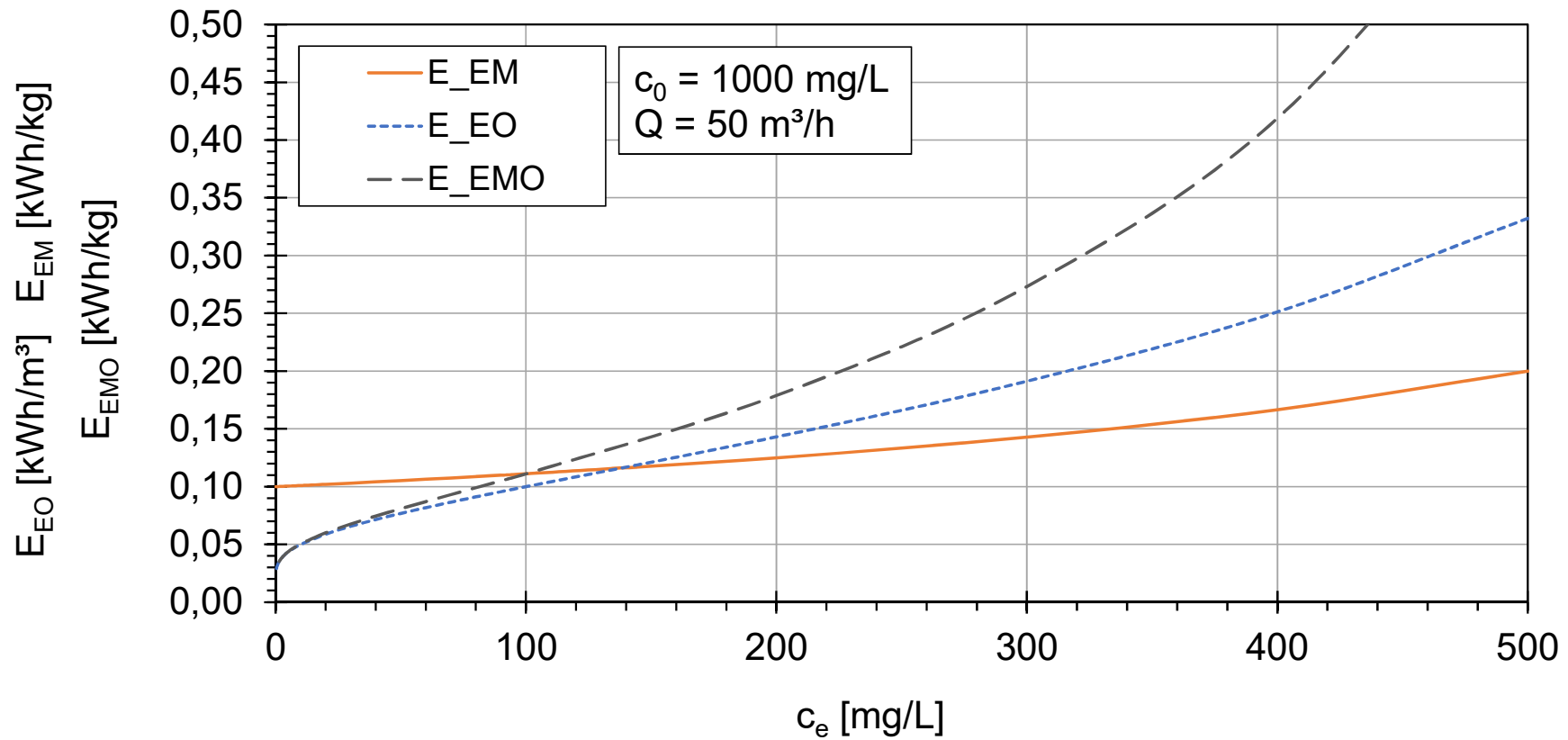
- **E_{EM} [kWh/kg] „electric energy per mass“**
 - load-based approach; balances actually eliminated pollutant load via input and effluent concentration (*Bolton et al., 2001*)
- **E_{EO} [kWh/m³] „electric energy per order“**
 - designed to assess treatment success of trace substance elimination (lower substance concentrations)
 - energy required to reduce a pollutant by one order of magnitude in a given volume
- **E_{EMO} [kWh/kg] „energy per mass and order“**
 - introduction of a further quality criterion in the denominator (log-step reduction of the eliminated load)
 - more exact statements of the actual specific energy consumption especially at low effluent concentrations

$$E_{EM} = \frac{P}{Q \cdot (c_0 - c_e)}$$

$$E_{EO} = \frac{P}{Q \cdot \lg\left(\frac{c_0}{c_e}\right)}$$

$$E_{EMO} = \frac{P}{Q \cdot (c_0 - c_e) \cdot \lg\left(\frac{c_0}{c_e}\right)}$$

Modified KPI: Energy demand



Taschenbuch der Industrieabwasserreinigung (2020). Rosenwinkel, K.-H., Austermann-Haun, U., Köster, S., Beier, M. (Hrsg.), 2. Auflage 2020, Vulkan-Verlag GmbH, ISBN 978-3-8356-7398-4

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