Oceanologia, uncorrected, in press
Polish Academy of Sciences
Institute of Oceanology

https://doi.org/10.5697/...

The recast of the EU Urban Wastewater Treatment Directive: Implications for the Baltic Sea

Aneta Luczkiewicz*, Anna Remszewska-Skwarek, Marta Julia Marta Szczerska, Sylwia Fudala-Książek

Abstract
The Baltic Sea is a shallow, semi-enclosed basin highly sensitive to land-based pollution. EU Urban Wastewater Treatment Directives (UWWTDs) underpin HELCOM Baltic Sea Action Plan objectives by reducing point-source loads. Directive 91/271/EEC drove WWTP upgrades and major declines in organic matter and nutrients, supporting eutrophication mitigation and bathing-water quality. The recast UWWTD (Directive (EU) 2024/3019) has strengthened municipal wastewater nutrient management and introduces requirements for the implementation of quaternary treatment addressing hazardous substances. In the study, the key cost drivers, affordability constraints, as well as the need for prioritisation and transparent communication are discussed, with a focus on Poland.

Keywords
Urban Wastewater Treatment Directive (UWWTD); Conventional and advanced treatment; Nutrients and micropollutants; Extended producer responsibility (EPR), Baltic Sea

Faculty of Civil and Environmental Engineering, Gdansk University of Technology, 11/12 Gabriela Narutowicza Street, Gdansk 80-233, Poland
***Correspondence**: aneta.luczkiewicz@pg.edu.pl (A. Łuczkiewicz)

Received: 3 February 2026; **revised:** 15 May 2026; **accepted**: 10 July 2026

Abbreviations

- BSAP – Baltic Sea Action Plan
- EPR – extended producer responsibility
- IA – impact assessment
- p.e. – population equivalent
- REFIT – Regulatory Fitness and Performance
- UWWTD – Urban Wastewater Treatment Directive
- WWTP – wastewater treatment plant

1. Introduction

1.1 The Baltic Sea as a semi-enclosed marine basin subject to multiple land-based pressures

The Baltic Sea is a shallow, brackish and semi-enclosed marine basin that drains a catchment area of about 1.6–1.7 million km^2 (HELCOM, 2021). Due to its distinctive hydrographic and geomorphological characteristics, restricted water exchange, strong stratification in parts of the basin, and relatively long residence times, the Baltic Sea is frequently described as a “model” or “indicator” system for other coastal and shelf seas. In such systems, the cumulative effects of multiple anthropogenic pressures and mitigation measures can manifest comparatively rapidly.

The drainage basin of the Baltic Sea encompasses some of the most industrialised regions of northern and central Europe. It is inhabited by over 82 million people across 14 countries, of whom approximately 46% reside in Poland (HELCOM 2021). The total long-term mean flow rate of all rivers discharging into the Baltic Sea is about 15,200 m^3 s^{-1}, of which approximately 1,655 m^3 s^{-1} (≈ 10.9%) drains into the Baltic Sea via the Vistula (1,081 m^3 s^{-1}) and the Oder (574 m^3 s^{-1}) rivers (Skowrońska et al., 2009).

The input of pollutants into the marine environment largely depends on human activities within the catchment area. In particular, agriculture, as well as municipal and industrial wastewater management, is key for pollutants of concern, including nutrients, hazardous substances, microplastics, and microorganisms (HELCOM, 2021). It should be highlighted that meteorological and hydrographical conditions (precipitation/evaporation, runoff dynamics, and episodic high flow events) can substantially influence the mobilisation and transport of contaminants from both diffuse and point sources mentioned above.

Land use patterns across the catchment reflect a north–south gradient: northern areas are dominated by forests and peatlands, whereas the southern and south western parts are characterised by intensive cultivation. In Poland, agricultural land accounts for roughly 60–61% of the national geodetic area, while forests and woody or bushy land represent about 30–31%; the remaining area comprises built-up/urbanised land, waters, and other categories (Statistics Poland, 2024). The Baltic Sea is also among the world's busiest regions for maritime transport, while at the same time supporting intensive coastal tourism and offshore recreational activities (European Commission, 2025b).

The political and legal response to eutrophication in the Baltic Sea has evolved over time. Increasing nutrient loads and recurrent algal blooms in the 1960s–1970s created the background for negotiating the 1974 Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention, 1974, 1992; Elmgren et al., 2015). This Convention was the first regional agreement to address pollution from land-based sources, dumping, shipping and airborne inputs. It also established the Baltic Marine Environment Protection Commission (HELCOM) as the governing body responsible for its implementation. A subsequent political commitment in 1988 to reduce nutrient and hazardous substance inputs by 50% by 1995 (HELCOM, 1988, 1998) paved the way for more comprehensive frameworks, most notably the HELCOM Baltic Sea Action Plan (BSAP), adopted in 2007. The BSAP translated broad regional objectives into country-allocated nutrient reduction targets (CARTs), complemented by lists of sector-specific measures, timetables and indicators (HELCOM, 2007; HELCOM, 2007b). The initial BSAP aimed to reduce eutrophication and other pressures on the Baltic Sea ecosystem and to achieve good environmental status of marine water by 2021. The nutrient reduction scheme based on basin-wise Maximum Allowable Inputs was also introduced, estimated at approximately 21,000 Mg of P and 600,000 Mg of N per year for the Baltic Sea as a whole (HELCOM, 2007; HELCOM, 2007b).

In 2013, HELCOM revised the Nutrient Reduction Scheme by recalculating the Maximum Allowable Inputs and the Country-Allocated Reduction Targets based on updated eutrophication targets (HELCOM, 2013). For Poland, the revised targets required annual reductions of 43,610 Mg of N and 7,480 Mg of P in total inputs (from land and air) relative to the 1997–2003 reference period (HELCOM, 2013). Scientific assessments suggest these reductions correspond to approximately 30% of Poland's total nitrogen inputs and 66% of total phosphorus inputs to the Baltic Sea (Pastuszak et al., 2018). The BSAP update adopted in 2021 reconfirmed eutrophication as a core priority alongside biodiversity, hazardous substances, microplastics and marine litter, as well as the sea-based activities.

The 2021 BSAP update also reformulated the regional nutrient-reduction framework by replacing the earlier Country-Allocated Reduction Targets (CARTs) with Nutrient Input Ceilings (NICs) (HELCOM, 2021; HELCOM, 2023a). NICs define maximum inputs of nutrients via water and air that are compatible with achieving good status with respect to eutrophication in Baltic Sea sub-basins (HELCOM, 2021). For Poland, the transboundary-river NICs assigned to the Vistula and Oder river systems are 70,062 and 43,923 t y^{-1} for total nitrogen (TN), and 2,240 and 1,365 t y^{-1} for total phosphorus (TP), respectively (HELCOM, 2023a). Thus, the combined Polish NICs for these two river systems amount to 113,985 t y^{-1} for TN and 3,605 t y^{-1} for TP (calculated from HELCOM, 2023b). In 2023, the total loads of TN and TP transported to the Baltic Sea via the Vistula and Oder rivers were 137,519 t and 4,229 t, respectively (Zalewska et al., 2025). These loads corresponded to approximately 121% of the combined TN ceiling and 117% of the combined TP ceiling; expressed inversely as the ceiling-to-load ratio, this represents about 83% and 85% target achievement, respectively. The remaining exceedances were therefore about 23,534 t TN and 624 t TP. These figures underline the continuing importance of nutrient-control measures in Poland and justify the Polish case study in the context of Baltic Sea protection.

The relevance of the recast UWWTD is therefore twofold: it supports BSAP eutrophication targets through stricter wastewater-collection and tertiary-treatment obligations, while its quaternary-treatment provisions address the BSAP hazardous-substances objective by targeting selected wastewater-derived organic micropollutants (HELCOM, 2021; UWWTD, 2024).

In practice, meeting nitrogen and phosphorus reduction requirements relies heavily on improvements in municipal and industrial wastewater treatment, complemented by measures reducing diffuse agricultural losses and atmospheric nitrogen emissions, reflecting the multi sectoral approach embedded in the eutrophication segment of the BSAP and subsequent HELCOM recommendations.

1.2 Frameworks supporting the protection of the Baltic Sea: the role of EU urban wastewater directives (UWWTDs)

Since the introduction of the activated sludge concept in the early twentieth century (Ardern and Lockett, 1915), municipal wastewater treatment has evolved from a primarily sanitary intervention into one of the most consequential technological pillars of freshwater and coastal-water protection (Figure 1). Over subsequent decades, the technology of activated sludge was repeatedly modified and intensified to address eutrophication drivers in advanced biological nutrient removal configurations. In the Baltic Sea context, these upgrades have been essential for reducing point-source nitrogen and phosphorus loads and supporting regional commitments under HELCOM and the Baltic Sea Action Plan.

A central component of the EU regulatory framework enabling substantial reductions in nitrogen and phosphorus inputs from point sources has been Council Directive 91/271/EEC of 21 May 1991 concerning urban waste water treatment (UWWTD, 1991) (Figure 1). The directive seeks to protect water resources from pollution and eu-

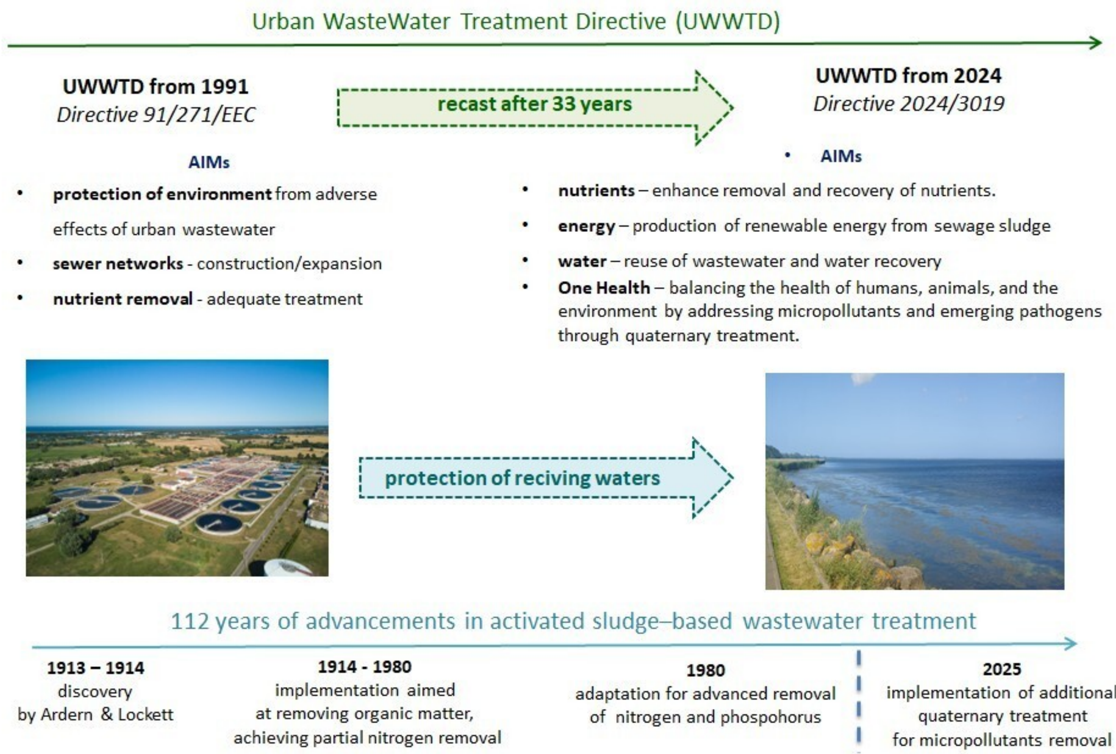

Figure 1. Wastewater treatment processes and the EU Urban Wastewater Treatment Directives (UWWTDs) as instruments for protecting the Baltic Sea

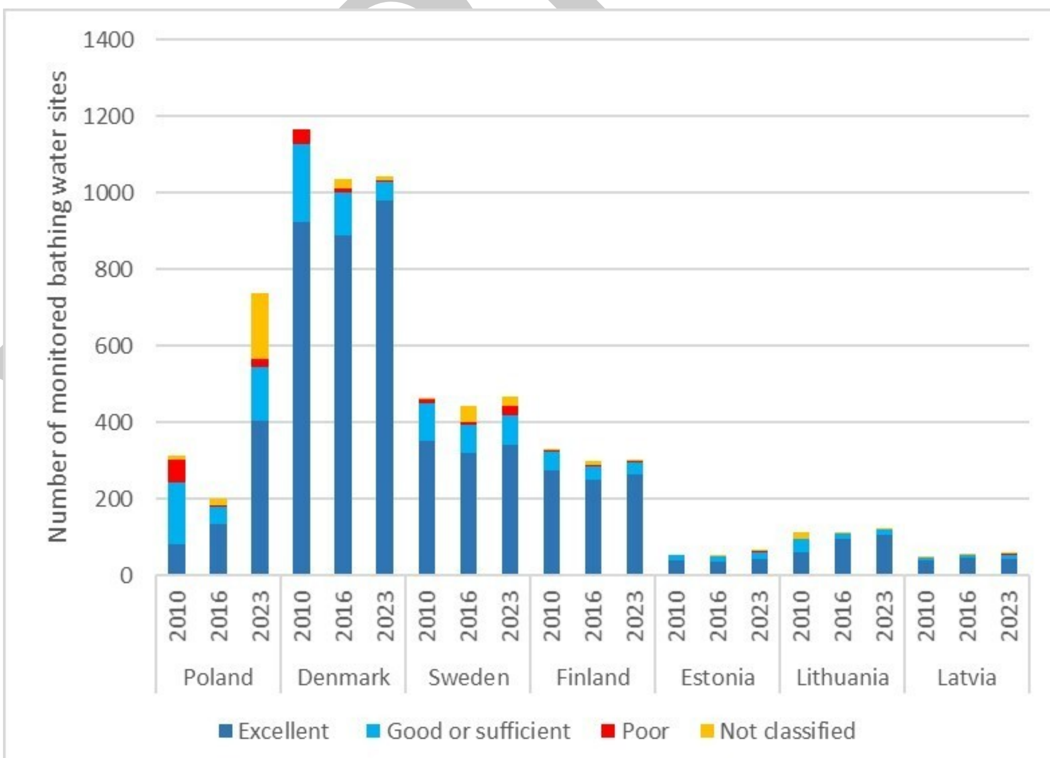

Figure 2. Trend in the number of monitored bathing-water sites by quality class in selected Baltic Sea countries (European Commission, 2025).

trophication by requiring (i) the collection of urban wastewater through sewerage systems and (ii) appropriate treatment prior to discharge, with particular attention to limiting nutrient emissions. Reducing nitrogen and phosphorus at wastewater treatment plant discharges can yield relatively rapid benefits in receiving waters. In contrast, the control of diffuse nutrient sources, especially from agriculture, is typically more complex and challenging to implement and is slower to translate into measurable ecological improvements. HELCOM reporting indicates that inputs from direct point sources discharging directly into the sea have decreased since 1995 (by approximately 58% for TN and 84% for TP) and, in 2022, constituted a minor share, about 4.5% (TN) and 5.8% (TP) of total waterborne inputs to the Baltic Sea (HELCOM, 2024). The implementation of Council Directive 91/271/EEC (UWWTD, 1991) has also indirectly contributed to improvements in the microbiological quality of bathing waters across Europe, including in the Baltic Sea (Figure 2).

Evidence syntheses supporting the REFIT evaluation (the EU's Regulatory Fitness and Performance review) indicate that implementation of the UWWTD has achieved substantial reductions in emissions of organic matter, nutrients and faecal indicator bacteria to surface waters, and has contributed to improved compliance of inland and coastal bathing waters with 'excellent' and 'good' microbiological standards (Pistocchi et al., 2019).

Nonetheless, an evaluation of the 1991 UWWTD (Council Directive 91/271/EEC), carried out in 2019, concluded that despite the directive's overall effectiveness in reducing loads of conventional pollutants, several persistent and emerging challenges were not fully addressed (European Commission, 2019). The assessment grouped these shortcomings into three overarching problem areas: (i) residual pollution from urban sources, including contaminants of emerging concern and other non-nutrient pollutants insufficiently targeted by the treatment standards; (ii) insufficient alignment with evolving societal ambitions and EU policy objectives, notably the European Green Deal and the Zero Pollution approach; and (iii) uneven governance and information management across Member States, reflected in persistent compliance gaps and outdated or non-comparable reporting and public-information practices (Table 1).

In late 2024, after 33 years, Council Directive 91/271/EEC on urban wastewater treatment (UWWTD, 1991) was recast and replaced by Directive (EU) 2024/3019 (UWWTD, 2024) (Figure 1)). The recast strengthens the protection of the environment and human health while explicitly linking urban wastewater management to broader societal objectives, including climate mitigation and adaptation, the transition to a circular economy, access to sanitation for all, and enhanced transparency and public information. In line with a One Health perspective,

Table 1. Principal problem areas identified during the evaluation of the 1991 Urban Wastewater Treatment Directive (UWWTD, 1991), informing the recast (European Commission, 2019).

Principal problem area	Key elements highlighted by the evaluation
Residual pollution from urban sources and contaminants of emerging concern	• Stormwater overflows and polluted discharges of urban runoff, which are becoming more prominent and are mobilized by more frequent and intense precipitation events under climate change; • Small agglomerations and non-connected dwellings not comprehensively covered by the original scope, which may still pose pressure on receiving waters. • Increasing concern regarding emerging contaminants and other non-nutrient pollutants insufficiently targeted by conventional WWTPs (e.g., pharmaceutical residues and microplastics).
Insufficient alignment with evolving societal ambitions and policy objectives	• Need to modernise urban wastewater management so that it contributes more explicitly to: (I) climate mitigation and adaptation (including improved sectoral energy performance, measurable progress towards energy neutrality and reduced greenhouse-gas emissions); (II) circular-economy objectives (including improved sludge management and environmentally safe resource recovery, e.g., nutrients), • Protection of human health and ecosystems.
Uneven governance and information management across Member States	• Persistent compliance gaps and delays linked to governance arrangements, administrative capacity and investment prioritisation • Outdated and divergent reporting and public-information practices that do not fully exploit digitalisation reduce comparability and can limit transparency for the public and regulators.

it also introduces requirements for regular surveillance of selected public health parameters in urban wastewater. Finally, the recast addresses the growing policy concern regarding micropollutants by introducing quaternary treatment and associated monitoring obligations.

This article provides a narrative policy analysis of the recast UWWTD (Directive (EU) 2024/3019) and discusses its implications for Baltic Sea protection, with particular attention to implementation drivers and constraints in Poland, including cost drivers, affordability and public acceptance.

2. Methods

The paper follows a narrative review and policy-analysis approach focused on EU urban wastewater regulation and its relevance for the Baltic Sea. The analysis emphasises the transition from conventional treatment and nutrient control towards advanced treatment for selected organic micropollutants, and examines implementation implications using Poland as a case study.

2.1 Policy, legal document and literature analysis

EU legal acts (Council Directive 91/271/EEC and Directive (EU) 2024/3019) and key supporting policy documents (e.g., REFIT evaluation materials, Council voting documents and statements) were reviewed to extract requirements relevant to wastewater collection, secondary/tertiary treatment, quaternary treatment, energy-neutrality objectives, circular-economy provisions and monitoring/transparent reporting obligations. To avoid terminological ambiguity, the term "micropollutant" is used here in the legal sense also introduced by Directive (EU) 2024/3019, as substances within the meaning of Regulation (EC) No 1907/2006 (European Parliament and Council, 2006), including their breakdown products, that are usually present in the aquatic environment, urban wastewater or sludge and may be hazardous even at low concentrations according to Regulation (EC) No 1272/2008 (European Parliament and Council, 2008). Microplastic, as an important wastewater-related pressure, is addressed separately under the recast UWWTD as a particulate contaminants contaminant, and the Commission is required to adopt implementing acts establishing methodologies for microplastics monitoring in urban wastewater by July 2027 (UWWTD, 2024).

Peer-reviewed literature and regional assessments were screened to support a targeted narrative evidence synthesis on Baltic Sea pressures and wastewater-derived organic micropollutants. Sources were selected for their relevance to the UWWTD scope, the Baltic Sea catchment and the interpretation of quaternary-treatment requirements. The purpose of this screening was to identify key substance groups, occurrence evidence and treatment implications, rather than to conduct a systematic review or compile an exhaustive concentration database. National implementation progress and remaining gaps were summarised using official Polish programme reporting (NPWWTP/KPOŚK), national statistics on sewerage access, and audit findings on governance and information management. These sources were used to contextualise how new UWWTD obligations may interact with existing infrastructure deficits and planning constraints.

2.2 Cost and affordability framing

Indicative cost ranges for quaternary treatment and financing shares under extended producer responsibility (EPR) were drawn from published EU-level cost models and impact assessments. Affordability and social-acceptance considerations were informed by comparative analyses of water affordability and OECD evidence on the distributional and social consequences of water and sanitation tariffs. Findings from the above strands were integrated through qualitative content analysis to identify recurring implementation themes (cost drivers, risk-based prioritisation, monitoring and transparency, and public acceptance) and to formulate implications for implementation planning in Poland and the wider Baltic Sea region.

3. Result and discussion

3.1 Key operational requirements of the recast UWWTD relevant to the Baltic Sea

The recast UWWTD expands regulatory coverage by lowering the agglomeration threshold from $> 2{,}000$ population equivalents (p.e.) to $> 1{,}000$ p.e. and by strengthening environmental performance requirements. Compared with the 1991 framework, it also strengthens and systematises tertiary (nutrient) treatment by (i) requiring tertiary treatment at urban wastewater treatment plants (WWTPs) $\geq 150{,}000$ p.e. under a phased compliance schedule (30% by 2033; 70% by 2036; 100% by 2039) and (ii) extending tertiary-treatment obligations to WWTPs $\geq 10{,}000$ p.e. in areas affected by, or at risk of, eutrophication, with full coverage by 2045 (with intermediate milestones) (Table 2). In addition, the directive sets explicit effluent limit values for total nitrogen (TN) and total phosphorus (TP), with stricter standards for larger plants (e.g., TN 8 mg/L and TP 0.5 mg/L for WWTPs $\geq 150{,}000$ p.e.; TN 10 mg/L and TP 0.7 mg/L for WWTPs between 10,000 and 149,999 p.e.).

The most novel operational requirement in the recast UWWTD is the formal introduction of 'quaternary treatment', aimed at removing a broad spectrum of micropollutants. For WWTPs $\geq 150{,}000$ p.e., quaternary treatment is mandatory under a progressive rollout: 20% of discharges by 2033, 60% by 2039, and 100% by 2045. In addition, for agglomerations between 10,000 and 150,000 p.e., quaternary treatment is required where discharges of micropollutants represent a risk to the environment or human health. By 31 December 2030, Member States must establish a list of such areas, taking into account criteria related, inter

Table 2. Key requirements of the Urban Waste Water Treatment Directive (1991) and the 2024 recast relevant to the Baltic Sea.

Regulatory element	UWWTD 91/271/EEC baseline	Recast UWWTD 2024/3019	Relevance for the Baltic Sea (nutrients/micropollutants)
Wastewater collection	Requirements applied to agglomerations of 2,000 p.e.	Extends the regulatory scope down to agglomerations of 1,000 p.e., with a phased timetable for collection and secondary treatment obligations (including 1,000–2,000 p.e. discharges from 2035)	Improves coverage in smaller settlements in the Baltic catchment; potential to reduce uncontrolled discharges and supports consistent compliance, including in fast-growing coastal towns
Sensitive areas	Member States identified 'sensitive areas' and applied more stringent treatment where relevant.	Requires an updated national listing approach, linked to EU water and marine frameworks	Supports harmonised identification of eutrophication-relevant receiving waters in a shared sea basin.
Tertiary treatment	More stringent (nutrient) treatment required for discharges into sensitive areas, depending on size thresholds	Systematises nutrient removal: mandatory and tighter removal requirements for the largest plants (≥ 150,000 p.e.) and for ≥ 10,000 p.e. where eutrophication risk is identified	Targets controllable point-source N and P loads; supports meeting HELCOM/ BSAP reduction targets in point-source segments
Quaternary treatment	No formal quaternary-treatment requirements in the 1991 framework	Introduces quaternary treatment targeting organic micropollutants; mandatory for UWWTPs ≥ 150,000 p.e. and according to risk-based assessment for WWTP from 10,000 to 150,000 p.e.	Limiting chemical pressures in bathing waters, estuaries and coastal zones where dilution is low or ecological/social value is high; addressing micropollutants not captured by conventional treatment.
Extended Producer Responsibility (EPR)	Not applicable	Applies EPR for pharmaceuticals and cosmetics sector, requiring to cover min. 80% share of eligible costs for quaternary treatment and associated monitoring	Improves implementation feasibility for advanced treatment and reduces cost pressure on utilities and consumers
Energy neutrality/ GHG emissions	No explicit energy-neutrality target; energy performance not a core compliance element	Introduces an energy-neutrality objective (by 2045 for WWTPs ≥ 10,000 p.e.) and periodic energy audits; links wastewater management to decarbonisation and the Green Deal	Relevant for climate mitigation and long-term operational resilience of WWTPs in the Baltic Sea catchment (including coastal tourism areas).

alia, to drinking-water abstraction catchments, bathing waters, aquaculture areas, rivers and streams with a dilution ratio below 10, coastal and transitional waters, lakes, and certain protected or regulated areas (e.g., Natura 2000 sites). According to Annex I, Part B, Table 3 of recast Directive (EU) 2024/3019 the performance of quaternary treatment is assessed against a minimum average removal of 80%, calculated in relation to the influent load for selected organic indicator substances (UWWTD, 2024). The calculation must be based on at least six substances, with the number of Category 1 substances (very easily treated) being twice the number of Category 2 substances (easily disposed of). Category 1 includes amisulpride, carbamazepine, citalopram, clarithromycin, diclofenac, hydrochlorothiazide, metoprolol and venlafaxine, whereas Category 2 includes benzotriazole, candesartan, irbesartan and a mixture of 4 methylbenzotriazole and 5 methylbenzotriazole. These categories should therefore be understood as an operational indicator set for compliance assessment rather than as a hazard-based ranking or an exhaustive list of Baltic Sea micropollutants (UWWTD, 2024) (Figure 3).

Recent evidence underscores the importance of point-source emissions of micropollutants in the Baltic Sea region. Kisielius et al. (2024) analysed 35 pharmaceuticals and iodinated X-ray contrast media in effluents from 82 urban WWTPs across eight countries in the Baltic Sea catchment, including 10 plants in Poland. The results confirmed the widespread occurrence of the investigated compounds in treated wastewater. In the Polish subset, several persistent and policy-relevant compounds occurred at μg L^{-1} levels, with the highest national median concentrations reported for clarithromycin (0.17 μg L^{-1}) and carbamazepine (1.91 μg L^{-1}), thereby underlining the need for advanced micropollutant removal and the protection of sensitive receiving waters (Kisielius et al., 2024).

In addition to tightening effluent-quality requirements, Directive (EU) 2024/3019 introduces an energy neutrality objective for the urban wastewater sector (UWWTD, 2024). Under the recast, Member States must ensure, at national level, that renewable energy generated on-site or off-site by, or on behalf of, owners or operators of urban WWTPs treating ≥10,000 p.e. is equivalent to 100% of the total annual energy used by those plants by 31 December 2045. This target should be supported by four yearly energy audits that identify cost effective measures to reduce energy use and enhance energy recovery (e.g., biogas production from sewage sludge and waste heat utilisation). Advanced treatment requirements interact with this objective: quaternary processes can increase energy demand. The recast UWWTD strengthens the circular economy orientation of the sector not only through energy recovery but also through resource recovery provisions, prioritising reuse, recycling and recovery of resources, particularly phosphorus and nitrogen. Where environmentally safe and feasible, the UWWTD also promotes the reuse of treated wastewater; where reuse serves agricultural irrigation, it must comply with Regulation (EU) 2020/741.

3.1.1 Micropollutants of concern in the Baltic Sea and relevance of quaternary treatment

The relevance of quaternary treatment for the Baltic Sea is supported by regional evidence on pharmaceuticals and other wastewater-derived trace organic compounds. HELCOM/UNESCO assessments identify municipal WWTP effluents as an important pathway for pharmaceuticals in the Baltic Sea region and indicate that anti-inflammatory and analgesic medicines, cardiovascular agents and compounds affecting the central nervous system are among the most frequently reported groups (UNESCO and HELCOM, 2017). Direct seawater screening has shown that pharmaceuticals are also present in Baltic coastal and offshore waters; for example, Björlenius et al. (2018) detected 39 of 92 investigated pharmaceuticals, with carbamazepine

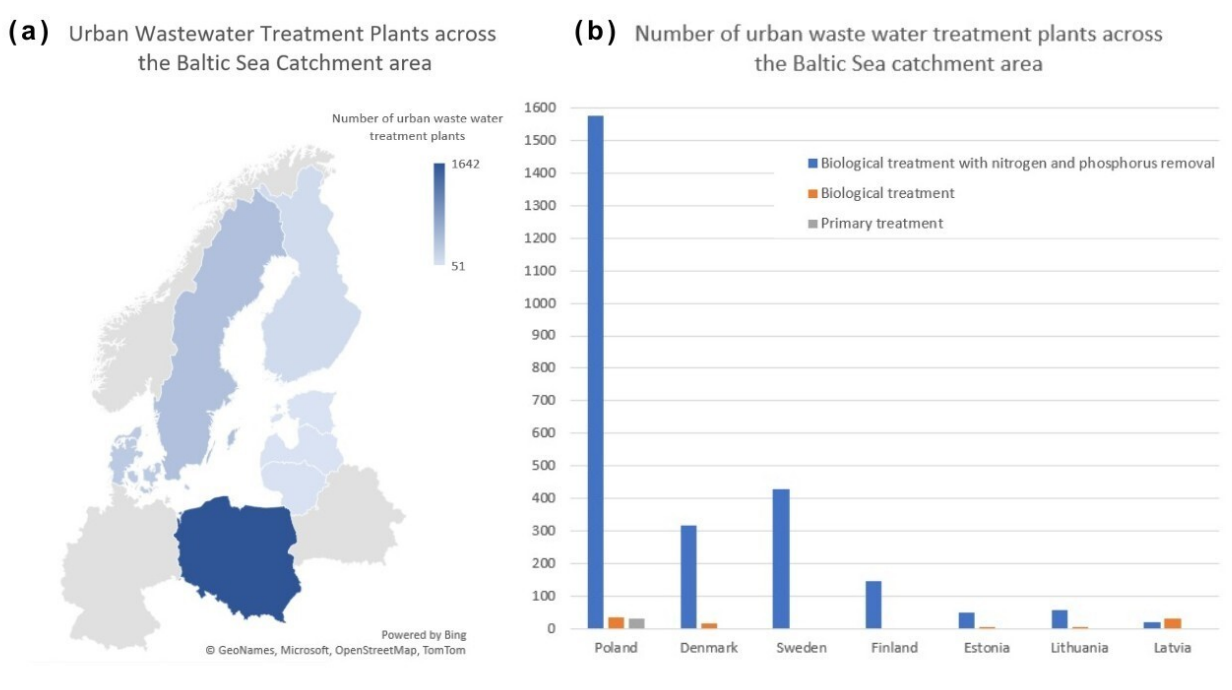

Figure 3. Number (a) and treatment-level distribution (b) of urban wastewater treatment facilities in selected Baltic Sea catchment countries; Germany is excluded because national totals are not directly comparable, as only about 8% of its territory drains to the Baltic Sea catchment (HELCOM, 2023a)

being widespread and persistent. More recently, Kisielius et al. (2024) measured 35 pharmaceuticals and iodinated X-ray contrast media in effluents from 82 WWTPs across eight Baltic Sea catchment countries, confirming the continuous discharge of wastewater-derived micropollutants from point sources. Selected micropollutants and contaminant groups relevant to Baltic Sea protection and their implications for wastewater treatment are presented in Table S1 (supplementary materials).

The substances listed in Directive (EU) 2024/3019 are therefore not an exhaustive inventory of Baltic Sea contaminants, but a compliance-oriented indicator set representing different chemical classes and treatment behaviours. Diclofenac is especially relevant because it is both a UWWTD Category 1 indicator substance and a HELCOM pre-core indicator for the Baltic Sea (HELCOM, 2023). As already mentioned, micropollutants are usually insufficiently controlled by conventional treatment. Thus, the expected benefit of the recast UWWTD is a reduction in continuous emissions from large WWTPs and risk-relevant medium-sized agglomerations, especially where discharges affect low-dilution rivers, transitional waters, coastal waters, and bathing waters. It is important to note that quaternary treatment, such as ozonation, activated carbon and membrane-based processes, can substantially reduce many micropollutants, although removal remains compound-specific, and persistent micropollutants (e.g., as mentioned in Category 2) may require combined treatment (Ek Henning, 2023; Kosek et al., 2020).

3.2 Financing and implementation incentives for quaternary treatment: Extended Producer Responsibility (EPR)

A key enabling condition for deployment of quaternary treatment under the recast UWWTD (UWWTD, 2024) is its financing architecture, which uses the polluter-pays principle through an extended producer responsibility (EPR) scheme. Quaternary treatment is intended to remove a wide range of organic micropollutants and, in practice, typically relies on advanced processes such as ozonation and/or activated carbon. In addition to significant capital expenditure, these technologies generate substantial operational costs, including higher energy consumption, additional staffing needs and intensive monitoring. Against this backdrop, Article 9 introduces EPR, shifting at least 80% of eligible costs for quaternary treatment and associated monitoring from wastewater utilities and public authorities to producers of product groups listed in Annex III (medicinal products for human use and cosmetic products). The directive also provides for exemptions under specified conditions (e.g., small quantities placed on the market, rapid biodegradability, or no generation of micropollutants at end-of-life).

A critical question is whether EPR-related costs will be absorbed by producers or ultimately passed on to consumers and healthcare systems. Stakeholders have argued that the competitiveness of EU-based producers could be affected, although the scheme applies to all products placed on the EU market, including those manufactured outside the EU. From an affordability perspective, the ability of the pharmaceutical and cosmetics sectors to absorb and manage these costs without unintended social impacts remains contested. As a context indicator, in 2022 the pharmaceutical industry generated roughly €311 billion in gross value added in the EU-27 (EFPIA/PwC, 2024). The European cosmetics and personal-care market reached around €96 billion in retail sales value in 2023 (Cosmetics Europe, 2023). By comparison, the urban wastewater sector is largely operated by small and medium-sized municipal entities; according to Eurostat, net turnover amounted to €25.2 billion in 2022 (Eurostat, 2025). These differences in sectoral scale are part of the policy rationale for limiting the direct tariff impact on wastewater users through EPR.

It should also be noted that EPR's approach, by linking financial contributions to the quantities and hazardousness of substances placed on the market, can (at least in principle) encourage substitution towards less hazardous and/or more biodegradable substances, thereby supporting pollution prevention at source. Thus, EPR can function as more than a financing instrument within the wastewater sector. By addressing the source of pollution, it may promote innovation in the pharmaceutical and cosmetic industry to minimise pollution and the costs of its control measures.

In an updated report by the European Commission's Joint Research Centre (JRC), Pistocchi (2025) notes that the Commission's impact assessment (IA) for the UWWTD recast assumed mandatory quaternary treatment for WWTPs $>$ 100,000 p.e., while for plants in the 10,000–100,000 p.e. range only where a risk-based assessment triggers the requirement. In the adopted legal text, however, quaternary treatment is mandatory for a smaller number of WWTPs ($\geq$ 150,000 p.e.). As a result, the total EU-wide cost of implementation should be lower than in the original IA-scenario (Pistocchi et al., 2019), and is in the range of roughly 1.48–1.8 billion EUR per year (at 2025 prices) for full implementation of quaternary treatment by 2045 by EU-27 (Pistocchi, 2025). Under the IA-based cost model applied to the adopted scope, the highest annual nominal costs occur in Germany (€166.7 million), Spain (€116.4 million), Italy (€115.9 million), France (€94.6 million), and Poland (€68.1 million) (Figure 4). Applying the directive's minimum EPR share of 80% implies that, in these countries, most of the incremental quaternary-treatment cost would be financed by producers rather than through water tariffs or municipal budgets. This allocation is particularly relevant for the Baltic Sea region: based on the country-level estimates, the Baltic Sea EU Member States (Denmark, Germany, Estonia, Finland, Latvia, Lithuania, Poland, Sweden) together account for roughly one-third of

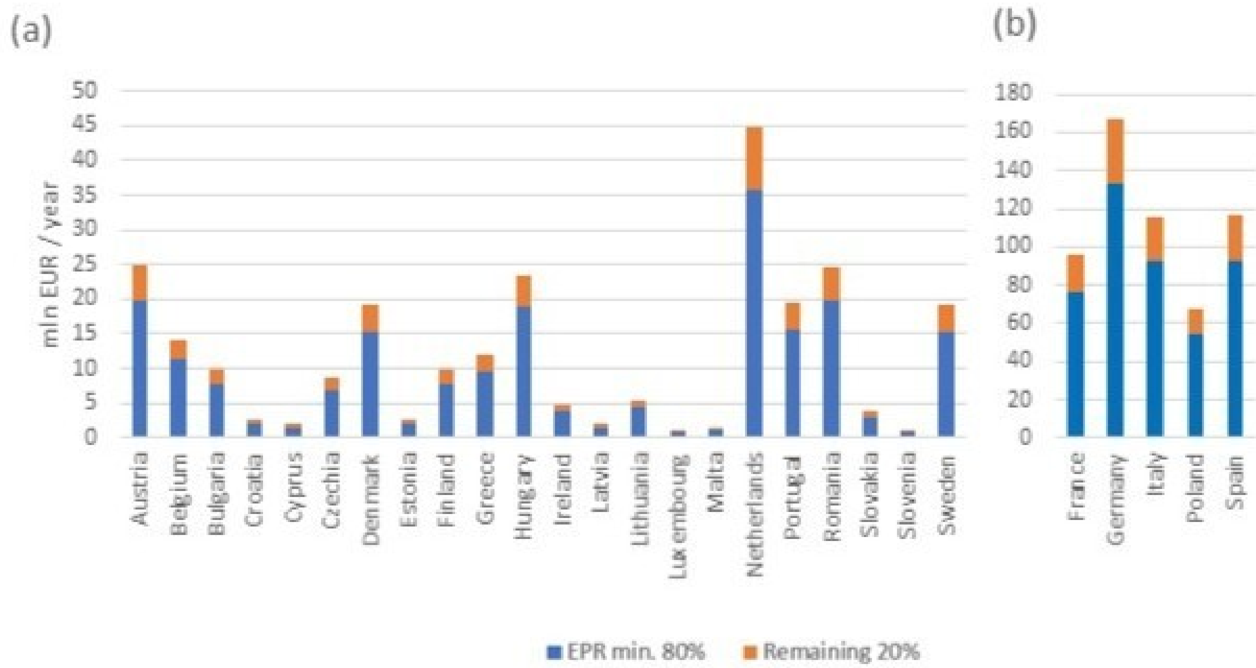

Figure 4. Estimated according to Pistocchi (2025), annual costs of quaternary treatment by EU Member State, together with indicative EPR financing shares. Member States are categorised by population size: a) < 20 million; b) ≥ 20 million. Note: Values are model-based estimates (cost-function outputs) at the Member State level, not project-specific investment budgets. EPR amounts reflect the Directive's minimum 80% producer contribution; the remaining 20% is shown illustratively as the residual share.

the EU-27 annual quaternary-treatment costs under the IA-based model.

The Directive explicitly recognises the need to consider potential national-level impacts on affordability and accessibility of products, particularly medicines. In illustrative calculations, the JRC suggests that, even under higher-cost scenarios and assuming 80% EPR coverage, the implied per-capita cost in 2045 remains on the order of a few euros per year at the EU level (Pistocchi, 2025).

3.3 Polish case study

Upon its accession to the EU in May 2004, Poland committed to aligning its urban wastewater management system with the requirements laid down in Council Directive 91/271/EEC (UWWTD, 1991). In this context, the National Programme for Municipal Wastewater Treatment (NP WWTP, 2023), adopted by the Council of Ministers on 16 December 2003, has served as Poland's strategic implementation instrument for Council Directive 91/271/EEC. The programme identifies agglomerations that must be provided with collecting systems (sewerage networks) and municipal WWTP, to ensure compliance with the Directive (UWWTD, 1991). To date, NP WWTP has been updated six times, in 2005, 2009, 2010, 2015, 2017 and 2022 (NP-WWTP, 2023).

Between 2003 and 2022, implementation of NP WWTP resulted in the construction of approximately 100,000 km of sewerage network and the completion of 480 new municipal WWTPs, with cumulative investment expenditure of approximately PLN 91 billion. In 2022 alone, total investment outlays amounted to PLN 5.2 billion (NP WWTP, 2023). At the end of 2022, the total length of the sewerage network in Poland reached approximately 177,614 km and 285 investments related to municipal WWTPs were implemented, including four newly built plants (NP WWTP, 2023).

Overall, these results indicate substantial progress in wastewater collection and treatment, including upgrades to nutrient removal in large agglomerations. However, national statistics point to disparities between urban and rural areas in access to sewerage networks and reliance on individual systems. In 2024, 77.7% of residential buildings in urban areas and 40.5% in rural areas were connected to sewerage networks (Statistics Poland, 2025a). National audit findings have also highlighted challenges in governance, investment planning and data quality, which become directly relevant as new obligations (e.g., quaternary treatment) are introduced under the recast UWWTD (Supreme Audit Office, 2022).

Poland has recognised the need to modernise the

UWWTD framework and has broadly supported the European Commission's vision for strengthening urban wastewater regulation. Nevertheless, it expressed reservations regarding the final compromise text. In a formal statement (Council of the European Union, 2024), Poland emphasised that substantial investment is still required to achieve full compliance with Directive 91/271/EEC (e.g., sewer network expansion, WWTP upgrades, monitoring of individual systems, and sludge management). Poland also noted that extending the directive's scope to smaller agglomerations (1,000–2,000 p.e.) would entail very large capital expenditure and higher operating costs, with expected pass-through to wastewater tariffs, and that the final compromise tightened requirements and shortened certain implementation timelines. It should also be noted that, in the Council vote on the adoption of the recast UWWTD (Directive (EU) 2024/3019), Poland – together with Hungary – voted against, while Estonia abstained (Council of the European Union, 2024).

Thus, acceptance of additional wastewater investment is likely to be influenced by how costs are allocated among user tariffs, public budgets, and EPR contributions, as well as by the transparency of tariff-setting and communication (OECD, 2020). A data analysis of water affordability across 23 European countries reported high affordability pressures in Poland (Martins et al., 2023). This suggests that tariff-driven cost recovery for advanced treatment, if not accompanied by compensatory social measures, could face legitimacy constraints and exacerbate the risks of water poverty (OECD, 2020).

Poland also questioned the feasibility and the 'true polluter pays' character of an EPR model that targets only two sectors, pharmaceutical and cosmetic producers, while other sources of micropollutants are not subject to EPR obligations under the recast UWWTD. On 10 March 2025, the Republic of Poland brought an action for annulment, seeking (Case C-193/25), inter alia, the annulment of the EPR provisions for micropollutants (Article 9(1) of Directive (EU) 2024/3019 in conjunction with Annex III) (European Union, 2025). The Court's eventual approach to these claims will be consequential for the legal durability and political legitimacy of EPR as the key financing mechanism intended to enable wide-scale deployment of advanced treatment across the EU.

In Poland, the total number of urban WWTPs exceeds 1,500. Of these, approximately 45 plants serve $>150{,}000$ p.e. and are therefore subject to mandatory quaternary treatment; a further ~ 500 plants fall in the 10,000–150,000 p.e. range, where quaternary-treatment obligations depend on the national risk assessment and the prioritisation of identified areas (Figure 3). Additionally, a recent regional assessment for the Mazovian Voivodeship, representing approximately 10% of municipal WWTPs in Poland, suggested that under the recast directive, nearly half of plants above 10,000 p.e. would require modernisation for improved phosphorus removal, illustrating the scale of upgrade needs beyond the largest agglomerations (Karczmarczyk et al., 2025).

A further implementation-relevant issue concerns the social acceptance of investments required under the recast UWWTP. Survey-based studies in Poland indicate that subjective assessments of tap-water quality are shaped mainly by sensory attributes (taste, odour, hardness) and seasonal variability, which can influence trust in public water services and willingness to support tariff increases (Ober et al., 2021). At the same time, reviews of pharmaceuticals and personal care products in the Polish water environment underline that such substances are not routinely monitored in a way that is visible to the public (Ślósarczyk et al., 2021).

Evidence of localised impacts downstream of WWTP outfalls can support communication efforts (Kosek et al, 2020; Kruć Fijałkowska et al., 2025), but it needs to be translated into clear messages on environmental and health relevance and on the effectiveness of implemented measures. In this context, targeted water literacy interventions could facilitate the translation of technical measures into measurable ecosystem and societal benefits, as public awareness of the presence of emerging micropollutants in water remains limited and uneven across the Polish population (Oleksiuk et al. 2022).

A pragmatic implication for implementation planning is that technical compliance pathways should be complemented by a communication and engagement strategy, including transparent reporting on micropollutant monitoring, a clear explanation of cost drivers and financing (including EPR), and explicit social safeguards for vulnerable users where tariffs are affected.

4. Conclusion

Since the introduction of the activated sludge concept in the early twentieth century (Ardern and Lockett, 1915), municipal wastewater treatment has evolved from a primarily sanitary intervention into one of the most consequential technological pillars of freshwater and coastal-water protection (Figure 1). Over subsequent decades, the technology of activated sludge was repeatedly modified and intensified to address eutrophication drivers in advanced biological nutrient removal configurations. In the Baltic Sea context, these upgrades have been essential for reducing point-source nitrogen and phosphorus loads and supporting regional commitments under HELCOM and the Baltic Sea Action Plan.

The recast UWWTD (Directive (EU) 2024/3019) provides a coherent regulatory architecture that can strengthen the Baltic Sea protection agenda by tightening nutrient controls, addressing wet-weather pollution pathways and reducing emissions of selected micropollutants. The potential environmental benefits are substantial, but implementation will depend on credible risk-based prioritisation, feasible financing mechanisms, and integration of energy and climate objectives with advanced treatment upgrades. Continued alignment with HELCOM measures and basin-wide cooperation will be essential (HELCOM, 2021).

Principally, the Council Directive 91/271/EEC (UWWTD, 1991) can be interpreted as the EU's policy mechanism that translated the activated-sludge paradigm into enforceable, basin-scale infrastructure outcomes. By requiring the collection and treatment of urban wastewater and strengthening nutrient controls in relevant receiving waters, the urban WWTPD drove large-scale investments that substantially reduced emissions of organic matter and nutrients from point sources. These measures contributed to improvements in aquatic environmental quality, including microbiological conditions relevant to bathing waters, and supported progress towards nutrient-reduction targets in the Baltic Sea catchment.

However, the current phase of water resources protection is increasingly defined by micropollutants and other contaminants of emerging concern, whose fate and transport are not adequately controlled by conventional WWTPs. While activated sludge can partially remove some micropollutants via biodegradation and sorption to sludge, performance is compound-specific, variable, and often insufficient to prevent continuous low-level emissions to receiving waters. Consequently, activated sludge can no longer be considered a standalone protective barrier for sensitive coastal ecosystems where dilution is limited and cumulative exposure matters. This, and other EU ambitions of zero waste and circular economy, constitute a key rationale for policy and technological change in the wastewater sector.

The recast WWTPD (Directive (EU) 2024/3019) responds to these goals by expanding regulatory coverage to resource recovery, by introducing quaternary treatment as a dedicated micropollutant-mitigation strategy, and by aligning urban wastewater surveillance aligned with a One Health perspective. Collectively, these provisions signal a structural transition: from "wastewater treatment as end-of-pipe compliance" toward "wastewater management as integrated environmental and public-health infrastructure". In addition, by adopting extended producer responsibility (EPR) as an upstream prevention lever, the recast UWWTD is expected to reduce micropollutant emissions at their sources.

Notwithstanding its strategic logic, implementation of the recast directive will face substantial challenges. The quaternary treatment entails high capital expenditure, additional operational costs, increased energy demand, and cost-intensive monitoring.

The effectiveness and societal acceptance of EPR will depend on durable legal design, administrative feasibility, and the management of affordability concerns, especially for medicinal products. Additionally, the ongoing legal and political debates on the EPR model, which targets only two sectors, pharmaceutical and cosmetic producers (including Polish action for annulment of Article 9(1) of Directive (EU) 2024/3019, may further influence implementation stability.

The recast UWWTD offers a coherent policy architecture, and its implementation supports the HELCOM Baltic Sea Action Plan. However, in the Baltic Sea basin, progress on wastewater-related pressures must remain coordinated with broader catchment measures, as diffuse nutrient inputs and emissions from other sectors continue to shape ecosystem outcomes.

Acknowledgements

This work was partly presented at the Baltic Sea Science Congress 2025 and supported by the APRIORA project, funded under the INTERREG Baltic Sea Region Programme 2021–2027. The authors would like to thank Ewa Kotlarska for providing the photograph of the Baltic Sea.

Supplementary material

Supplementary material associated with this article can be found here.

Conflict of interest

None declared.

References

Ardern, E., Lockett, W.T., 1915. *Experiments on the oxidation of sewage without the aid of filters*. J. Soc. Chem. Industry 34, 523–539.

Björlenius, B., Ripszám, M., Haglund, P., Lindberg, R.H., Tysklind, M., Fick, J. 2018. *Pharmaceutical residues are widespread in Baltic Sea coastal and offshore waters – Screening for pharmaceuticals and modelling of environmental concentrations of carbamazepine*. Sci. Total Environ. 633, 1496–1509. https://doi.org/10.1016/j.scitotenv.2018.03.276

Cosmetics Europe, 2023. *Market Performance 2023 European Cosmetic*, Toiletry & Perfumery Data, 34 pp. https://psvak.gr/wp-content/uploads/2024/06/CE_Market_Performance_2023.pdf

Council of the European Union, 2024. *Voting result – Directive of The European Parliament and of the Council concerning urban wastewater treatment (recast)*. Adoption of the legislative act 4055th meeting of the Council of the European Union (Economic and Financial Affairs) 5 November 2024, Brussels. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=consil:ST_15226_2024_INIT

EFPIA/PwC, 2024, *European Federation of Pharmaceutical Industries and Associations (EFPIA) Economic footprint* *of the pharmaceutical industry in Europe*, PWC, 143 pp. https://www.vaccineseurope.eu/wp-content/uploads/2024/11/economic-footprint-of-the-pharmaceutical-industry-in-europe-slides.pdf

Elmgren, R., Blenckner, T., Andersson, A., 2015. *Baltic Sea management: Successes and failures*. Ambio 44, 335–344. https://doi.org/10.1007/s13280-015-0653-9

European Commission, 2019. *Commission Staff Working Document: Executive Summary of the evaluation of the Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment*. SWD(2019) 701 final. European Commission, Brussels. https://commission.europa.eu/system/files/2020-04/swd_2019_0701_en.pdf

European Commission, 2025. *European bathing water quality in 2024: 85% of Europe's bathing waters are rated excellent* (news release, 20 June 2025), European Commission. https://www.eea.europa.eu/en/analysis/publications/european-bathing-water-quality-in-2024

European Commission, 2025b. *The EU Blue Economy Report*. Coastal tourism. Directorate-General for Maritime Affairs and Fisheries, European Commission. https://op.europa.eu/webpub/mare/eu-blue-economy-report-2025/blue-economic-sectors/coastal-tourism.html (accessed 4 June 2026).

European Parliament and Council, 2006. *Regulation (EC) No 1907/2006* of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency. OJ L 396, 30.12.2006, 1–849.

European Parliament and Council, 2008. *Regulation (EC) No 1272/2008* of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006. OJ L 353, 31.12.2008, 1–1355.

European Union, 2025. *Case C-193/25: Action brought on 10 March 2025 – Republic of Poland v European Parliament and Council*. Official Journal of the European Union. https://eur-lex.europa.eu/eli/C/2025/2189/oj/eng

Eurostat, 2025. *Businesses in the water supply, sewerage, waste management and remediation sector*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Businesses_in_the|_water_supply,_sewerage,_waste_management_and_remediation_sector, (accessed 6 June 2026).

HELCOM, 1988. *Declaration on the Protection of the Marine Environment of the Baltic Sea Area*. Baltic Marine Environment Protection Commission (Helsinki Commission), Helsinki. https://helcom.fi/helcom-at-work/ministerial-meetings/1988-helsinki/

HELCOM, 1998. *The Third Baltic Sea Pollution Load Compilation*, Balt. Sea Environ. Proc. No. 70. https://archive.iwlearn.net/helcom.fi/stc/files/Publications/Proceedings/bsep70.pdf

HELCOM, 2007. *Baltic Sea Action Plan*. Baltic Marine Environment Protection Commission – Helsinki Commission (HELCOM), HELCOM Ministerial Meeting, Krakow, Poland, 15 November 2007, 101 pp. https://www.helcom.fi/wp-content/uploads/2019/08/BSAP_Final.pdf

HELCOM, 2007b. *Towards a Baltic Sea Unaffected by Eutrophication*. HELCOM Overview 2007, background document for the HELCOM Ministerial Meeting, Krakow, Poland, 15 November 2007, 35 pp. https://archive.iwlearn.net/helcom.fi/stc/files/Krakow2007/Eutrophication_MM2007.pdf

HELCOM, 2013. *Summary report on the development of revised Maximum Allowable Inputs (MAI) and updated Country Allocated Reduction Targets (CART) of the Baltic Sea Action Plan*. Baltic Marine Environment Protection Commission – Helsinki Commission (HELCOM), Helsinki. helcom.fi/wp-content/uploads/2019/08/Summary-report-on-MAI-CART-1.pdf

HELCOM, 2021. *Baltic Sea Action Plan: 2021 update. Helsinki Commission*. https://helcom.fi/wp-content/uploads/2021/10/Baltic-Sea-Action-Plan-2021-update.pdf

HELCOM, 2023. *Diclofenac. HELCOM pre-core indicator report*. Baltic Marine Environment Protection Commission – Helsinki Commission.

HELCOM, 2023a. *Wastewater treatment*. HELCOM driver indicator report. Baltic Marine Environment Protection Commission – Helsinki Commission, Helsinki. https://indicators.helcom.fi/indicator/wastewater-treatment/ (accessed 4 June 2026).

HELCOM, 2023b. *Nutrient Input Ceiling (NIC) assessment 1995–2020 – Technical report*. Baltic Marine Environment Protection Commission – Helsinki Commission, Helsinki. https://helcom.fi/wp-content/uploads/2023/12/Nutrient-Input-Ceilings-assessment-1995-2020-technical-report.pdf

HELCOM, 2024. Lars M. Svendsen Bo Gustafsson, 2024. *Waterborne nitrogen and phosphorus inputs and water flow to the Baltic Sea 1995–2022*. Baltic Sea Environment Fact Sheet (BSEFS). Baltic Marine Environment Protection Commission – Helsinki Commission. https://helcom.fi/wp-content/uploads/2024/10/BSEFS-on-Waterborne-nitrogen-and-phosphorus-inputs-and-water-flow-to-the-Baltic-Sea-1995-2022.pdf

Helsinki Convention, 1974. *Convention on the Protection of the Marine Environment of the Baltic Sea Area*. Signed at Helsinki, 22 March 1974. https://helcom.fi/wp-content/uploads/2019/10/1974_Convention.pdf

Helsinki Convention, 1992. *Convention on the Protection of the Marine Environment of the Baltic Sea Area*, Helsinki Commission, Helsinki. https://helcom.fi/wp-content/uploads/2019/06/Helsinki-Convention_July-2014.pdf

Karczmarczyk, A., Bus, A., Kaczor, G., 2025. *Adapting wastewater infrastructure to the new EU directive: Modernization challenges and environmental benefits – Masovian Voivodship case study*. Desalin. Water Treat. 323, 101286. https://doi.org/10.1016/j.dwt.2025.101286

Kisielius, V., Äystö, L., Lehtinen, T., Kharel, S., Stapf, M., Zhiteneva, V., Perkola, N., Bester, K., 2024. *Pharmaceutical residues in effluents from wastewater treatment plants in the Baltic Sea catchment*. J. Hazard. Mater. 476, 134998. https://doi.org/10.1016/j.jhazmat.2024.134998

Kosek K., Luczkiewicz A., Fudala-Książek S., Jankowska K., Szopińska M., Svahn O., Tränckner J., Kaiser A., Langas V., Björklund E., 2020. *Implementation of advanced micropollutants removal technologies in wastewater treatment plants (WWTPs) – Examples and challenges based on selected EU countries*, Environ. Sci. Policy 112, 213–226, https://doi.org/10.1016/j.envsci.2020.06.011

Kruć-Fijałkowska, R., et AL., 2025. *Occurrence and temporal changes of pharmaceuticals in the Warta River in Poland during and after the COVID-19 pandemic*. Sci. Rep. 15, 29451. https://doi.org/10.1038/s41598-025-14568-x

Martins, R., Quintal, C., Teotónio, C., Antunes, M., 2023. *Water affordability across and within European countries: a microdata analysis*. Utilit. Policy 83, 101609. https://doi.org/10.1016/j.jup.2023.101609

NP-WWTP, 2023. *State Water Holding Polish Waters (referred to Państwowe Gospodarstwo Wodne Wody Polskie)*. Report on the Implementation of the National Urban Wastewater Treatment Programme in 2022, Warsaw, June 2023. https://www.gov.pl/attachment/e9835dcb-18fc-4d7d-8fa9-d538f2185b51 (last access: 2026-01-03).

Ober, J., Karwot J., 2021. *Tap water quality: seasonal user surveys in Poland*. Energies 14(13), 3841. https://doi.org/10.3390/en14133841

OECD, 2020. *Addressing the social consequences of tariffs for water supply and sanitation*. OECD Environment Working Papers No. 166. OECD Publishing, Paris. https://doi.org/110.1787/afede7d6-en

Oleksiuk, K., Krupa-Kotara, K., Wypych-Ślusarska, A., Głogowska-Ligus, J., Spychała, A., Słowiński, J., 2022. *Microplastic in Food and Water: Current Knowledge and Awareness of Consumers*. Nutrients 14 (22), 4857. https://doi.org/10.3390/nu14224857

Pistocchi, A., 2025. *Updated estimation of the costs of quaternary wastewater treatment in the EU – A comparison of cost models*, JRC144745. Publ. Office EU, Luxembourg, https://doi.org/10.2760/6476421 https://data.europa.eu/

Pistocchi, A., Dorati, C., Grizzetti, B., Udias, A., Vigiak, O., Zanni, M., 2019. *Water quality in Europe: effects of the Urban Wastewater Treatment Directive*. Retrospective and scenario analysis of Dir. 91/271/EEC, EUR 30003 EN, JRC115607. Publ. Office EU, Luxembourg, https://doi.org/110.2760/303163

Skowrońska, K., Chrzanowski, W., Namieśnik, J., 2009. *Identification of Chemical Pollution Problems and Causes in the Baltic Sea in Relation to Socio-Economic Drivers*. Polish J. Environ. Stud. 18(4), 701–709.

Statistics Poland, 2025. *Poland in figures 2024*. Statistics Poland, Warsaw.

Statistics Poland, 2025a. *Municipal infrastructure – water supply and sewage system in 2024*. Statistics Poland, Warsaw.

Supreme Audit Office, 2022. *Collection and Treatment of Municipal Wastewater*, (audit report). Supreme Audit Office, Warsaw (in Polsh; Najwyższa Izba Kontroli (NIK), Zbieranie i oczyszczanie ścieków komunalnych (audit report). Najwyższa Izba Kontroli, Warsaw.

Ślósarczyk, K., Jakóbczyk-Karpierz, S., Różkowski, J., Witkowski, A.J., 2021. *Occurrence of Pharmaceuticals and Personal Care Products in the Water Environment of Poland: A Review*, Water 13 (16), 2283. https://doi.org/10.3390/w13162283

UNESCO and HELCOM, 2017. *Pharmaceuticals in the aquatic environment of the Baltic Sea region – A status report*. UNESCO Emerging Pollutants in Water Series – No. 1. UNESCO Publ., Paris.

UWWTD, 1991. *Council Directive 91/271/EEC of 21 May 1991 concerning urban wastewater treatment*. Council of the European Communities. https://eur-lex.europa.eu/eli/dir/1991/271/oj/eng

UWWTD, 2024. *Directive (EU) 2024/3019 of the European Parliament and of the Council of 27 November 2024 concerning urban wastewater treatment (recast)*. European Parliament and Council. https://eur-lex.europa.eu/eli/dir/2024/3019/oj/eng

Zalewska, T., Iwaniak, M., Kowalska, B., Marosz, M., Marciniewicz-Mykieta, M., 2025. *Dopływ biogenów do Bałtyku – trendy i wyzwania*. [In:] Magnuszewski, A. (Ed.), *Ekologiczne zagadnienia gospodarki wodnej w Polsce*. Monografie Komitetu Nauk o Wodzie i Gospodarki Wodnej Polskiej Akademii Nauk, Zeszyt 47, Warszawa, 35–70.

https://publikacje.pan.pl/chapter/138513/ekologiczne-zagadnienia-gospodarki-wodnej-w-polsce-br