Removal of antibiotic resistances from hospital effluents

Policy brief - From Monitoring to Action: Tackling Antimicrobial Resistance in Hospital Wastewater

Blanca Perdigones

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Abstract

The intensive use of antimicrobial drugs in clinical environments contributes to the global antimicrobial resistance (AMR) challenge. Hospital wastewater represents an important point source of pharmaceutical residues, antibiotic-resistant bacteria (ARB) and antibiotic resistance genes (ARGs), which can enter municipal sewerage systems and potentially reach receiving waters. Conventional wastewater treatment plants are not specifically designed to ensure the complete removal of these contaminants, highlighting the potential value of complementary control-at-source strategies.

The LIFE GENESYS project, co-funded by the European Union under the LIFE Programme, is implementing and demonstrating a decentralised hospital wastewater treatment solution at Parc Taulí University Hospital in Sabadell, Spain. The system combines a membrane bioreactor (MBR) with UV-LED/H_2O_2 advanced oxidation and a Clinical-Environmental Decision Support System (CDSS). The digital platform aims to integrate hospital activity, pharmaceutical consumption, wastewater monitoring and AMR indicators to support pharmaceutical load prediction, treatment optimisation and antimicrobial stewardship.

This policy brief examines the opportunities and challenges associated with hospital wastewater management in the context of the recast Urban Wastewater Treatment Directive (Directive (EU) 2024/3019), Directive (EU) 2026/805 and Spain's proposed HEBAR (from Spanish *Herramienta Basada en la vigilancia de las Aguas Residuales*) wastewater surveillance framework. It presents policy recommendations focused on harmonising AMR monitoring methodologies, promoting targeted control at source, strengthening One Health surveillance integration and facilitating implementation through appropriate financing and cooperation mechanisms.

As part of the preparation of this policy brief, stakeholder interviews were conducted within LIFE GENESYS, involving professionals from public authorities, wastewater utilities, healthcare institutions and clinical and environmental research organisations. The insights presented reflect the individual professional perspectives of those consulted and should not be interpreted as official positions or endorsements by their respective organisations.

Glossary of Acronyms

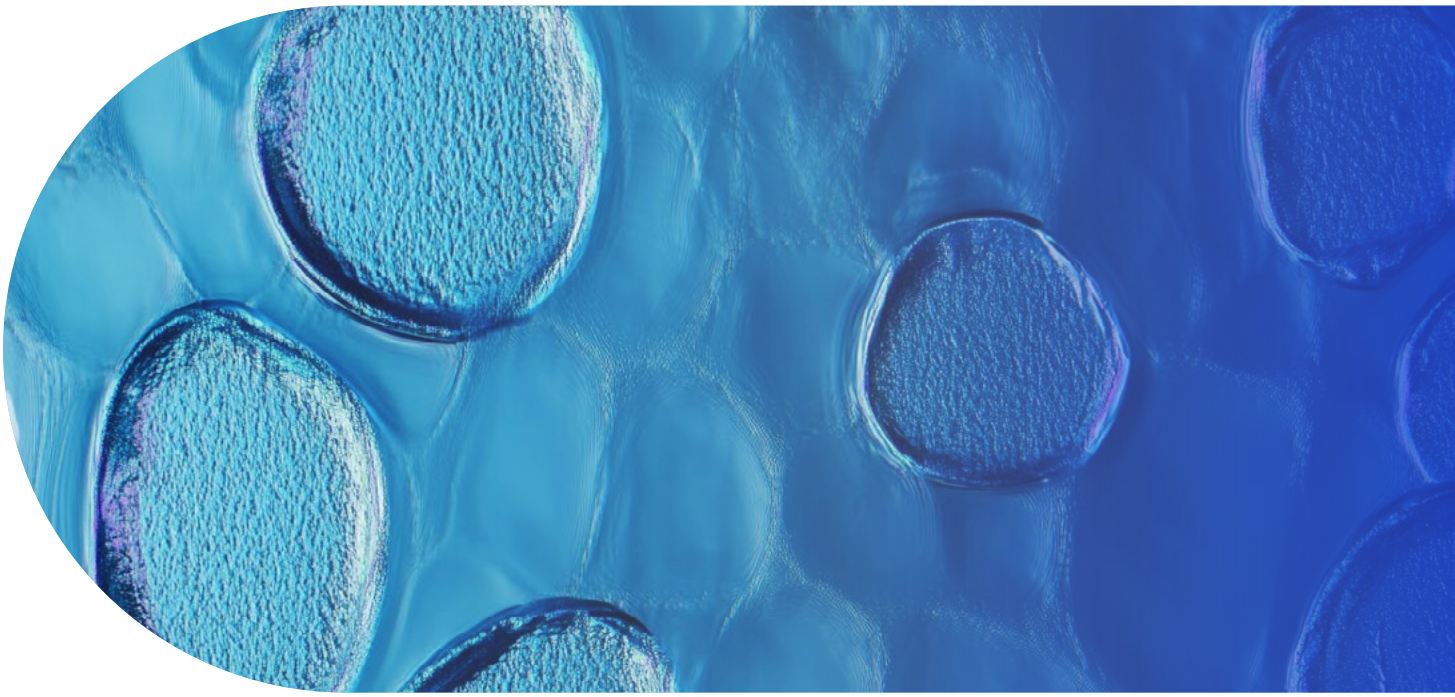
AEMPS	Spanish Agency for Medicines and Health Products
AMR	Antimicrobial Resistance
AOP	Advanced Oxidation Process
ARBs	Antibiotic-Resistant Bacteria
ARGs	Antibiotic Resistance Genes
AWaRe	Access, Watch, Reserve
CDSS	Clinical-Environmental Decision Support System
PPI	Public Procurement of Innovation
DDD	Defined Daily Dose
ECDC	European Centre for Disease Prevention and Control
ECHA	European Chemicals Agency
EPR	Extended Producer Responsibility
HEBAR	Wastewater-based environmental epidemiological tool (from Spanish *Herramienta Epidemiológica ambiental Basada en el control de las Aguas Residuales*)
HGT	Horizontal Gene Transfer
HPCIAs	Highest Priority Critically Important Antimicrobials
JRC	Joint Research Centre
MBR	Membrane Bioreactor
MITECO	Ministry for the Ecological Transition and Demographic Challenge
OMC	Open Market Consultation
PCP	Pre-Commercial Procurement
PNEC	Predicted No-Effect Concentration
PPP	Purchasing Power Parity
PRAN	National Plan against Antibiotic Resistance
PRAN-MA	National Plan against Antibiotic Resistance - Environmental Working Group
PROA	Antibiotic use optimisation programs (from Spanish Programa de Optimización del Uso de los Antibióticos)
qPCR	Quantitative Polymerase Chain Reaction
TRL	Technology Readiness Level
UWWTD	Urban Wastewater Treatment Directive
WWTP	Wastewater Treatment Plant

Antimicrobial resistance and the One Health paradigm

The World Health Organization (WHO) has identified antimicrobial resistance (AMR) as one of the major global public health threats [1]. The global epidemiological burden is already substantial: a comprehensive systematic analysis published in *The Lancet* estimated that 1.14 million deaths were directly attributable to bacterial AMR worldwide in 2021 [2]. Looking ahead, according to the same analysis, bacterial AMR is projected to be directly attributable to approximately 1.91 million deaths globally in 2050, with 8.22 million deaths indirectly associated with bacterial AMR [2]. AMR also imposes a considerable economic burden: across 34 OECD and EU/EEA countries, resistant infections are estimated to generate up to USD 28.9 billion annually in additional healthcare expenditure and USD 36.9 billion annually in labour-market output losses up to 2050 [3].

Historically, antimicrobial stewardship has been confined within strict clinical and veterinary boundaries, focused almost exclusively on the prudent prescription of drugs in hospitals and farms. However, the international scientific consensus has transitioned toward a "One Health" approach [4]. This framework establishes that the health of humans, animals, and ecosystems is fundamentally interconnected and cannot be managed in isolation[4]. Under this holistic paradigm, the environmental vector, specifically the aquatic environment, is increasingly recognised as an important pathway for the dissemination, persistence and potential selection of antimicrobial resistance determinants. Municipal wastewater systems, which aggregate waste from both community and clinical sources, act as major conduits where active pharmaceutical ingredients, resistant pathogens, and genetic elements mix, facilitating the persistence and dissemination of antimicrobial-resistant bacteria and resistance genes that can eventually reinfect human populations through water resources [5,6].

Although environmental AMR involves multiple interconnected sources and transmission pathways, identifiable point sources offer opportunities for targeted interventions. Hospital wastewater represents an important point source of clinically relevant antimicrobial residues, resistant bacteria and resistance genes [7,8]. Intercepting these contaminants at the hospital boundary is therefore being investigated as a potential control-at-source strategy to reduce their transfer into municipal sewer networks.



The evolving European and national regulatory frameworks

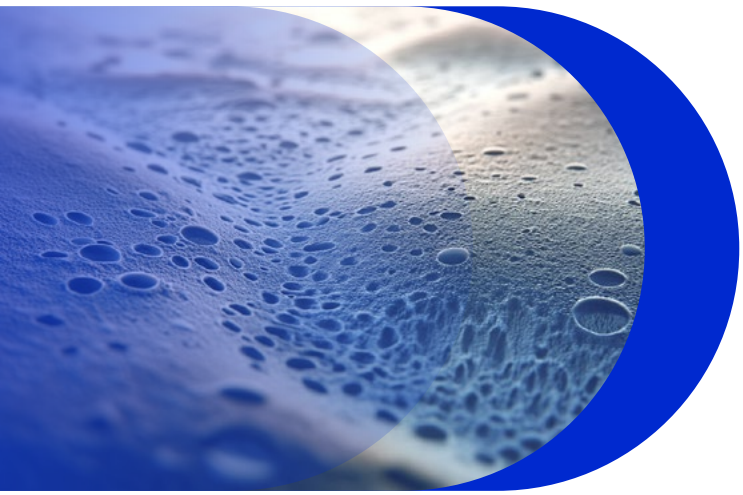
The regulatory architecture governing European water quality, sanitation, and public health is undergoing a profound transformation. A sequence of newly adopted and draft directives are creating an increasingly stringent regulatory framework that mandates the joint monitoring and control of antimicrobial determinants in the urban water cycle.

The recast Urban Wastewater Treatment Directive (Directive (EU) 2024/3019)

Adopted on 27 November 2024, the recast Urban Wastewater Treatment Directive (UWWTD) fundamentally redefines the mandate of public sanitation systems by directly linking wastewater treatment with public health protection and circular economy objectives [9]. The directive introduces several significant regulatory provisions:

Mandatory quaternary treatment (Article 8 & Annex III)

The recast UWWTD requires the progressive implementation of quaternary treatment to remove a broad spectrum of micropollutants. For urban wastewater treatment plants treating a load of 150,000 population equivalents (p.e.) and above, quaternary treatment will become mandatory progressively, covering 20% of plants by 2033, 60% by 2039 and all such plants by 2045. For agglomerations of 10,000 p.e. and above, quaternary treatment will also be progressively required where discharges enter areas identified by Member States as being at risk from micropollutant pollution in accordance with Article 8(2), reaching full coverage of the relevant agglomerations by 2045.



Extended Producer Responsibility (EPR / Article 9)

By 31 December 2028, EU Member States must establish extended producer responsibility schemes for producers of medicinal products for human use and cosmetic products. Under these schemes, producers must collectively cover at least 80% of the relevant costs of quaternary urban wastewater treatment to remove micropollutants associated with their products, including investment, operation and micropollutant monitoring costs. However, the EPR provisions are currently subject to legal challenge before the Court of Justice of the European Union, creating uncertainty regarding their future implementation [10].

Antimicrobial resistance surveillance (Article 17)

The recast UWWTD requires EU Member States to monitor antimicrobial resistance (AMR) in urban wastewater from agglomerations of 100,000 p.e. and above. The European Commission was required to establish a harmonised monitoring methodology and minimum sampling frequency by 2 July 2026. As of September 2026, these requirements had not yet been adopted, leaving the specific analytical methods, indicators and sampling frequencies to be defined. Member States must implement AMR monitoring within two years of the entry into force of the corresponding implementing act.

The Water Framework and Groundwater Directives Amendment (Directive (EU) 2026/805)

Adopted on 30 March 2026, Directive (EU) 2026/805 introduces a major update to the EU water-quality framework by amending the Water Framework Directive, the Groundwater Directive and the Environmental Quality Standards Directive. Its provisions strengthen the monitoring and control of chemical and emerging pollution across surface waters—including rivers, lakes, transitional and coastal waters—and groundwater [11]. Within this broader framework, the Directive explicitly recognises 'microorganisms, genes or genetic material reflecting the presence of microorganisms resistant to antimicrobial agents' as a category of water pollutants to be considered in the protection and management of European waters.

The European Chemicals Agency (ECHA) is tasked with providing scientific support to the European Commission in selecting substances and indicators for inclusion in the relevant watch lists. The Commission shall include appropriate indicators of the presence, evolution or transmission of AMR in these watch lists and is required to identify reliable sampling and analytical methods that do not entail excessive costs by 1 December 2027. Once included, Member States will be required to monitor these indicators at representative monitoring stations over a 24-month period, generating harmonised data to support the assessment of their risks to or via the aquatic environment and inform future regulatory reviews. These provisions establish a regulatory pathway for the progressive incorporation of AMR indicators into EU water-quality monitoring.

Importantly, the scientific evidence considered by ECHA in this process may include data from research projects, scientific publications, *in situ* sensors, modelling and advanced data-analysis approaches, creating a clear pathway for applied research to inform the future development of the EU monitoring framework.

Irene Morante identified the potential contribution of LIFE GENESYS to assessing analytical reproducibility, interlaboratory comparability, sensitivity, turnaround times and costs.

Irene Morante Sánchez

Head of the Sanitation and Wastewater Treatment Area at the Spanish Ministry for the Ecological Transition and Demographic Challenge (MITECO)

Ricardo Carapeto

Coordinator of the National Plan against Antibiotic Resistance - Environmental Working Group (PRAN-MA) at AEMPS, co-opted (environment) member of the Committee of Veterinary Medicinal Products at EMA and member of the EMA Environmental Risk Assessment Working Party (ERAWP)

Ricardo Parapeto emphasised the importance of research findings, including those that challenge initial hypotheses, in informing public health and regulatory decisions and identifying appropriate, cost-effective surveillance approaches.

The Spanish Sanitary Surveillance System for Urban Wastewater (Public Consultation on a Draft Royal Decree, July 2026)

In alignment with the requirements of Directive (EU) 2024/3019, the Spanish Ministry of Health launched a public consultation in July 2026 (concluding on 16 July 2026) on a new Royal Decree aimed at establishing a national sanitary-environmental surveillance system based on urban wastewater monitoring [12]. The proposed regulation includes the creation of the HEBAR platform (from Spanish *Herramienta Epidemiológica ambiental Basada en el control de las Aguas Residuales*, wastewater-based environmental epidemiological tool).

HEBAR is envisaged as a web-based information system collecting data on biological, chemical and physical environmental agents in wastewater that may affect human health, together with information on urban wastewater collection and treatment systems and their monitoring. The wastewater surveillance system is intended to complement and support public health and clinical surveillance and to function as an early-warning tool for the emergence or re-emergence of diseases. In accordance with Directive (EU) 2024/3019, surveillance may encompass relevant public-health parameters such as SARS-CoV-2 and its variants, poliovirus, influenza virus, emerging pathogens and antimicrobial resistance. The location and frequency of sampling are to be determined according to public-health information needs and, where relevant, local epidemiological conditions.

Additionally, Spain's National Action Plan against Antibiotic Resistance (PRAN) 2025–2027 reinforces the One Health approach to AMR, including its environmental dimension [13]. In this context, the PRAN-MA has developed technical recommendations for the environmental surveillance of antibiotic resistance determinants, contributing to the scientific and methodological basis for AMR monitoring in Spain [14].

Irene Morante Sánchez
MITECO

Irene Morante highlighted that hospital wastewater monitoring could complement Spain's HEBAR surveillance system by providing additional information on AMR sources before they enter municipal sewerage networks. However, she stressed that any integration of hospital sampling points would need to be assessed in coordination with the Ministry of Health, which oversees HEBAR.

Hospital wastewater and the rationale for control at source

Co-funded by the EU under the LIFE Programme (Grant Agreement No. 101147763), the LIFE GENESYS project explores a decentralised strategy for removing pharmaceutical residues, ARBs, and ARGs from hospital wastewater. The initiative seeks to validate an advanced, cost-effective treatment sequence coupling membrane bioreactor (MBR) technology with UV-LED/H_2O_2 oxidation, supported by a digital tool designed to quantify AMR and pharmaceutical loads directly at source.

Understanding the fate of clinical pollutants in sewer infrastructure is crucial for establishing effective, localised mitigation strategies. By addressing pollutants directly where they are generated, healthcare facilities can significantly reduce the dissemination of resistant strains into public sanitation channels and safeguard downstream ecosystems.

The hospital sewer as an active hotspot

Hospitals represent unique hotspots where high-density antimicrobial consumption coincides with a concentrated pool of infectious pathogens [5]. Depending on the specific antibiotic, approximately 20–90% of the administered dose may be excreted through urine and faeces as unchanged compounds or metabolites, providing a direct pathway for antibiotic residues to enter hospital wastewater [15]. Consequently, hospital effluents contain complex mixtures of:

- **Antibiotic residues**

  Residues of clinically important antibiotics, including carbapenems, fluoroquinolones and third-generation cephalosporins, have been detected in hospital wastewater [15].

- **Antibiotic-resistant bacteria (ARB)**

  Clinically relevant resistant bacteria, including ESBL-producing *Enterobacterales*, carbapenem-resistant bacteria and vancomycin-resistant enterococci [7].

- **Antibiotic resistance genes (ARGs)**

  Clinically relevant resistance determinants, including carbapenemase genes such as *blaKPC* and *blaOXA-48* and plasmid-mediated quinolone resistance genes such as *qnrS* [16,17].

Sewerage networks as biological reactors

Sewer networks are not simply passive transport systems. During wastewater conveyance, microbial communities develop within biofilms on pipe surfaces and interact continuously with microorganisms and chemical residues transported in the wastewater [18]. These biofilms can accumulate antibiotic-resistant bacteria (ARB) and antibiotic resistance genes (ARGs), while increases in the relative abundance of specific ARGs have been observed along

sewer pipes [19,20]. Consequently, the AMR profile reaching the wastewater treatment plant does not necessarily represent a diluted version of that discharged at the hospital outlet. Mixing with other wastewater sources and biological processes occurring during sewer transport can modify the abundance and composition of ARB and ARGs [19]. This reinforces the value of hospital-level monitoring and control-at-source strategies as a complement to the essential role played by urban wastewater treatment plants in reducing the release of AMR determinants to the environment.

Ricardo Carapeto
AEMPS

Ricardo Parapeto noted that resistant bacteria can proliferate within sewer networks, complicating the interpretation of wastewater AMR data. He considered hospital outlets particularly valuable sampling points, as they could provide information less affected by these processes and facilitate comparisons with resistance patterns observed within healthcare facilities.

Alicia Gadea Gadea
Head of Wastewater Treatment at EMUASA

Alicia Gadea highlighted that treating AMR and emerging contaminants at source could facilitate their detection and removal before dilution in municipal sewer networks. She emphasised the need for closer cooperation between healthcare institutions and wastewater operators, including the development of appropriate discharge criteria, to reduce pollutant loads entering municipal WWTP and avoid placing the responsibility for their removal on downstream facilities.

Complementing centralised treatment with control at source

Municipal wastewater treatment plants (WWTPs) provide an essential barrier for reducing the release of organic matter, nutrients and microbial contaminants into the environment. They can also substantially reduce antibiotic-resistant bacteria (ARB) and antibiotic resistance genes (ARGs), although removal through conventional treatment varies according to the target, treatment configuration and operating conditions. Advanced treatment processes can further enhance the removal of ARB and ARGs, with the removal efficiencies achieved depending on the technology and operating conditions [21,22].

Control at source offers a complementary approach by targeting hospital wastewater before it is diluted and mixed with substantially larger municipal wastewater flows. Hospitals constitute identifiable point sources of antibiotic residues and clinically relevant resistance determinants: antibiotic concentrations in hospital wastewater can be several times higher than in municipal wastewater [23], while systematic evidence shows a higher occurrence of antibiotic resistance determinants in hospital wastewater than in community wastewater [24]. Treating this smaller, more concentrated and source-specific wastewater stream creates favourable conditions for targeted removal before these contaminants enter the wider sewer network, potentially increasing treatment efficiency and reducing the contaminant load transferred downstream. LIFE GENESYS is evaluating this control-at-source approach.

Lluís Jordan
Managing Director of Aigües Sabadell and Grup CASSA

Lluís Jordan advocated for a multi-barrier approach combining pollution prevention, targeted treatment at source and centralised municipal wastewater treatment. He stressed that decentralised solutions should complement municipal treatment and be implemented where justified by pollutant loads, environmental risks and wastewater characteristics. He also highlighted the need to assess life-cycle costs and environmental impacts when comparing treatment options.

The LIFE GENESYS integrated solution: physical treatment and digital decision support

The LIFE GENESYS pilot will be installed and operated at Parc Taulí University Hospital in Sabadell, Spain, providing a full-scale demonstration of an integrated, decentralised hospital wastewater treatment system designed to treat the hospital's entire wastewater flow (approximately 240 m^3/day).

The physical treatment train

The physical plant will treat the hospital's raw effluent directly at the boundary of the healthcare facility through a specialised, two-stage barrier process [25]:

- **Membrane Bioreactor (MBR)**

  Combines activated sludge biological treatment with hollow-fibre ultrafiltration membranes. This stage provides an effective physical barrier for the retention of suspended solids, biomass and bacteria, including antibiotic-resistant bacteria (ARB), substantially reducing their transfer into the treated effluent. The biological treatment also contributes to the removal of organic matter and certain pharmaceutical residues.

- **Advanced Oxidation Process (AOP)**

  The ultrafiltered effluent undergoes advanced oxidation using UV-LED irradiation combined with hydrogen peroxide (H_2O_2). This process generates highly reactive hydroxyl radicals (•OH), which promotes the degradation of pharmaceutical compounds, including antibiotic residues, thereby reducing the selective pressure associated with antimicrobial resistance. In addition, UV irradiation and oxidative reactions provide a complementary barrier against any antibiotic-resistant bacteria (ARB) passing through the MBR, contributing to their inactivation and potentially damaging antibiotic resistance genes (ARGs). This combined treatment aims to enhance the removal of antibiotic residues and reduce the biological risks associated with ARB and ARGs in the treated effluent.

The LIFE GENESYS full-scale demonstration will assess the treatment performance of this integrated system under real hospital wastewater conditions, with particular emphasis on the removal of antibiotic residues, antibiotic-resistant bacteria and antibiotic resistance genes. The project will also evaluate operational reliability, energy consumption and technical feasibility, generating evidence to support the potential replication of decentralised hospital wastewater treatment solutions.

The digital support platform: A dual-action decision support system

Alongside the physical wastewater treatment system, LIFE GENESYS is developing an innovative digital platform designed to connect hospital activity, pharmaceutical consumption, wastewater quality and antimicrobial resistance (AMR) monitoring. The platform functions as a Clinical-Environmental Decision Support System (CDSS), providing complementary information to support hospital antimicrobial stewardship, environmental surveillance and wastewater treatment optimisation.

The GENESYS digital tool will reach Technology Readiness Level (TRL) 8 through demonstration and validation under real operating conditions at Parc Taulí University Hospital.

Integration of clinical, environmental and analytical data

The CDSS combines several complementary data sources, collected and updated at different frequencies. The monitoring programme has been defined in collaboration with specialists from Parc Taulí University Hospital to ensure that the selected indicators and analytical methodologies address clinically and environmentally relevant priorities.

- **Clinical data (aggregated and anonymised)**

  Hospital activity indicators, including the number of hospitalised patients and pharmaceutical consumption and prescription patterns, particularly for antibiotics. These data provide information on the potential sources of pharmaceutical residues entering hospital wastewater.

- **Hydraulic and physicochemical data**

  Wastewater flow rates and relevant water-quality parameters determined by online sensors and laboratory analyses to characterise the hospital effluent and evaluate treatment performance.

- **Pharmaceutical and antibiotic analytical data**

  Targeted monitoring of pharmaceutical compounds in hospital wastewater using high-performance liquid chromatography coupled with tandem mass spectrometry (HPLC-MS/MS). Measured concentrations provide essential evidence to validate pharmaceutical load predictions and assess the effectiveness of the treatment process.

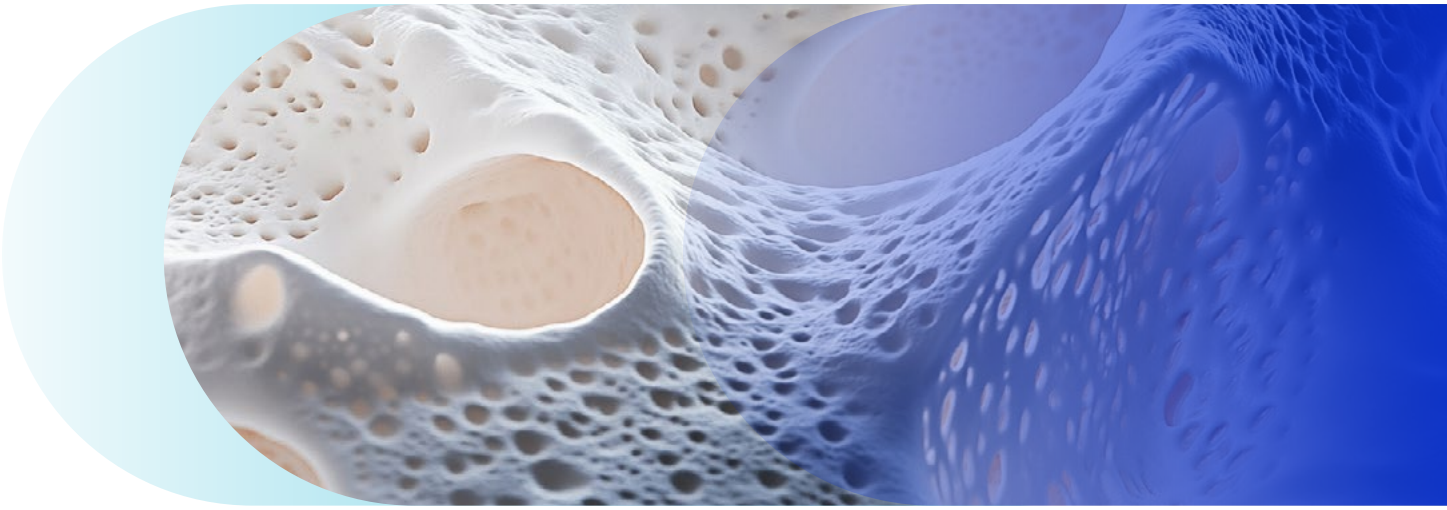
- **Microbiological and molecular data**

  Monitoring of ARBs and ARGs in hospital wastewater using culture-based methods and quantitative polymerase chain reaction (qPCR), respectively. The 16S rRNA gene is used for normalisation, while metagenomic analyses provide complementary information on the broader wastewater resistome.

- **Scientific and reference data**

  Information on pharmaceutical metabolism, environmental persistence and predicted no-effect concentrations (PNECs) for antimicrobial resistance selection, together with relevant clinical and antimicrobial stewardship guidance, supporting the interpretation of monitoring results and the assessment of potential risks.

The integration of these datasets enables pharmaceutical load estimates to be compared with measured wastewater concentrations and supports the analysis of relationships between hospital activity, environmental AMR indicators and wastewater treatment performance.



A dual-action decision support approach

The GENESYS digital platform is designed to support decision-making at two complementary levels: operational management of the wastewater treatment system and strategic clinical-environmental surveillance. Its architecture encompasses four main functionalities.

Prediction and early warning

The platform combines hospital activity, pharmaceutical consumption and wastewater flow data to predict pharmaceutical loads in hospital wastewater. By comparing estimated antibiotic concentrations with relevant reference thresholds, including AMR-related predicted no-effect concentrations (PNECs), it aims to identify potential risks and support early warning and preventive action. Analytical measurements will be used to validate and refine these predictions.

Ricardo Carapeto
AEMPS

Ricardo Carapeto highlighted the complementary roles of wastewater monitoring in anticipating treatment needs and supporting public health surveillance. While recognising its considerable potential, he stressed that further scientific evidence is needed to reliably interpret wastewater AMR data for epidemiological purposes.

Wastewater treatment optimisation

The CDSS supports the optimisation of the GENESYS treatment system by integrating wastewater quality, pharmaceutical concentrations and antimicrobial resistance indicators measured at different sampling points: the hospital wastewater outlet, after the membrane bioreactor (MBR) and after the complete treatment train. This enables the performance of each treatment stage to be assessed and supports the optimisation of UV irradiation and hydrogen peroxide (H_2O_2) dosing to improve treatment effectiveness while minimising chemical consumption, energy requirements and operational costs.

Alicia Gadea Gadea
EMUASA

Alicia Gadea stressed that continuous monitoring and predictive tools at critical discharge points, such as hospital outlets, could support preventive adjustments to quaternary treatment processes, improving performance while optimising chemical and energy consumption. Despite current technical and analytical limitations, she considered this a promising direction for wastewater management.

Clinical dashboard

The platform is designed to provide hospital professionals with access to relevant clinical indicators, historical information and AMR surveillance results through an integrated visual interface. This functionality aims to facilitate the interpretation of hospital activity and antimicrobial resistance trends and provide complementary information to support antimicrobial use optimisation programmes (PROA, from Spanish *Programa de Optimización del Uso de los Antibióticos*), in line with the monitoring requirements established by the Spanish PROA certification standards [26]. In addition, each alert provides links to Parc Taulí Hospital's empirical treatment guidelines, including recommendations for patients with allergies, as well as PROA guidelines and WHO GLASS resources.

Dr Oriol Gasch noted that hospital antimicrobial stewardship teams currently lack information on antibiotic residues, resistant microorganisms and resistance genes in hospital wastewater. He considered such information potentially valuable for developing hospital-wide antimicrobial stewardship policies in the longer term, provided that a causal relationship between antibiotic prescribing and wastewater AMR indicators can be established.

Dr Oriol Gasch Blasi

Infectious Diseases Specialist at Parc Taulí University Hospital and President of the Catalan Society of Infectious Diseases and Clinical Microbiology

Detection and alert system

By integrating clinical AMR data with microbiological and molecular analyses of hospital wastewater, the CDSS aims to identify trends and investigate potential relationships between clinical and environmental resistance indicators. This information could complement hospital AMR surveillance and potentially contribute to antibiogram interpretation and clinical decision-making, supporting a One Health approach. However, its clinical applicability will require validation with hospital specialists, as wastewater-based surveillance is intended to complement, rather than replace, individual patient diagnostics and clinical microbiology.

Internal Medicine and Preventive Medicine professionals

from the Xàtiva-Ontinyent and Alcoy Health Departments

Consulted through FISABIO Foundation, these professionals reported limited coordination between antimicrobial stewardship teams and hospital infrastructure departments. They expressed strong interest in an integrated dashboard linking antibiotic prescribing and wastewater AMR indicators, while highlighting major barriers to accessing and integrating clinical and environmental data within public healthcare systems. They also stressed the importance of primary care antibiotic prescribing and the need to investigate whether wastewater AMR data could reliably inform clinical decision-making.

Supporting the development of wastewater surveillance methodologies

Beyond evaluating treatment performance, LIFE GENESYS will generate practical evidence to inform the development of monitoring strategies for pharmaceutical residues and antimicrobial resistance in hospital wastewater.

The project combines targeted chemical analysis, culture-based methods, qPCR and metagenomics, providing complementary information on pharmaceutical occurrence, viable resistant bacteria, selected resistance genes and the broader resistome.

The monitoring programme also applies different sampling frequencies and locations according to the analytical technique and project phase, including measurements at the hospital wastewater outlet, after the MBR and after the complete treatment train.

This approach will contribute to assessing the suitability of different analytical indicators, methods and sampling strategies, considering their ability to characterise AMR occurrence, capture temporal variability and evaluate treatment effectiveness.

By linking clinical expertise, environmental monitoring and wastewater treatment demonstration, LIFE GENESYS aims to provide a practical evidence base for more integrated and harmonised approaches to antimicrobial resistance surveillance in hospital wastewater. Figure 1 summarises the integrated GENESYS approach, illustrating how the physical treatment train and digital decision support system contribute to reducing the environmental release of pharmaceutical residues and antimicrobial resistance determinants.

The experience gained through LIFE GENESYS may therefore help inform future risk-based guidance on which pharmaceutical compounds, resistant bacteria and resistance genes should be monitored, which analytical methodologies should be employed, and where and how frequently samples should be collected.

Lluís Jordan

Aigües de Sabadell and Grup CASSA

Lluís Jordan highlighted the value of coordinated monitoring between hospitals and wastewater utilities, including joint sampling, data sharing and communication protocols for unusual discharges. He noted that predictive monitoring could support preventive wastewater treatment management, provided that measurements are reliable, appropriately validated and integrated into existing operational systems.

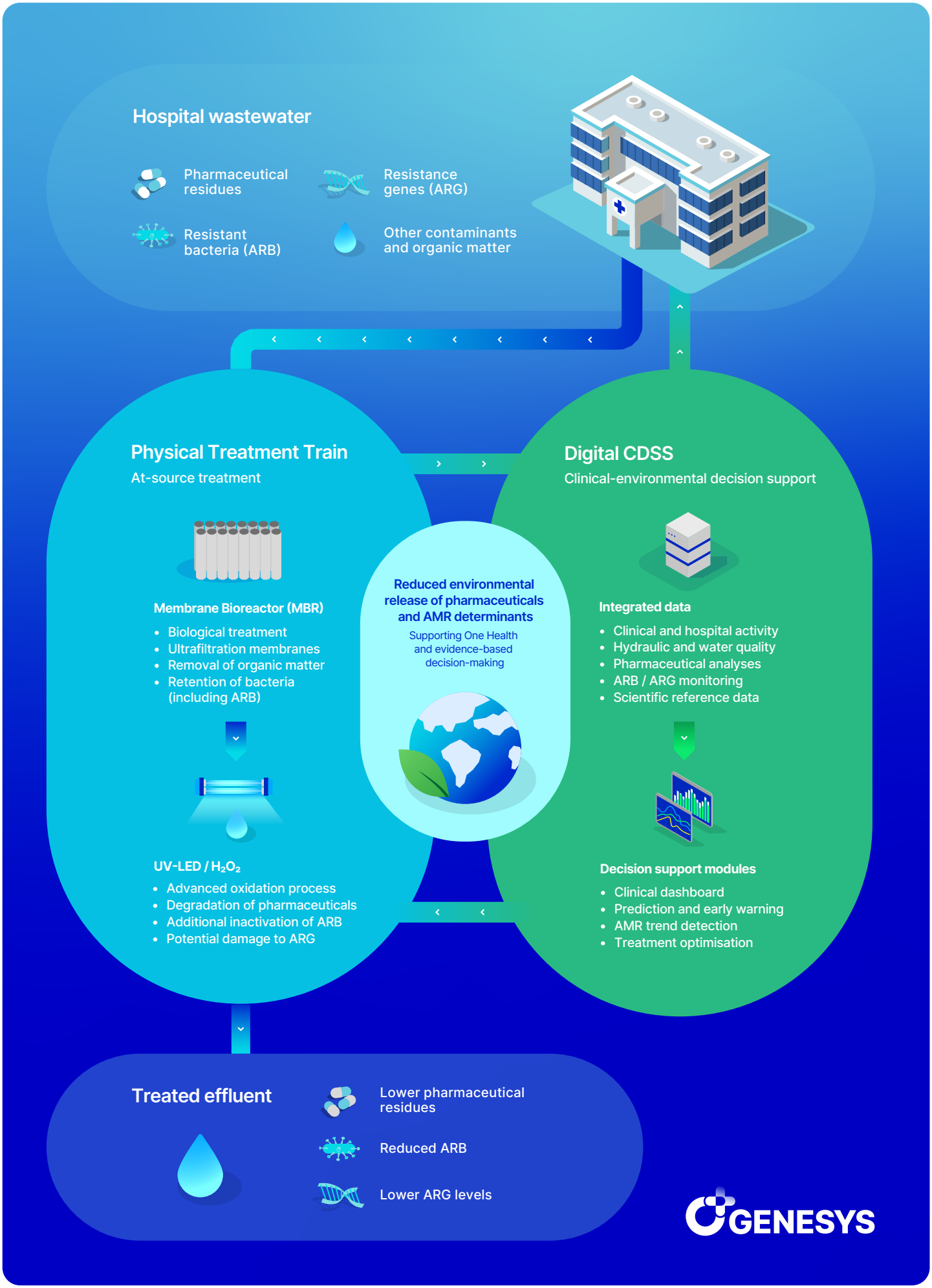


Figure 1. Overview of the LIFE GENESYS integrated solution, combining on-site hospital wastewater treatment (MBR and UV-LED/H_2O_2) with a clinical-environmental decision support system (CDSS) for treatment optimisation and AMR surveillance.

Policy recommendations and implementation pathways

Translating advances in hospital wastewater treatment and environmental antimicrobial resistance (AMR) surveillance into effective public policies requires coordinated action across healthcare, public health and wastewater management. Building on the evolving European regulatory framework and the evidence to be generated by LIFE GENESYS, four priority actions are proposed to strengthen monitoring methodologies, promote targeted control at source, support One Health integration and facilitate the implementation of innovative solutions.

The following recommendations identify potential policy actions, the stakeholders involved and the contribution of LIFE GENESYS to supporting evidence-based decision-making.

Stakeholder consultations also highlighted the importance of developing appropriate financing and incentive mechanisms to enable the implementation of hospital-level wastewater treatment solutions.

Policy recommendation	Proposed action	Target stakeholders	Contribution of LIFE GENESYS
Harmonise AMR monitoring in wastewater	Develop risk-based guidance on priority pharmaceuticals, ARB and ARG, analytical methodologies, sampling locations and monitoring frequencies.	Public health and environmental authorities; regulatory and standardisation bodies.	Evidence from targeted pharmaceutical analyses, culture-based methods, qPCR and metagenomics, including the evaluation of different sampling strategies.
Promote targeted control at source	Encourage site-specific assessments of decentralised hospital wastewater treatment as a complementary measure to municipal wastewater management, considering technical, environmental and economic feasibility.	Water authorities, healthcare institutions and wastewater operators.	Full-scale demonstration of MBR + UV-LED/H_2O_2 treatment at Parc Taulí University Hospital, including assessment of pharmaceutical, ARB and ARG removal.
Strengthen One Health surveillance integration	Explore the integration of environmental AMR indicators with clinical surveillance and antimicrobial stewardship programmes (PROA), supported by appropriate validation and data governance.	Public health authorities, hospitals and antimicrobial stewardship programmes.	Development and validation of a clinical-environmental decision support system combining hospital activity, pharmaceutical consumption and wastewater monitoring data.
Facilitate implementation and replication	Promote collaborative funding, procurement and institutional coordination mechanisms to support the adoption of innovative wastewater treatment and monitoring solutions where justified.	Healthcare administrations, environmental authorities, funding bodies and wastewater operators.	Technical, environmental and economic assessments to inform investment decisions, procurement specifications and replication strategies.

Francesc Luque

Finance Director at Parc Taulí University Hospital

Francesc Luque emphasised that reducing the environmental impact of hospital wastewater should form part of healthcare institutions' environmental and social responsibility. He proposed sanitation fee reductions or exemptions for hospitals demonstrating measurable reductions in pollutant loads, alongside a progressive application of the polluter-pays principle. Such incentives could encourage investments in treatment at source while protecting resources allocated to healthcare services.

María José Mora

Sustainability Lead, Innovation Department at Fisabio

María José Mora suggested that local authorities could help incentivise hospital wastewater treatment through potential reductions in sanitation fees linked to lower pollutant loads. Alternatively, investments could be funded through annual hospital budgets allocated by regional healthcare authorities. However, given competing healthcare priorities, she stressed that such investments would need to demonstrate tangible savings in treatment costs or hospital admissions to justify their funding.

Irene Morante Sánchez

MITECO

Irene Morante highlighted that existing extended producer responsibility provisions cover quaternary treatment for micropollutant removal, but not the removal of microbiological or AMR parameters. She also noted that no specific public co-financing or incentive mechanisms for hospital-level treatment have been defined by MITECO.

Call to action

Addressing the environmental dimension of antimicrobial resistance requires moving towards a more integrated One Health approach that connects healthcare, wastewater management and environmental protection. LIFE GENESYS provides an opportunity to demonstrate the potential of targeted hospital wastewater treatment and clinical-environmental surveillance, while generating evidence to inform future monitoring methodologies, risk-based control-at-source strategies and implementation pathways. European, national and regional authorities, together with healthcare institutions and wastewater operators, are encouraged to build on this evidence to strengthen cross-sector collaboration and support effective, proportionate and scientifically informed measures to reduce the environmental dissemination of antimicrobial resistance.

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