ENVIRONMENTAL SUSTAINABILITY POSITION PAPER

Executive Summary

This position paper outlines the growing importance of environmental sustainability in the European pharmaceutical sector and defines the strategic role of the industrial pharmacist in supporting the transition toward greener, safer, and more sustainable medicines. Driven by the European Green Deal and reinforced by an increasingly stringent regulatory framework, environmental performance is no longer optional but a core determinant of pharmaceutical development, manufacturing, and market access.

At the EU level, climate neutrality by 2050, mandatory sustainability reporting (CSRD), and reinforced environmental legislation (REACH, Industrial Emissions Directive, Water Framework Directive, Urban Waste Water Treatment Directive) are reshaping the operating landscape for pharmaceutical companies. Sector-specific reforms, including the revised Environmental Risk Assessment (ERA) guideline and the forthcoming EU Directive on medicinal products, mark a paradigm shift: environmental considerations now directly affect marketing authorisation, lifecycle management, and continued supply of medicines.

The revised ERA framework significantly expands the scope and complexity by mandating assessments of persistence, bioaccumulation, toxicity (PBT), endocrine-disrupting properties, secondary poisoning, and antimicrobial resistance. Notably, incomplete or missing ERA documentation may result in the refusal, suspension, or revocation of marketing authorisations, and retroactive ERA requirements may apply to older active substances. This represents a fundamental change from earlier practice, where environmental risk did not influence authorisation decisions.

In response, the paper identifies key critical areas and opportunities for action across the pharmaceutical lifecycle:

- **Sustainable R&D**: Adoption of green chemistry principles, solvent reduction, improved atom economy, and early integration of environmental considerations in drug design. The "benign-by-design" approach aims to develop medicines that remain effective for patients while degrading safely after use.
- **Life-cycle assessment (LCA)**: Systematic evaluation of environmental impacts from raw materials to end-of-life, supporting informed decision-making and alignment with the EU's Safe and Sustainable by Design framework.
- **Sustainable manufacturing**: Redesign of operations through process intensification, continuous manufacturing, renewable energy use, water reuse, digitalisation, and circular economy principles to reduce emissions, waste, and resource consumption.
- **Packaging and waste management**: Transition toward recyclable, reduced, and eco-designed packaging in line with the new Packaging and Packaging Waste Regulation, while maintaining GMP and patient safety requirements.

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Throughout these areas, the industrial pharmacist is identified as a key enabler of change, contributing scientific, regulatory, and operational expertise to ensure compliance, innovation, and sustainability. The paper emphasises that environmental sustainability is not only a regulatory obligation but also a strategic opportunity to improve efficiency, resilience, and long-term competitiveness of the pharmaceutical industry.

EIPG commits to keeping this position paper updated as legislation, science, and technologies evolve, supporting industrial pharmacists in navigating the environmental challenges that will define the future of medicines in Europe.

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1. Introduction

1.1 Scope

This report aims to provide an overview of the main critical aspects of industrial pharmaceutical activities. These aspects must be evaluated to identify alternative solutions or changes that can be implemented over the next few years.
Following a review of current regulatory requirements, some of which remain undefined, the main environmental criticalities in the process of obtaining a medicine are identified, highlighting potential interventions in which the industrial pharmacist can make a tangible contribution.

The environmental sustainability of industrial activities has attracted increasing attention over the past few decades. This has led to the development of European legislation, which is being implemented. The pharmaceutical sector is also involved in this process, with the peculiarity of generating products intended for both human and animal health, yet with the potential for significant environmental impacts. The industrial pharmacist, who is involved in the research, production, and distribution of medicines, should identify the interventions that the pharmaceutical industry must progressively implement to comply with the new regulations.

This document, prepared with the contributions of colleagues with expertise in various areas, is not intended to be exhaustive of all analyses and solutions related to the environmental impact of pharmaceutical activities. The aim is to highlight how the industrial pharmacist, in various positions, can contribute their skills to the development of new solutions and the implementation of changes in the pharmaceutical industry.

EIPG aims to keep this document current by periodically updating its contents in response to specific, ongoing regulatory interventions affecting pharmaceutical activities and by articulating technological solutions to reduce environmental impact.

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2. Regulatory situation of the European Pharmaceutical sector

2.1 Overview

The European pharmaceutical industry operates within a robust and evolving regulatory landscape driven by broad climate and environmental goals.

The European Green Deal, adopted in 2019, is the EU's flagship strategy to make the continent climate-neutral by 2050.[1] This entails legally binding targets (climate neutrality by 2050 and a 55% reduction in emissions by 2030) codified in the EU Climate Law (Regulation (EU) 2021/1119).[2]

The 2025 Clean Industrial Deal (CID) departs from the 2019 European Green Deal's broad policy framework, adopting an implementation-focused, competitiveness-driven strategy. It prioritises reducing energy costs for industry, accelerating permitting, boosting demand for low-carbon products through public procurement, and scaling up clean technology manufacturing, with the aim of reconciling strict climate targets with economic viability. The CID maintains the core 2050 climate neutrality goal of the 2019 Deal but changes the methodology to be more industry-friendly, addressing energy costs and competitive pressures to prevent industrial leakage.

Under these frameworks, all sectors, including the pharmaceutical industry, are expected to decouple growth from resource use and drastically reduce greenhouse gas emissions. [1,2]

At the same time, EU sustainability policies (e.g., the Corporate Sustainability Reporting Directive – CSRD) now require large companies (including major drug manufacturers) to disclose detailed environmental and social impacts. [3] In short, the EU has set an ambitious net-zero emissions target by 2050, along with a suite of regulatory initiatives to shift industry toward clean, resource-efficient operations.[1,2]

These overarching policies directly impact the pharmaceutical sector. For example, the Commission's new Pharmaceutical Strategy explicitly links reforms to the Green Deal, committing to higher environmental standards in the production of medicines.[4] Likewise, an EU Strategic Approach to Pharmaceuticals in the Environment calls for reducing drug residues and other pollutants from manufacturing and use. In sum, the regulatory situation integrates general climate/environmental goals with sector-specific rules.

The following section outlines the legislative framework: EU laws and directives that govern climate, environmental protection, and medicines in the pharmaceutical industry.

The current regulatory situation combines broad EU climate and environmental objectives with specialised pharmaceutical legislation. The EU climate and environmental agenda – encapsulated

by the European Green Deal and related laws – compels all industries to meet stringent sustainability criteria. The European Climate Law (Regulation 2021/1119) makes the 2050 climate-neutrality goal legally binding and establishes an interim target of a 55% reduction in emissions by 2030. [2]

Complementing this, the Corporate Sustainability Reporting Directive (CSRD) requires large companies (including pharma firms) to report on environmental and social risks and impacts, ensuring transparency of their sustainability performance [3]. These instruments are expressly part of the Green Deal's push for a resource-efficient economy. [1,3]

Parallel to climate policy, Europe's chemical and industrial regulations seek to protect health and ecosystems. The REACH Regulation (EC 1907/2006) is the EU's primary law on chemicals, placing the burden on industry to register substances and assess their hazards, thereby safeguarding human health and the environment. [4] Under REACH, manufacturers and importers (including pharmaceutical companies) must submit data on all chemicals produced/imported in quantities exceeding 1 tonne/year to the European Chemicals Agency [4].

Likewise, the Industrial Emissions Directive (IED, 2010/75/EU) sets integrated permits and Best Available Techniques (BAT) requirements for large industrial plants. The IED aims to achieve "a high level of protection of human health and the environment as a whole" by reducing industrial pollutant discharges through BAT-based emission limits [5]. Parts of this legislation are currently undergoing the legislative process as part of the Environmental Omnibus, which the EC published in December 2025.

Pharmaceutical manufacturing facilities are subject to this regime and must comply with stringent emissions standards and pollution control requirements.

Water protection is another key pillar. The Water Framework Directive (WFD, 2000/60/EC) is the cornerstone of EU water law and has been in effect since 2000, ensuring that all surface waters achieve "good chemical and ecological status" [4]. The WFD sets quality objectives for priority pollutants (listed in its annexes) and requires Member States to phase out harmful substances in water [4].

Notably, pharmaceutical compounds are increasingly recognised as contaminants in water, and the WFD process enables the EU to list drugs on priority or watch lists to set concentration limits and monitor them. In practice, the Commission has considered categorising certain medicines as high-risk under the WFD to restrict their presence in water [4].

Complementing this, the Urban Waste Water Treatment Directive (91/271/EEC) – currently being recast – governs the collection and treatment of municipal and some industrial wastewater to protect ecosystems. [6]. The new revision (Directive (EU) 2024/3019, published Dec 2024) explicitly targets pharmaceuticals (and cosmetics) by imposing stricter limits on micropollutants and introducing an "extended producer responsibility" fee on drug makers to fund advanced wastewater treatment [7].

Finally, core pharmaceutical product regulations apply. Directive 2001/83/EC (the EU's "Community code" on medicinal products) consolidates rules for the authorisation, manufacture, distribution, labelling, and monitoring of human medicines. [8]. It requires that all medicines placed on the EU market have prior marketing authorisation (at national level or via the EMA) and meet detailed safety and quality standards. [8]. While primarily focused on health and safety, this directive also provides the legal basis for future environmental measures (e.g., requiring environmental risk assessment for new medicines). This Directive has been revised, and we are waiting for the final adopted text which makes changes to strengthen the environmental requirements

In sum, the legislative framework for the European pharmaceutical sector is multi-layered: it spans EU climate and sustainability policies (Green Deal, Climate Law, CSRD) that set overarching targets, general environmental/industrial laws (REACH, IED, WFD, UWWTD) that limit pollutants from industrial activities and wastewater, and specific pharma laws (Directive 2001/83/EC) governing medicines themselves. Each element contributes to a regulatory regime pushing the industry toward greener and safer practices.

2.2 Legislative Framework

European Green Deal. The European Green Deal is the EU's flagship policy initiative (Communications and strategy) to transform the Union into a "modern, resource-efficient and competitive economy" with no net greenhouse gas emissions by 2050 [4]. It commits one-third of the EU budget and NextGenerationEU funds to climate-related investments. While not a legislative act itself, the Green Deal underpins all EU environmental policy and explicitly guides sectoral strategies. For example, the 2023 Pharmaceutical Strategy states that its actions are "in line with the priorities outlined in the European Green Deal" [4]. In practice, this means that EU pharmaceutical policy must now account for climate and environmental objectives alongside public health goals.

EU Climate Law (Regulation (EU) 2021/1119). The European Climate Law codified the Green Deal's goals into binding law. Adopted in 2021, it enshrines the EU's obligation to reach climate neutrality by 2050 at the latest [2]. It also sets an interim target: total greenhouse gas emissions must be reduced by at least 55% by 2030 relative to 1990 levels [2]. By making these goals legally binding, the Regulation ensures that all sectors (industry, transport, buildings, etc.) contribute to the effort. For the pharmaceutical industry, this translates into requirements to decarbonise manufacturing processes, improve energy efficiency, and report on emissions progress, in line with the EU's climate-neutrality path.

Corporate Sustainability Reporting Directive (CSRD). The CSRD (Directive 2022/2464) significantly expands EU rules on non-financial reporting. It requires large companies (including pharmaceutical firms with large workforces or turnover) to publish audited sustainability reports covering environmental, social, and governance matters. Specifically, affected firms must disclose risks and opportunities associated with climate change, pollution, resource use, and social impacts [3]. These disclosures adhere to the Common European Sustainability Reporting Standards (ESRS)

and are explicitly aligned with the European Green Deal agenda [3]. The first companies will apply CSRD in 2024 (for reports published in 2025) [3]. For pharmaceutical companies, the CSRD requires detailed public reporting of metrics, including carbon emissions, water use, waste generation, and chemical management, across their entire value chain.

REACH Regulation (EC No 1907/2006). REACH is the EU's central chemicals regulation, designed to protect health and the environment from hazardous substances. It requires manufacturers and importers of chemicals (including active pharmaceutical ingredients and excipients) to register substances with the European Chemicals Agency and provide data on their properties [4]. Substances identified as of "very high concern" (e.g. persistent, bioaccumulative toxins) may be phased out or restricted under REACH. The regulation imposes a "no data – no market" principle: substances cannot be marketed without proper registration and safety data. In the pharmaceutical context, REACH generally exempts final medicinal products and certain intermediates, but it applies to raw materials and excipients used in the manufacture of drugs. Thus, compliance with REACH (and its periodic updates) is a crucial component of the pharmaceutical industry's environmental obligations. Overall, REACH is the primary EU law designed to protect human health and the environment from the risks posed by chemicals [4]. This legislation remains relevant, however is expected to be revised in Q2 of 2026

I**ndustrial Emissions Directive (IED, 2010/75/EU**). The IED is the key EU law governing pollution from large industrial installations. It requires operators of major plants (including pharmaceutical manufacturing facilities) to obtain integrated environmental permits. These permits incorporate emission limit values based on Best Available Techniques (BAT) identified in EU reference documents. The stated aim of the IED is "to achieve a high level of protection of human health and the environment as a whole" by reducing harmful emissions across the EU, in particular through the application of BAT (eipie.eu). In practice, this means that a drug factory must implement state-of-the-art processes (e.g., energy-efficient equipment, solvent recovery, waste abatement) to minimise emissions of air and water pollutants. The IED also enforces waste hierarchy measures (reduce, reuse, recycle) and mandates public access to emissions data. In 2024, the EU adopted a revision of the IED (the so-called "IED 2.0") to further align it with the zero-pollution and climate-neutrality objectives of the Green Deal, reinforcing emission limits and expanding the scope of covered activities.

Water Framework Directive (WFD, 2000/60/EC). The WFD provides a comprehensive framework for protecting surface and groundwater in the EU. Since 2000, it has been the "main legal instrument for water protection in Europe" [4]. The WFD requires Member States to achieve "good ecological and chemical status" for all water bodies by specified deadlines. It does so by setting quality standards for priority pollutants (listed in Annexe X) and requiring reductions or elimination of emissions for those substances [4]. The Directive takes an integrated approach, treating river basins as whole ecosystems. In practice, this has led to EU monitoring and control of many industrial contaminants (e.g. heavy metals, nutrients). Importantly for the pharmaceutical industry, the WFD includes a "watch list" mechanism: the EU can identify emerging pollutants (including active

pharmaceutical ingredients) for monitoring. The Commission has indicated that certain medicinal products may be added to this list or treated as priority substances under the WFD, which would impose concentration limits in water bodies [9,4].

Urban Waste Water Treatment Directive (91/271/EEC, revised 2024). The UWWTD is the EU's directive on urban wastewater treatment and discharge. Its aim is "to protect the environment from the harmful effects of urban wastewater" [10]. The original 1991 Directive (amended up to 2013) required Member States to collect and treat municipal sewage and certain industrial effluents (from large plants) to specified standards [10]. Key provisions included deadlines for constructing sewerage networks, secondary treatment requirements, rules for sludge disposal, and monitoring of treated discharges [10]. In 2024, the Directive was entirely recast (Directive (EU) 2024/3019) to address industrial micropollutants. The new law imposes stricter effluent limits (including lower limits for a broad range of organic micropollutants) and requires an additional purification stage (tertiary treatment) at wastewater treatment plants. Crucially, the revision introduces an Extended Producer Responsibility scheme for pharmaceuticals and cosmetics: manufacturers must share in the costs of upgrading municipal plants to remove micro-pollutants [11]. According to industry estimates, this could cost tens of billions of euros over several decades. In summary, the UWWTD (both the old and new versions) governs the treatment of wastewater from cities and industries, and the recent amendments explicitly target pharmaceutical residues.

Directive 2001/83/EC on Medicinal Products. This Directive, often referred to as the EU Community code for medicinal products, consolidates the rules governing the authorisation and regulation of human medicines. It "brings together all the existing provisions in force on the sale, production, labelling, distribution and advertising of medicinal products for human use in the EU" [8]. Under it, no medicine may be marketed in the EU without a prior authorisation – either at the national level or via the centralised EMA process [8]. The Directive also sets detailed requirements: manufacturers must demonstrate quality, safety, and efficacy, provide patient information (including labelling and leaflets), and comply with pharmacovigilance requirements. Although primarily focused on public health, the Directive provides the framework for any future environmental requirements (such as environmental risk assessment of drugs). Currently, most environmental concerns are addressed in parallel regulations, but any new rules (for example, requiring greener manufacturing or environmental monitoring of medicines) would build on this legal foundation.

References

1. commission.europa.eu

2. https://www.loc.gov/item/global-legal-monitor/2021-08-31/european-union-european-climate-law-on-achieving-climate-neutrality-by-2050-enters-into-

force/#:~:text=codifies%20the%20European%20Union%E2%80%99s%20,On%20July%2014

3. https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en#:~:text=EU%C2%A0law%20requires%20companies%20above%20a,on%20people%20and%20the%20environment

4. https://environment.ec.europa.eu/topics/chemicals/reach-regulation_en#:~:text=The%20Regulation%20on%20the%20registration%2C,of%20the%20EU%20chemicals%20industry

5. https://eipie.eu/the-sevilla-process/the-industrial-emissions-directive/#:~:text=The%20Industrial%20Emissions%20Directive%20or,1

6. https://www.bmluk.gv.at/en/topics/water/eu-international-affairs/urban-waste-water-treatment-directive-91271ecc.html#:~:text=The%20aim%20of%20this%20Directive,effects%20of%20urban%20waste%20water

7. https://www.taylorwessing.com/en/insights-and-events/insights/2024/08/new-eu-urban-wastewater-directive#:~:text=On%205%20November%202024%2C%20the,of%20urban%20wastewater%20from%201991

8. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2001:311:0067:0128:en:PDF

9. https://www.pharmtech.com/view/regulating-pharmaceuticals-environment

10. https://www.bmluk.gv.at/en/topics/water/eu-international-affairs/urban-waste-water-treatment-directive-91271ecc.html#:~:text=The%20aim%20of%20this%20Directive,effects%20of%20urban%20waste%20water

11. https://www.taylorwessing.com/en/insights-and-events/insights/2024/08/new-eu-urban-wastewater-directive#:~:text=On%205%20November%202024%2C%20the,of%20urban%20wastewater%20from%201991

2.3 The ERA requirements

The environmental impact of pharmaceutical products (i.e., ERA) has been the subject of sustained attention by stakeholders, authorities, and the general public since the late 1990s, when hazardous levels of active pharmaceutical ingredients were detected in surface and groundwater worldwide (e.g., Diclofenac). The EU Commission adopted a clear scientific and political position in 2016 with the publication of the official document titled “Options for a strategic approach to pharmaceuticals into the environment, Task 1 report, revised version 2016 European Commission”. In general, the topic is identified by the acronym PIE, which stands for Pharmaceuticals Into Environment.

In 2006, following a lengthy stakeholder discussion, EMEA (now EMA) published a guideline on the risk assessment (ERA) and the environmental impact of medicinal products for human and veterinary use. It focused on assessing the environmental risk posed by medicinal products, primarily in humans, when released by patients or treated animals following therapeutic use. The guideline was inspired by the principles of "Risk Assessment" typically applied in the chemical sector (mainly contained in the REACH regulation and subsequently) and required, in short, a calculation of the PEC (Predicted Environmental Concentration) and relating it to a safe concentration value (PNEC = Predicted Non-Effective Concentration) relating to the active ingredient (API) under study. The relationship between two values represents the level of risk associated with environmental impact.

In more detail, the assessment is based on a tiered approach comprising three steps: Phase I (pre-screening), under which a “simple” evaluation of environmental exposure is requested, including an initial bioaccumulation property assessment using data from a Log Po/w experimental study. The risk is determined by comparing a reference PEC (0.01 mg/L) with a calculated potential exposure, accounting for bioaccumulation. The second step, called Phase II, Tier A, initial risk assessment, is triggered by the outcome of the Phase I pre-screening approach when the PEC exceeds 0.1 mg/L (the reference value). Phase II, Tier A, included ecotoxicology and environmental fate studies to determine both environmental toxicity (in fish, algae, and Daphnia) and the fate of the active pharmaceutical substance, thereby establishing PNECs for various environmental compartments. The following Phase II, Tier B step is again triggered by the results of the initial risk assessment for Phase II, Tier B. Additional experimental studies may be requested in this phase, along with a re-calculation of the Risk Assessment for the various compartments. During this final phase, additional evaluation may be needed, including metabolites and degradation products, as well as specific testing and RA. At this level, a consumption data assessment can also be conducted to refine the overall evaluation.

In summary, we are adopting a relatively straightforward scientific approach. From an essentially theoretical calculation phase, it was possible/should be, if necessary, to move on to an experimental testing phase to obtain the results of ecotoxicology and environmental fate studies, providing valuable data for defining the environmental hazard and, subsequently, as mentioned, risk.
Generic drugs, biotechnological drugs, GMOs and obviously all active ingredients already on the market at that date (2006) were excluded from the application of this initial guideline for various

reasons. The ERA projects managed at that moment were, therefore, very varied depending on the degree of in-depth analysis necessary to reach a satisfactory characterisation of the risk, from simple mini-dossiers of exemption (waiving) from the application of the guideline (waiving) to very substantial dossiers including a considerable amount of experimental data. Sometimes, it was necessary to recalculate the initial PEC, taking into account all marketing data (consumption) for the drug within a specific European geographical entity (Phase II, Tier B).

In 2018, the draft revision of the 2006 guideline was published, updating the scientific approach to risk calculation and, with particular emphasis, introducing the evaluation of potential endocrine interference and other safety endpoints. Again, a translation of principles from the chemical world was adopted; a specific (ED) guideline was published for the biocides and plant protection products sector in the same year. The assessment of the potential for endocrine interference (EDS = Endocrine Disrupting Substances) became as much of a priority as the environmental risk assessment, with the method already adopted. In addition to the ED assessment, assessments of PBT (Persistence, Bioaccumulation, and Toxicity), Secondary Poisoning, and Antibacterial Properties are now requested. Reasons for such additional requirements can be summarised as follows: endocrine interference is a primary endpoint of concern, as many chemical substances, including pharmaceutical actives, may induce hormonal mechanisms of action that could lead to significant adverse effects on organisms, including reproductive impairments. The crucial endpoint of this evaluation is to establish a robust relationship/link between adverse effects caused by a substance and its endocrine activity (biological plausibility) to determine if a substance can be considered EDS or not. PBT and vPvB assessments are crucial for determining how a given substance may be distributed among environmental compartments and for assessing its potential to act as a toxicant to organisms within these compartments. Bioaccumulation potential is a factor in the evaluation of secondary poisoning. Secondary poisoning is a pathway that can lead to toxic effects on animals at higher trophic levels through the food chain (e.g., predatory fish, birds, mammals, and humans) resulting from consuming contaminated prey (e.g., aquatic invertebrates or fish) in aquatic ecosystems. It is particularly relevant for compounds that accumulate in the food chain, i.e., mainly lipophilic compounds. It's therefore a vital safety endpoint. Last but absolutely not least, the Antibacterial Properties of certain substances are strongly related to the matter of antimicrobial resistance. As a result, a detailed, targeted effects assessment is requested within the general ERA.

It's worth noting that evaluations of ED, PBT, Secondary Poisoning, and antibacterial properties are now to be carried out, irrespective of the PEC action limit approach mentioned in the 2006 guideline, which remains applicable only to ecotoxicity. In conclusion, the ERA evaluation is becoming increasingly complex and comprehensive. The 2018 draft version was finalised in March 2024 and has been in application since September 1st 2024.

It's also worth noting that, up to the last March 2024 guideline, the following statement remained valid and accepted:

"*The evaluation of the potential environmental risk posed by medicinal products should be submitted, their environmental impact should be assessed, and on a case-by-case basis, specific arrangements to limit the impact should be considered. In any event, this impact should not constitute a criterion for the refusal of a marketing authorisation*"

The last sentence, "in any event", was generally interpreted by all as "with any Risk Assessment results and conclusion", i.e., Marketing Authorisation was not affected by the ERA conclusion.

2.4 The ERA in the New EU Directive for Medicines.

The proposal for the new EU Directive on medicines, published in April 2023, includes several relevant new approaches and requirements for assessing the environmental risk (ERA) of medicinal products, as outlined in various paragraphs of the document.

In brief:

- Marketing Authorisation will be refused if the ERA assessment is missing or incomplete. This represents a significant shift in the regulatory landscape. This concept/position is reiterated in several places throughout the document. The worst-case interpretation suggests that Marketing Authorities are now affected by the ERA conclusion, particularly in cases of missing or incomplete information.

- The need to update the ERA document is also requested based on the well-known principle regarding the "technical and scientific progress" which is also well described in other European safety regulations (e.g. CLP Reg. for safety classification, REACH, etc.). Additional environmental studies, the availability of new scientific methods (for both experiments and risk assessment), and the use of new therapies may necessitate revisions to the ERA documents.

- In the EU new directive document, the EU Green Deal is often cited as the most critical European regulation that has to do with environmental assessments, which are already harmonised. The OS-OA (One Substance, One Assessment) principle, which underpins the evaluation of active pharmaceutical ingredients in the ERA, is referenced.

- The evaluation of the ability to induce Antibiotic Resistance in the ERA (a particular type of evaluation) is also included, citing antibiotics among the potential drugs that cause unwanted effects in the environment (already discussed in the last ERA guideline).

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- The preparation of a new EMA guideline with the contribution of ECHA and EFSA is announced (therefore, probably very restrictive!). It will take into account the principles of the CLP Regulation (Classification, Labelling and Packaging), including the environmental classification criteria (e.g., EDS for human health and the environment). In particular, the chemical classification criteria will also be adopted for drugs. Specific emphasis will be given to PBTs (Persistent, Bioaccumulative, and Toxic) and, as is no longer new, to EDS (Endocrine Disrupting Substances), which, as already anticipated, will be one of the central themes of the new ERA assessment. The participation of the ECHA and EFSA Agencies in matters related to medicines is a novelty.

- For some active ingredients that EMA considers potentially having an impact on the environment (according to a risk-based approach) but registered before 30 October 2005, an ERA evaluation will be required. Hence, a potential retroactive request. We can expect hormones or hormone-like actives, antibiotics and others;

- The sharing of data, which is a principle already applied in other EU regulations (REACH, BIOCIDES) and already written in the previous and recent ERA guidelines, has been reported. It was indeed applied poorly for competitive reasons, but it is now clearly stated in the EU Directive. The data-sharing approach refers to data generated on an active ingredient and owned by a company that may be of common interest to other companies. The European Commission is seeking to encourage data sharing. Frankly, we can say that it is a controversial requirement leading pharma companies to involve legal departments to dispute any possible data sharing with “competitors”. We will examine whether and how EMA and/or National Authorities can encourage companies to share their experimental data.

- EMA will prepare monographs on individual ERAs based on a "risk-based prioritisation" approach. Nothing similar existed at the EU level before. This indeed can help smaller pharmaceutical companies to have public experimental data and/or have a “formalised” risk assessment procedure and results on a given active substance. However, we expect the EMA monographs to take some time to be published.

- The medical prescription will always be required for drugs containing active ingredients that fall into some CLP classifications, such as PBT. We are not yet talking about substances with endocrine-disrupting properties (EDS) here, but their involvement is expected given that the ED classification has recently been introduced in CLP. Many active ingredients will be classified as PBT and therefore subject, for this reason, to medical prescription intended as a "deterrence method" against marketing. There is concern about the environmental risks associated with over-the-counter medicines, and an environmental risk assessment will be conducted. Will they shift to medical prescriptions?

- The possibility of requesting post-submission experimental studies is mentioned in some cases, meaning that the ERA evaluation must be supported by quality studies that would otherwise be rejected even after the first authorisation.

- The possibility of revoking, suspending or varying a Marketing Authorisation (MA) is reiterated in cases where ERA is not clearly supported or the active pharmaceutical ingredient has apparent effects on the environment;

- The concept of the prohibition of supply in the case of severe, harmful effects on the environment or public health via the environment is reiterated. It may significantly affect the marketing of certain medicines.

Many of these points represent a genuine "revolution" in the regulation of medicines and may pose obstacles to the marketing of certain medicines, as stated. In the 2006 first version of the EMA guidance, it was clearly stated that" in any event this impact (the ERA evaluation) should not constitute a criterion for refusal of a marketing authorisation". It's now evident that the new approaches outlined in the revised EU directive on medicines will overturn this paradigm, making it increasingly complex to strike the right balance between human well-being and the protection of the natural environment.

2025 will be a pivotal year for gaining a deeper understanding of how the new ERA principles will be applied and how pharmaceutical companies will respond to these new requirements, given the significant investment required.

3. The critical areas of challenging and potential actions

3.1 A Substaminale R&D

3.1.1 Green chemistry, green design, green processes

Green chemistry is at the core of modern chemical synthesis, enabling the manufacture of products aligned with the Sustainable Development Goals [1]. This covers the selection of raw materials (renewable vs. fossil) for the manufacturing process, the life cycle analysis of the chemical, and the evaluation of its environmental fate (biodegradable vs. persistent) and possible ecotoxicity. While the production and use of hazardous substances are regulated by law, green chemistry is a scientific approach to (re)designing products and their manufacturing methods, including chemical syntheses.

The production of active pharmaceutical ingredients (APIs) and pharmaceutical products requires numerous chemicals, from the early stages of drug development through final production, including reagents, catalysts, solvents, and various excipients. For example, solvents are needed in many steps of the synthetic production of pharmaceuticals – to dissolve the reagents, extract reaction mixtures, isolate desired reaction products, and purify them, as well as for pharmaceutical formulations. The "greenness" of solvents is primarily determined by the manufacturing process of the solvent itself, specifically whether the production of the solvent involves fossil or renewable raw materials. Criteria often include occupational safety factors, regulatory requirements (such as solvent toxicity), life-cycle analysis of the solvent (including recyclability, reuse, and solvent regeneration), and the solvent's environmental impacts.

The foundation of green chemistry is based on twelve principles [1], most of which are widely applicable to pharmaceutical manufacturing and especially useful for reducing environmental harm caused by raw materials and their production and use. In addition to favouring green solvents, the goal is to reduce the use of raw materials, the use of toxic substances, and the waste generated and energy consumed during manufacturing. Additionally, green chemistry has been incorporated into the European Pharmacopoeia (Ph. Eur., 1742 (01/2008)), which controls the quality of medicines. This ambition also extends to the monographs, which describe the methods of analysis for medicines, with the aim of eliminating the use of hazardous and harmful reagents therein.

Still, there are also persistent challenges. The general problem with these multi-step synthesis routes arises from their often low overall yield. A significant portion of waste can arise from poor atom economy, i.e., the proportion of the reacting substances' atoms that are incorporated into the desired product versus the number of atoms lost to unwanted by-products. Since waste is always a by-product that incurs disposal costs, any new synthesis route which improves the efficiency of (catalytic) reactions and atom economy is also economically viable. In addition, the production of

biomass- and carbon dioxide-based chemicals, which favours renewable raw materials, is one of the most significant academic and industrial challenges. This approach also enables techno-economic synthesis routes for producing entirely new product types, such as pharmaceuticals.

Other challenges are also linked to human safety and the efficacy of medicines. Many APIs are per- and polyfluorinated alkyl substances (PFAS), as adding a fluorine atom to a drug molecule often significantly enhances its bioavailability and distribution to target tissues. In addition, PFAS are also used in industrial drug production, for example, in the production equipment. By definition, all PFAS compounds contain a carbon-fluorine bond, which is one of the most durable chemical bonds in organic chemistry. As a result, they degrade very slowly in the environment and can migrate far from the initial release site. PFAS compounds have been detected in groundwater and even drinking water in the EU and globally. Due to environmental exposure, PFAS compounds can bioaccumulate in the tissues of organisms and humans and cause health issues, including organ damage, chronic diseases, and reproductive disorders. For this reason, the European Commission is committed to gradually reducing the use of PFAS compounds. However, these restrictions and goals primarily concern the general use of PFAS compounds in society, while acknowledging the necessity of fluorinated molecules for medicinal use.

3.1.2. The impact of ERA requirements

Environmental risk assessment (ERA) of new APIs has been a mandatory part of the marketing authorisation dossier in the EU since 2006 (Article 8 (3)(ca) of Directive 2001/83/EC). In the EU, the ERA is conducted in accordance with guidance from the European Medicines Agency [2], typically in parallel with late-stage clinical trials. In this context, the risk is evaluated based on the predicted environmental exposure (calculated from predicted consumption) of APIs, as well as their environmental fate and effects, specifically persistence (P), bioaccumulation (B), and toxicity (T) in the environment and in environmental organisms. The assessment of PBT properties is based on standardised (OECD) tests, many of which are costly and consume significant amounts of APIs. For the time being, however, there are neither regulatory requirements nor sufficiently mature high-throughput screening techniques to incorporate PBT assessment into the early stages of the drug discovery and development pipeline. Some standardised tests (e.g., OECD 305: Bioaccumulation in Fish) also require large numbers of animals, further limiting their feasibility for high-throughput screening due to ethical concerns (animal rights). At the same time, several ongoing EU initiatives affecting pharmaceutical R&D are underway, such as the recast of the Urban Wastewater Treatment Directive [3], which aims to introduce an extended producer responsibility obligation for the pharmaceutical industry to incentivise the development of less-toxic products.

Overall, the PBT properties strongly correlate with desired molecular properties that define the pharmacological efficacy and safety of APIs in humans. To be pharmacologically effective, the API should bind specifically to the target receptor at very low concentrations (typically a protein or enzyme). Most human drug target proteins are evolutionarily conserved across species, particularly in fish [4]. As a result, environmental residues of APIs can elicit similar pharmacological responses,

i.e., ecotoxic effects, in exposed organisms. On the other hand, an effective API should also be chemically and metabolically stable under physiological conditions and sufficiently lipophilic to penetrate biological membranes and reach the target tissue. Often, although not always, chemically stable APIs are also relatively persistent, exhibiting very slow degradation kinetics in the environment (or at the wastewater treatment processes). High lipophilicity, in turn, can increase the bioaccumulation of the API residues in environmental organisms unless their elimination mechanisms are capable of biotransforming the API form into readily excreted metabolites. As a result, the fundamental pillars of drug design often produce APIs that are inherently problematic for the environment.

3.1.3. The "benign-by-design" approach

Efforts to mitigate the environmental risks posed by APIs can also be pursued through the so-called 'benign-by-design' approach. The central idea is to design pharmaceuticals to be inherently less harmful to the environment. This has been highlighted as one of the action points in the EU's Strategic Approach to Pharmaceuticals in the Environment [5] and in several recent opinion papers on sustainable drug development, drafted by international working groups [6]. However, combining favourable environmental fate with human safety and efficacy at the molecular level is challenging, especially when avoiding the migration and bioaccumulation of API residues in the environment. Thus, for the time being, research following the benign-by-design approach has primarily focused on improving the ready biodegradability (i.e., reducing persistence) of APIs [6]. In accordance with Green Chemistry principles (#10 Design for Degradation), the overall goal is to design pharmaceuticals that degrade into harmless and non-toxic substances (after being excreted by humans) in municipal wastewater and/or the environment. Prior case studies, although still limited in number, have generated confidence that this approach may also be feasible for APIs [7]. Recent stakeholder consultations also indicate that the benign-by-design approach has attracted attention from the pharmaceutical industry, as it is seen as one of the most straightforward opportunities to implement the EU's strategic approach to designing pharmaceuticals that are intrinsically less harmful to the environment [8]. Albeit adding environmental degradability as a criterion alongside human efficacy and safety in the drug design and development programs still requires persistent development of validated, high-throughput screening tools to meet this goal, not only for APIs but ideally extending to pharmaceutical excipients, many of which can be equally slowly degrading in the environment [9].

3.1.4. Life cycle assessment

The life cycle of pharmaceutical products is inherently complex, spanning a global network of production, distribution, consumption, and disposal. The environmental impacts of pharmaceutical products range from greenhouse gas emissions (from production, distribution, and waste incineration) to wastewater discharges that affect aquatic environments (Van Wilder et al., 2024). The environmental footprint of individual drug products is typically assessed through life-cycle

assessments (LCA) that account for the entire production process, including material and energy consumption, waste generation, recycling, and labour resources [10]. In addition, various reporting standards and systems, such as the Global Reporting Initiative (GRI), the Task Force on Climate-Related Financial Disclosures (TCFD), and the Carbon Disclosure Project (CDP), exist for assessing the environmental impacts of pharmaceutical production activities ('cradle-to-gate'). The manufacturing processes of APIs are generally much more material-intensive than formulation processes. Therefore, compliance with the principles of green chemistry is critical in API production. However, the environmental footprint of pharmaceutical products also depends on many other boundary conditions, such as product requirements (e.g., for storage), the need for production volumes and frequencies, as well as external factors, such as the local goods, facilities, equipment and services necessary for distribution, use, and waste incineration. As a result, a good solution in one case is not always sensible in another, but the different solutions should be weighed against all these boundary conditions ('cradle-to-grave'). This need has triggered the development of new sustainability assessment systems for the pharmaceutical sector, as well as life cycle inventories necessary to fill the data gaps relating to the global distribution and supply chains [11]. The overall goal of these constantly evolving, LCA-based assessment systems is to facilitate prospective and retrospective environmental impact assessments of pharmaceutical products to favour, respectively, the development and use of safe and sustainably produced medicines – in accordance with the Safe and Sustainable by Design (SSbD) approach put forward in the Chemicals Strategy for Sustainability [12].

References

[1] Anastas, P. T.; Warner, J. C. Green Chemistry: Theory and Practice, Oxford University Press: New York, 1998, p.30.
[2] European Medicines Agency (2024), Guideline on the environmental risk assessment of medicinal products for human use. EMEA/CHMP/SWP/4447/00 Rev. 1- Corr. (22 August 2024).
[3] COM(2022) 541 final. Proposal for a Directive of the European Parliament and of the Council concerning urban wastewater treatment (recast).
[4] Gunnarsson et al., Environ. Sci Technol. 42 (2008) 5807-5813.
[5] COM(2019) 128 final. European Union Strategic Approach to Pharmaceuticals in the Environment.
[6] Moermond et al., Environ. Sci. Technol. Lett. 9 (2022) 699; Brodin et al., Nat. Sustain. 7 (2024) 949; Vidaurre et al., Drug Discov. Today 29 (2024) 104022 (10 pp).
[7] Rastogi et al., Environ. Sci Technol. 49 (2015) 11756-11763; Leder et al., ACS Sust. Chem. Eng. 9 (2021) 9358-9368.
[8] Puhlmann et al., Eur. J. Pharm. Sci 192 (2024) 106614; Riikonen et al., Eur. J. Pharm. Sci 196 (2024) 106743.
[9] Bading et al., Chemosphere 352 (2024) 141298.
[10] Emara et al. (2018). Life Cycle Management in the Pharmaceutical Industry Using an Applicable and Robust LCA-Based Environmental Sustainability Assessment Approach. In: Benetto, E., Gericke, K., Guiton, M. (eds) Designing Sustainable Technologies, Products and Policies. Springer, Cham. https://doi.org/10.1007/978-3-319-66981-6_9.
[11] Horizon TRANSPHARM (transforming-pharma.eu/); IHI JU PHARMECO (pharmeco.eu/).
[12] C(2022) 8854 final. Commission recommendation establishing a European assessment framework for 'safe and sustainable by design' chemicals and materials; COM(2020) 667 final. Chemicals Strategy for Sustainability.

3.2 Sustainable manufacturing processes

3.2.1 Operations redesign

Sustainability is integral at every stage of pharmaceutical manufacturing, from research and development (R&D) to treatment delivery. The industry's substantial environmental footprint - producing over 200 million metric tonnes of CO2 emissions and more than 300 million tonnes of plastic waste annually - demands immediate and sustained action. [5]

Globally, the pharmaceutical sector emitted approximately 52 megatonnes of CO2 in 2015, the most recent year for which detailed data are available. That's more than the automotive sector, which released 46.4 megatonnes in the same year, and the increased demand and complexity of medicines since then will only have swollen this figure. [6]

The pharmaceutical industry has long recognised the importance of sustainability in its operations, setting the target of achieving "zero carbon emissions" within the next 30 years (or sooner for some companies). However, it is not clear how we will achieve this goal.

Pharmaceutical engineers will play a crucial role in achieving this goal by continuously improving existing facilities and designing, equipping, and building new facilities that will be operational by 2050. The "zero-carbon scenario" requires radical changes while improving the supply chain's quality and resilience.

Current strategies for sustainable pharmaceutical production, while addressing sustainability, are insufficient to meet the required standards.

According to a report by Accenture and Dassault Systèmes, greenhouse gas (GHG) emissions from the pharmaceutical industry are increasing despite efforts to decarbonise. Analysis of emissions per million dollars of revenue reveals that the global pharmaceutical sector emits approximately 55% more than the automotive industry. This number is expected to grow in line with rising global demand for therapies.
Today, only 50% of the world's population has access to essential healthcare, which is halfway towards the United Nations' goal of achieving 100% universal coverage by 2040.

3.2.2. The use of Sustainable Design

The "eco-sustainable design" (also called environmentally conscious design, eco design, etc.) can be an essential tool for improvement: it is the philosophy of designing physical objects and services in accordance with the principles of ecological sustainability.

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The goal of sustainable design is to "eliminate negative environmental impacts through skilful and sensitive design." Sustainable design-based creations use renewable resources and innovation to minimise environmental impact and maintain balance between people and the natural environment. “Humans don't have pollution problems; they have a design problem. If they designed products, tools, furniture, homes, factories and cities more intelligently from the beginning, they wouldn't even need to think in terms of waste, contamination or scarcity. Good design would allow for abundance, endless reuse, and pleasure”.

Green chemistry techniques leverage renewable resources, reduce waste, and eliminate toxic reagents and solvents throughout the pharmaceutical manufacturing process. [5.1]
The focus has been on minimising the number of process steps and reducing waste, which are probably the most significant problems since many drug syntheses need many steps and each one of those consumes resources and generates waste. [2.2]

Three core pillars of green manufacturing are [4.1]:

- solvent reduction: pharmaceutical manufacturing is the most solvent-intensive of all chemical processes, and its reliance on solvents is commonly recognised as an environmental concern. These concerns generally relate to three areas: the source and synthesis of the solvent itself; its properties in use, including accidental discharge, and disposal. [4.1]

- yield improvement: when a process is improved to increase yield, waste is reduced, and fewer solvents are required. Ultimately, yield improvement means the process is more efficient, requiring fewer resources to achieve the same result, which is good news for emissions. [4.1]

- Efficient asset utilisation: efficient utilisation of assets not only reduces emissions from API manufacturing, but lowers costs and ultimately makes the process more economically viable. Asset utilisation is closely linked with yield improvement and solvent reduction. For example, making a process improvement that results in higher yield will not only reduce the number of solvents used, but also improve asset utilisation and batch cycle times. Whereas failing to iterate on existing methods will promote inefficiencies and poor asset utilisation. [4.1]

Traditional organic chemistry has extensively utilised halogenated solvents due to their beneficial properties; however, these solvents are particularly damaging to the environment and pose health hazards to workers. [2.3] The industry has employed a variety of approaches to eliminate solvents, La Porta says, citing enzymatic processing and intensification as examples. “The machinery of biosynthesis can perform complex chemistry in aqueous environments, perhaps eliminating several steps. Process intensification, including continuous processing, can also help. [2.3]

Traditional batch synthesis in the pharmaceutical industry has favoured low temperatures and pressures, as well as dilute solutions, resulting in greater solvent use. In contrast, intensified,

continuous conditions, as used in other industries, can enable better routing and reduce overall material use. [2.3]
The use of artificial intelligence and machine learning to increase the ability to explore and optimise synthesis routes supports process intensification, as pharmaceutical regulators do. [2.3]

3.2.3. Design sustainability into the manufacturing process [8]

Moving to a circular economy: drug manufacturers are transitioning from a 'take-make-waste' model to a circular model, where waste is minimised and resources are used more efficiently. This starts with rethinking product design and embedding sustainability throughout the product life cycle. [8.1]
Transitioning to renewable energy: Many manufacturing sites are converting to renewable energy sources, such as solar, wind, and hydroelectric, to further reduce carbon emissions. [8.1]

Rethinking materials: sourcing involves discovering and testing eco-friendly materials, including both recycled and new bio-based materials. [8.1] Using less water: Manufacturers are reducing water use, optimising water treatment systems, and reusing/recycling water where possible. [8.1]

3.2.4. Digitalisation [6]

One area that has not seen significant gains is the design, engineering, commissioning, and maintenance of a manufacturing plant. Here, digitalisation promises to significantly reduce the environmental impact of these key stages of the process, while also unlocking greater process optimisation and sizeable financial savings. [6]

The industry can reorder the process toward design-test-make by moving from the current model to an R&D approach based on detailed virtual modelling. By conducting iterative design and engineering in the virtual environment, developers can implement a 'right-first-time' philosophy and significantly reduce the number of physical prototypes required. [6.1]. This translates into less consumption of physical materials, less energy used to manufacture physical prototypes, and shorter road distances for logistics operations to ensure the right components are in the right place. [6.1]
With a digital twin, virtual modelling is combined with monitoring, analysis and simulation of a physical system, so the two are ‘twinned’. [6.3].
Digital twinning can unlock a higher level of optimisation than was possible in the pre-digital era, both in terms of efficiency and process safety, because operators now have access to far greater insight into the complex variables at play. [6.3]

Considerations on the Industrial Pharmacist's contribution to the sustainability of manufacturing

processes: for executives, prioritising sustainability is not only a moral imperative, but a strategic one, essential for improving revenues, reducing costs, and fostering innovation. [5]

3.2.5 Green packaging and recycling

Pharmaceutical packaging plays a crucial role in ensuring the integrity of medicines, promoting patient safety, and facilitating compliance with regulatory and distribution requirements. However, it can also significantly contribute to environmental degradation due to limited recyclability and energy-intensive production processes. With the European Green Deal and Circular Economy Action Plan aiming to reduce packaging waste, the pharmaceutical sector is advancing its transformation accordingly.

According to EFPIA's white paper, sustainability must be embedded from the design phase of packaging, emphasising eco-design principles, harmonised collection, and efficient recycling systems, all while maintaining compliance with Good Manufacturing Practices (GMP) and product protection requirements ***(1) EFPIA, 2023)***.

Additionally, a 2023 Pharmaceutical Technology report projects that the market for sustainable pharmaceutical packaging will grow at a 15.4% CAGR to $146.3 billion by 2027, with primary packaging expected to grow the fastest. This trend is driven by regulatory requirements and evolving consumer expectations for recyclability, renewability, and increased transparency in environmental impact reporting ***(2)—Sustainable Pharmaceutical Packaging Market by Raw Material - Global Forecast to 2027.***

3.2.6 Regulatory and Policy Developments in Packaging Sustainability

The regulatory landscape in the European Union is increasingly focused on reducing packaging waste and promoting circularity, with significant implications for the pharmaceutical sector. Indeed, the European Commission's *Guideline on the Packaging Information of Medicinal Products for Human Use* (originally issued in 2018, with updates in 2023) provides harmonised recommendations on labelling and packaging text for centrally authorised medicines. While its primary focus is regulatory compliance and patient and healthcare professional information clarity, it underscores the importance of standardising packaging elements. This aspect indirectly supports broader sustainability and safety objectives. ***((3) European Commission, 2018).***

Complementing this, the EU's approach to packaging sustainability is framed by the *Packaging and Packaging Waste Directive (94/62/EC)* and the new *Packaging and Packaging Waste Regulation (PPWR) (4)*. These legislative instruments apply to all packaging placed on the EU market, including

that used in the pharmaceutical sector. The regulation sets ambitious goals, including ensuring that all packaging is recyclable by 2030, introducing recycled content targets, and reducing unnecessary packaging. This is critical, as packaging accounts for 40% of plastics used in the EU, contributes to half of marine litter, and led to 186.5 kg of packaging waste per person in the EU in 2022. Although exceptions may apply for safety-critical applications, such as sterile pharmaceutical packaging, the sector is likely to be increasingly impacted by circularity and material efficiency requirements.

In parallel with regulatory developments, professional stakeholders have also acknowledged the environmental responsibilities of pharmaceutical actors. The *International Pharmaceutical Federation (FIP)*, in its 2023 policy statement on *Environmental sustainability within pharmacy*, highlights the importance of reducing environmental waste across the pharmaceutical supply chain. It encourages actions such as minimising single-use materials, optimising packaging-related processes in pharmacy practice, and supporting systems for responsible disposal and recycling. These recommendations signal a growing awareness within the sector of its contribution to packaging waste and the need to integrate sustainability into the pharmacy sector. ((5) ***FIP, 2023***)

3.2.7 Challenges in Sustainable Pharmaceutical Packaging

The pursuit of sustainability in pharmaceutical packaging faces several challenges, particularly concerning material complexity, environmental impact, and regulatory constraints.

One of the primary obstacles lies in the complexity of packaging materials. To ensure barrier properties, such as protection against moisture, oxygen, and contamination, pharmaceutical packaging often utilises multilayer laminates composed of combinations of plastic, aluminium, and paper. However, this design, while essential for product integrity, makes the materials difficult or impossible to recycle. A 2023 *Chemical Society Reviews* article highlights the resistance of pharmaceutical polymers, such as polyvinyl chloride (PVC) and multilayer films used in blister packs, to biodegradation and mechanical recycling, noting the sector's incompatibility with conventional circularity strategies ***(6) RSC, 2023)***. Even the use of recyclable mono-materials is limited by inadequate waste management infrastructure and lack of scale-adapted recycling systems ***(11) Forcino article)***.

From an environmental perspective, recycling pharmaceutical blister packaging is complicated by its multilayer composition, which often combines aluminium with PVC or other plastics. A 2022 study published in *JOM* highlights the challenges of recovering aluminium from such packaging, as well as the environmental risks posed by incinerating PVC-containing waste, which can release hazardous pollutants ***(7) Shukla et al.,2022)***. More recently, a 2024 study by *Bassani et al.* (8) emphasises that packaging production significantly contributes to life-cycle impacts, followed by transportation and packing. It advocates ecodesign approaches for pharmaceutical packaging,

emphasising the importance of material selection and end-of-life management to reduce environmental impacts.

Finally, regulatory and operational constraints may further complicate potential innovations in the field. Indeed, pharmaceutical packaging must comply with strict pharmacopoeial and quality standards to ensure the sterility, stability, and tamper resistance of the pharmaceutical product. Any change to packaging design or material composition must undergo extensive validation, which often delays projects and adds costs, deterring experimentation with more sustainable options.

3.2.8 Sustainable Packaging Solutions and Innovations in the Pharmaceutical Industry

Industry stakeholders are increasingly recognising the need to align pharmaceutical packaging with sustainability goals. In a 2023 expert panel hosted by the Convention on Pharmaceutical Ingredients (CPHI), professionals identified key strategies to improve sustainability in pharmaceutical packaging. These include shifting to recyclable or flexible materials (e.g., bio-based plastics, hemp, recycled cotton fibre, and sugarcane) to reduce single-use plastics and overpackaging, and adopting digital technologies to optimise manufacturing efficiency and minimise waste. While efficacy remains the top priority for patients, it has been noted that sustainable packaging practices, such as limiting secondary packaging, can enhance brand perception and meet evolving consumer expectations (9) (***CPHI Expert Panel, 2023).***

These expert insights are echoed in the 2024 *CPHI Pharmaceutical Packaging Report*, which emphasises the growing need to balance sustainability, regulatory compliance, patient safety, and operational efficiency. The report highlights the industry's growing interest in recyclable and biobased materials. However, challenges persist, particularly in primary packaging, where barrier requirements and contamination risks limit the use of greener alternatives. Efforts such as the Circularity in Primary Pharmaceutical Packaging Accelerator (CiPPPA) initiative are working to address recyclability in this area. The report also emphasises the environmental impact of packaging across the supply chain, with logistics and material choices playing a significant role in emissions. As regulatory pressure mounts, setting targets like 100% recyclability and 30% recycled content, the report calls for early action to meet future standards without disrupting quality or increasing costs ***(10) CPHI Packaging Report, 2023).***

Furthermore, the pharmaceutical industry is increasingly adopting circular economy principles to reduce its environmental impact. Companies are currently exploring sustainable packaging options, including mono-materials, biodegradable plastics, and plant-based alternatives. Key industry players have made significant strides, including reducing plastic packaging by 35% and aiming for 100% recyclable packaging by 2025, and introducing reusable clinical trial packaging with a 98% return

rate. These initiatives align with regulatory goals that promote sustainability, as outlined in the EFPIA white paper, which advocates eco-friendly materials and recyclable packaging systems. ***((1) EFPIA White Paper on Circular Economy)***

References

1. EFPIA White Paper on Circular Economy. EFPIA, 2023 : https://efpia.eu/media/htreo44j/white-paper-on-circular-economy.pdf
2. Sustainable Pharmaceutical Packaging Market by Raw Material (Plastics, Paper & paperboard, Glass, Metal), Product Type, Process (Recyclable, Reusable, and Biodegradable), Packaging Type(Primary Packaging), and Region - Global Forecast to 2027 : https://www.marketsandmarkets.com/PressReleases/sustainable-pharmaceutical-packaging.asp
3. European Commission Packaging Guidelines. European Commission, 2018
4. Packaging and Packaging Waste Directive & Regulation, European Commission : https://environment.ec.europa.eu/topics/waste-and-recycling/packaging-waste_en
5. International Pharmaceutical Federation (FIP), Statement of Policy, "Environmental sustainability within pharmacy", 2023: https://www.fip.org/file/5618
6. Chemical Society Reviews. RSC Review, 2023
7. JOM Journal, "Waste Pharmaceutical Blister Packages as a Source of Secondary Aluminium", Schukla et al. Springer, 2022
8. "Life cycle assessment of pharmaceutical packaging addressing end-of-life alternatives", Bassani et al., Elsevier, 2024 : https://www.sciencedirect.com/science/article/pii/S0956053X23007596?via%3Dihub
9. Sustainability in Pharma Packaging – Expert Panel. CPHI, 2023
10. CPHI Pharmaceutical Packaging Report. CPHI, 2023
11. Forcinio, H. "Packaging Becomes More Sustainable." *Pharmaceutical Technology*, April 2023, Vol. 47(4), pp. 36–38, 49 : https://www.pharmtech.com/view/packaging-becomes-more-sustainable

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3.3 Sustainable waste management

3.3.1 Company and municipal treatments

In the UK alone, for example, around 80 million tonnes of waste in total are generated every year. And with household waste alone, between 1991-92 and 2007-08, each person in England generated an average of 1.35 pounds of waste per day.

Experience has shown that there is no completely safe method of waste disposal. All forms of disposal have adverse effects on the environment, public innovation and local economies. Landfills have contaminated drinking water. Waste incinerated has contaminated the air, soil, and water. Most water treatment systems change the local ecology. Attempts to control or manage waste after it has been generated fail to eliminate environmental impacts.

Toxic components in household products pose serious health risks and exacerbate waste. In the United States, approximately seven pounds of poisonous materials are contained in every ton of household waste. These materials include heavy metals such as nickel, lead, cadmium, and mercury from batteries, as well as organic compounds found in pesticides and consumer products, including air freshener sprays, nail polishes, detergents, and other products. When burned or buried, toxic materials also pose a serious threat to public health and the environment.

The only way to avoid environmental damage from waste is to prevent its generation. Preventing pollution means changing the way activities are conducted and eliminating the source of the problem. It doesn't mean doing without; it means doing differently. For example, preventing waste pollution caused by disposable drink containers does not mean giving up drinks; it simply means using reusable bottles. When we plan to discard items, we often fail to exercise sufficient care in the design process.

3.3.2 Reduction of waste from the pharmaceutical industry

Millions of medicines are thrown away every year. This waste is mainly due to errors in the logistics phase. However, cases in which quality medicines, delivered in perfect conditions and within the expected timescales, still end up in waste are equally common. The reason? The expiry date.

90% of medicines remain safe and effective for at least five years after the "expiry" date, yet they are currently disposed of as soon as that date passes. By conducting more in-depth studies on the stability of drugs under development, it may be possible to set a more precise expiry date, thereby extending the average product life.

Some industry-wide efforts could also be made on drug packaging. Packs and blisters of different shapes and sizes require more complex and challenging disposal processes to standardise. By homologating the packages as much as possible, work during the disposal phase would be significantly simplified, streamlining processes.

3.3.3 Liquid waste - Environmental monitoring (EM) [7]

While pharmaceutical manufacturing's overall contribution is small relative to patient use and inappropriate disposal, inadequately managed manufacturing emissions can affect local environments and receiving waters. [7.1]

Environmental monitoring (EM) relies on mass balances to estimate losses and chemical analysis of waste stream samples to determine actual concentrations, thereby removing uncertainty. [7.1] Wastewater samples collected at or near the point of generation in manufacturing typically have much higher API concentrations, so they require less analytical sensitivity. [7.1] Testing wastewater at the manufacturing end of the pipe provides more representative data for actual contaminant concentrations. [7.1]

Selecting the most appropriate analytical method must be discussed and determined in concert with the analytical laboratory. It is essential to understand the quality assurance/quality control (QA/QC) specifications for the analytical methods to be used. These include the detection and quantitation limits, as well as matrix interferences. [7.2]

Technology innovations, such as real-time monitoring systems, can deliver more accurate, efficient, and cost-effective monitoring, potentially improving continuous monitoring, data integration, and predictive analytics, enhancing programmes to monitor pharmaceuticals in the environment. Moreover, regulatory changes will lead to more stringent quality standards and increased reporting requirements. [7.4]

Emerging contaminants, such as microplastics, PFAS, and endocrine-disrupting chemicals, may require updates to monitoring protocols to ensure effective management. [7.4]
Data management and analysis will extract meaningful insights and inform decision-making. Machine learning and artificial intelligence can be used to process large volumes of data and identify trends, anomalies, and potential risks associated with effluent discharges. [7.4]

3.4 Sustainable energy consumption

3.4.1 Energy consumption for pharmaceutical utilities

Data from an electrical energy analysis of a medium-sized pharmaceutical facility are presented in the following table.

Rank	Description	Electrical nominal power (KW)	%
I	Refrigeration units	1.180	67,8
II	Air conditioning systems	225,7	12,7
III	Air compressors	89	5,1
IV	Dust collectors	63,1	3,6
V	Steam generators	44,4	1,5
	Total of facility	**1740**	**100**

Approximately 84% of the installed electrical power is used for air treatment systems.

The facility's annual natural gas consumption is approximately 360,000 cubic meters, of which 204,000 cubic meters are used during the cold season (mid-October to mid-April), when environmental heating is required. In the remaining six months, the consumption is 156,000 cu m. The data clearly indicate that air treatment systems are the primary energy users for efficiency measures.

3.4.2 Energy consumption for pharmaceutical production

The difference between total consumption and total consumption for technological users can roughly estimate production energy consumption. With a more detailed analysis, it is possible to obtain more accurate values for the electrical and thermal consumption of each piece of equipment. The results of this analysis, in addition to providing helpful information for determining the production costs of each product, will highlight the most "energy-intensive" production processes on which to focus attention for reducing consumption.

3.4.3 Energy consumption for logistics processes

In logistics processes (warehousing and transport), the electrical/thermal energy needs are represented by the air treatment systems of the warehouses, the means of handling materials (forklifts, etc.) and the means of transport of production materials, semi-finished products, finished products and personnel entering/exiting respectively to/from the production site. In this case, it is also possible to conduct a detailed analysis of consumption and identify the priorities for interventions to reduce consumption or increase efficiency.

Future facilities will be sustainable [8.2]. The next generation of pharma facilities aspires to the highest sustainability certification. To achieve this, the entire project life cycle, from design and construction to operation, must be considered. Best practice in this regard focuses on:
- Significant reductions (of at least 40%) in water use;
- On-site renewable energy generation, such as rooftop solar panels and the use of electric boilers;
- Efficient LED lighting fixtures and less electric power use for lighting;
- Reduction strategies for embodied carbon used in construction materials (like concrete);
- Diverting on-site construction waste from landfills to recycling facilities. [8.2]

3.4.4 Use of green energy

The ongoing greening (decarbonization) of electricity grids is already changing our priorities as we map out the roadmap to zero carbon emissions.

The prioritisation challenge is particularly evident when evaluating the purchase of "green electricity" contracts as an effective carbon-reduction strategy. If, in the future, we have a 100% renewable grid, the use of (for example) electric vehicles and heat pumps will be truly green.
Examples of energy efficiency success stories can be found throughout our industry. A pharmaceutical company has adopted heat recovery from chillers (a subset of "heat pumps") as standard for all new models. This has improved suppliers' offerings and designers' understanding of this technology, benefiting those who have not yet tested this approach.

In Europe, eco-design regulations are helping us move towards net-zero carbon, with HVAC heat recovery now mandatory and fan, chiller, and boiler efficiency requirements driving rapid, incremental improvements in the efficiency of new pharmaceutical buildings.

Two key resources of interest to all pharmaceutical engineers are the ISO 50001 standard for energy management and the energy-efficient design (EED) process set out in Irish Standard (IS) 399.

3.4.5 Interventions for energy efficiency in the pharmaceutical industry

The results of a sound analysis of energy consumption can inform intervention priorities aimed at reduction. The following seven points indicate some types of interventions for energy efficiency:

- Recovery of saturated steam, handy for the sterilisation of production plants
- Heat recovery for the production of process hot water;
- Chilled water generation
- Reduction in consumption and consequent economic savings
- Investment paid off in a few years, thanks to the savings obtained
- Access to incentives (TEE or white certificates) for the installation of energy efficiency systems

- Greater environmental sustainability thanks to the reduction of polluting emissions.

A viable option for reducing energy consumption in the pharmaceutical industry is installing a cogeneration or trigeneration plant.

High-efficiency cogeneration (CAR) is among the most widely used technologies and is increasingly chosen by the pharmaceutical industry. Most of these industries require thermal energy, in the form of saturated steam, hot water and chilled water.
Cogeneration plants, also known as Combined Heat and Power (CHP) plants, are industrial facilities that produce both electricity and thermal energy simultaneously, resulting in fuel savings and improved energy efficiency.

The heat produced by electricity generation is, in fact, recovered and reused in other industrial processes. In this way, waste and harmful emissions are reduced.

Trigeneration is the combined production of electricity, heat and cooling energy (Combined Cooling, Heating and Power, CCHP). It is carried out using a cogeneration system that generates electricity and heat, combined with an absorption refrigeration machine powered by heat recovered from the cogenerator. For the pharmaceutical industry, the absorber that is installed can generate chilled water with a 7÷12 °C circuit for use in air treatment systems.

A significant environmental impact, in terms of energy and natural resource consumption, characterises systems that produce water and steam for pharmaceutical production. For this reason, companies should pay particular attention to both the efficiency of these systems and fluid consumption.
The companies' attention is focused, in particular, on the indirect steam generator, which is required to produce pure or ultra-pure, sterile, non-pyrogenic steam to sterilise components of specific equipment.

The key elements are:

- SIP systems
- Pre-product sterilisation
- Humidification
- Heat transfer for sanitary use
- Steam distribution and condensate recovery
- Steam generation

A significant reduction in energy consumption for these purposes can be achieved by improving system efficiency and reducing utility use.
Using process intensification to optimise space, time, and yield in manufacturing plants, along with comprehensive metrics that account for these factors, will be more indicative of the key drivers of sustainability. [1.2]

Improving process productivity and efficiency, implementing process intensification, and other innovative solutions can also reduce cleanroom classification, significantly improving sustainability footprints. [1.2]

Another option to reduce natural gas use is to replace stainless-steel reactors and piping with single-use plastics, eliminating the need for sterilisation-in-place cleaning. Single-use technologies, especially when combined with continuous processes, enable process intensification, thereby reducing energy use, environmental footprint, and carbon emissions. However, these technologies generate more plastic waste. [1.2]
Implementing single-use technologies in intensified processes offers significant energy, water, and electricity savings. [1.2]

3.5 Sustainable water conservation

Natural gas and water are the two most significant natural resources consumed in pharmaceutical production. Natural gas is primarily used to generate thermal energy. As regards the water resource, it needs to be clarified that in reality it is not "consumed" (as happens with natural gas, which is "destroyed in combustion and transformed into CO_2). The water is sourced from the environment (typically rivers or public or private wells), then purified and distributed to residential or industrial users. In pharmaceutical facilities, it is used in processes and for cleaning.

After use, the water is contaminated by soluble/insoluble substances, "released" during use, and is transformed into "wastewater".

Typically, all wastewater resulting from various uses is collected in dedicated drainage pipes. Based on their composition and the destination of the discharge (sewerage or surface water), wastewater can be subjected to a purification process, by which a part of the contaminating substances present in the wastewater are removed. The environmental impact of wastewater depends on several factors, such as quantity, contaminant concentration, and ecotoxicity; for APIs, the pharmacological activity should also be considered (e.g., antibiotics, endocrine-active substances, or endocrine disruptors).

3.5.1 Reduction of water consumption

In pharmaceutical production, cleaning is the activity that consumes the most energy and water. When a cleaning process is developed, a solvent (typically water), one or more detergents, sanitisers, and energy are used, including heating, fluid circulation, and drying, as well as the possible sterilisation of the equipment. Each of these elements has an environmental impact. Analysing the process in detail, we can make the following considerations:

- Water is generally the chosen liquid as it is non-polluting in itself and an excellent solvent because it is capable of dissolving or dispersing most substances. Water is generally used as is for a pre-wash, often prolonged at non-high-temperature conditions, to disperse or dissolve most residues. At the end of this first step, a solution/dispersion is obtained,

containing most of the residues. The first wastewater must undergo specific treatments capable of reducing the pollutant load by at least 90% to enable the residual water to be conveyed to conventional purification systems.

- Detergents are essential in cleaning processes. To make an ecological choice, we will focus on using the smallest possible quantity, selecting products that are fully biodegradable within a reasonable timeframe, excluding those that are highly toxic to living organisms (ecotoxicity), particularly substances with PBT properties (Persistence/Bioaccumulation/Toxicity).

- Similar considerations must be made for any sanitisers used at the end of the cleaning process, to ensure the elimination of the majority of microorganisms

- The sustainability of the energy consumption, necessary for the heating and circulation of fluids in automatic systems (CIP) and final sterilisation when required (SIP), must also be assessed.

3.5.2 Water conservation in Biomanufacturing [1]

Processes such as upstream cell culture and downstream purification are inherently highly water-intensive. [1.4]
Single-use plastics eliminate the need for sterilisation-in-place cleaning of stainless-steel bioreactors and piping. [1.2]
The DynaSpin Single-Use Centrifuge is a scalable, efficient solution for cell harvest unit operations, supporting the production of recombinant proteins, monoclonal antibodies, and bioengineered vaccines. It has been shown to generate significantly less filter and liquid waste than traditional depth-filtration workflows, which typically consist of two stages. The increased filter capacity reduces the number of filters needed. [1.4]

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3.5.3 Contribution of *Clean by Design*

A great deal has been written about cleanliness and its validation in pharmaceutical and biopharmaceutical applications. Much less has been written about designing systems, piping, process machinery, and vessels that are easy and quick to clean in a robust manner.
CIP cleaning is used by approximately 70% of biopharmaceutical plants globally. Nearly all of these facilities employ an “excessive” CIP cleaning process because the facility and its critical components were not designed for ease of cleaning.
Recently, new valve types have become available, but they are difficult to clean with CIP, so long, chemically aggressive CIP cycles are used (which, in turn, damage diaphragms and seals). The other 30% of biopharmaceutical plants continue to change all elastomers at product changes and perform manual cleaning of valves/COPs and other components.
Some technical measures can reduce CIP cycle time and water use by over 80%. These measures include the complete removal of dead legs, improved drainage, reduced total pipe volume and surface area, and the use of valve diaphragms compatible with the cleaning process conditions.

An 80% reduction in CIP cleaning water would result in a 33% reduction in energy consumption and significant water savings. The CbD (Clean by Design) approach provides a practical solution for significantly reducing the carbon footprint and water consumption.
Some improvements are possible in existing systems; however, the most significant gains, with a very short ROI, are achievable only with new systems designed with cleanability as a critical objective.

3.5.4 Carbon footprint of “pharma-grade” water and steam consumption

The production of water and steam to be used in the pharmaceutical production process involves, in addition to the consumption of the "water" resource, also the consumption of electrical and/or thermal energy. Water purification systems employ osmosis membranes and distillers to produce clean water or steam. For that, the use of "pharma grade" water and steam has a considerable environmental impact, which can be measured in terms of "*carbon footprint*".

ENVIRONMENTAL SUSTAINABILITY POSITION PAPER

3.6 Sustainable atmospheric emissions

3.6.1 Air pollution controls

A significant environmental impact of pharmaceutical production is the emission of pollutants into the atmosphere. These are quite diverse depending on their origin. We can refer to the following sources:

- Bulk API production with chemical synthesis processes
- Bulk API production with biotechnological processes
- Medicinal specialities production
- Services for pharmaceutical production.

Chemical synthesis processes generally have the greatest environmental impact due to the intrinsic toxicity and volatility of the substances used, and the difficulty of collecting and treating gaseous emissions. The contaminants in atmospheric emissions are not only gases or vapours but also dusts; suitable filters can be used to capture these.

3.6.2 Standardised assessment of the environmental impact of gaseous emissions

For a standardised evaluation of the environmental effects of gaseous emissions produced by production activities, the use of the "*GHG Protocol*" is recommended.
The World Resources Institute and the World Business Council for Sustainable Development developed the protocol. An application guide for this tool was published in September 2009 by the Department for Environment, Food and Rural Affairs (DEFRA), titled "*Guidance on how to measure and report your greenhouse gas emissions*".
The "*GHG Protocol*" is a methodology for identifying and quantifying greenhouse gas emissions, including both direct and indirect sources, through a comprehensive, detailed analysis.

Different technologies or equipment can be used, according to the type of emission:

a) localised or dedicated systems
   - wet scrubber
   - mechanical air filtration unit
   - activated carbon absorption systems
   - cryogenic systems

b) general systems:
   - incinerators of various types (with a collection system)
   - "waste-to-energy" facilities.

3.6.3 Example of Life Cycle Assessment (LCA) applied to a medicinal product

Starting Assumption:

- Functional unit: 1 pack = 10 tablets × 500 mg API/each (5 g total API).
- Key results (GWP & selected indicators)
- Estimated total GWP (baseline scenario): ≈ 0.56 kg CO_2e per pack (treatment course)
- Estimated water consumption: ≈ 7.7 L per package
- API potentially released into the sewage system (estimate, 70% excretion): 3.5 g per package

Main contributions to GWP (in descending order)

- API synthesis (dominant): 0.40 kg CO_2e
- Production energy: 0.08 kg CO_2e
- Packaging: 0.0375 kg CO_2e
- Excipients: 0.025 kg CO_2e
- Transport + End-of-life: 0.02 kg CO_2e

Example scenario based on the main assumption

- API mass per package: 0.005 kg (5 g)
- API GWP intensity (traditional synthesis): 80 kg CO_2e/kg
- Excipient GWP intensity: 5 kg CO_2e/kg
- Production energy: 0.20 kWh/package; electricity factor 0.40 kg CO_2e/kWh
- Total packaging: 0.015 kg (blister pack + box)
- % API excreted unchanged: 70%

Note: these are illustrative values. Replace with company inventories or LCA databases (e.g. ecoinvent) for operational assessments.

Sensitivity analysis - leverage examples

- API synthesis improvement: reduce API GWP from 80 to 30 kg CO_2e/kg → total GWP drops from 0.56 to 0.31 kg CO_2e (≈ -44%).
- 50% reduction in packaging → modest savings (~3%) on total GWP.

Conclusion: interventions in API synthesis offer the greatest potential for GWP reduction.

Operational recommendations

- Prioritise investments in green chemistry, yield optimisation and solvent recovery;
- Include LCA screening in the early stages (candidate selection) to assess trade-offs;

- Adopt process intensification (continuous manufacturing) and digital twins to reduce consumption;
- Ecodesign of packaging: favour recyclable mono-materials and evaluate e-leaflets where permitted;
- Estimate the annual mass of APIs released into the network and collaborate with WWTP/authorities on mitigation measures;
- Integrate environmental KPIs (kg CO_2e/package; L water/package; g APIs released/year) into CSRD reports and company dossiers.

3.7 Sustainable commercial phase

3.7.1 Package leaflet – the purpose and challenges

According to current European legislation, a paper package leaflet (PL) is mandatory for inclusion in every pharmaceutical package of a medicinal product that holds a Marketing Authorisation in a European country (1). The paper leaflets must be written in the official languages of the country of destination. The primary aim of the leaflet is to provide end users, such as patients and animal owners, with essential information about the medicinal product to enable safe and effective use. It is designed to inform patients about the medication's indications, dosages, administration, precautions, potential side effects, storage conditions, and other relevant information, presented in a structured format that adheres to specific content guidelines.

Despite its importance in supporting patient safety, paper leaflets present challenges (2). In the patient leaflet, information must be accurate, and the readability and language must be accessible to the reader. One challenge is the lengthy process of providing patients with the most up-to-date information about their medications. New quality and safety information is constantly being collected and incorporated into the package leaflet (PL) and the summary of product characteristics (SPC) through a regulated process. Regulatory updates and revisions must be accurately reflected in the package leaflet. Keeping the leaflet up to date with the latest information, including new safety warnings or changes to dosage recommendations, is an ongoing process. The regulatory process can take several years (and even a new regulatory process may need to be started in parallel before the previous one is finalised) before the updated information is available to the patients in the paper leaflet.

3.7.2 Electronic package leaflet as an alternative to paper leaflet?

To support the safe and sustainable use of medicines, there is a growing need to provide patients with accurate, comprehensive, and legible information throughout the entire product lifecycle. The electronic package leaflet may be superior to the paper leaflet in providing patients with up-to-date information more quickly. The limitations of the paper package leaflet have been discussed, particularly in light of the recent reform of European pharmaceutical legislation (3). The transition to a more digital world is envisioned to deliver cost reductions and environmental benefits (4). The

transition will be supported on several fronts, including the shift from paper-based medical records and prescriptions to electronic systems (5).

Proposed by the European Pharmaceutical strategy in 2020, a better use of electronic product information (ePI) (a combination of both the broader summary of product characteristics, SPC, and the package leaflet) could support a wider availability of medicines across European member states (6). The development of an electronic system in where the datamatrix code from the medicine pack can be scanned and the electronic product information accessed would also allow the removal of the paper leaflet from the pack, resulting in resource savings and better environmental sustainability (e.g. less energy and materials needed to produce packages without a paper package leaflet, smaller package dimensions, less storage capacity and less paper waste). Such a development could facilitate the easy provision of medical information in various languages and according to the patient's preference, which is crucial in today's societies. As medications become more complex and personalised, adaptable digital systems are also required.

Several pilot projects are underway in European countries to eliminate paper package leaflets from hospital products (2). The most recent pilot projects have evaluated the possibility of including prescription medicines administered by healthcare professionals, such as vaccines, in the program. Based on the pilot projects, there is general support for removing paper package leaflets from hospital products. Up-to-date product information is always electronically available, which is particularly important from a drug safety perspective. In addition, packaging without paper leaflets is considered more sustainable because it entails lower production and material costs. As measures are needed to address availability issues, standard packages could be considered.

On the other hand, several parties have emphasised the importance of maintaining the paper package leaflet and using ePL only as supplementary (7). In a joint statement, the Pharmaceutical Group of the European Union (PGEU) and several other parties called for inclusivity without enacting discriminatory practices that increase the digital divide and limit individual choice. The electronic package leaflet may impose a level of digitisation without taking into account those who do not want to or cannot use a smartphone/tablet, or who are unable to do so due to age, geographical location, disability, health, income, religion, or social situation. The different ways of offering a non-digital solution to those in need should be explored. Privacy and personal data protection should also be considered.

Some countries outside Europe have adopted electronic solutions, such as Australia, where ePLs (consumer medicines information, CMI) have been in use for several years (8), and Japan, where ePLs using GS1 coding have been introduced, and paper package leaflets were phased out by the end of July 2023 (9).

References

1. European Commission (EC), 2023. Notice to Applicants – Guideline on the packaging information of medicinal products for human use authorised by the Union. Rev. 14.8 https://ec.europa.eu/health/sites/health/files/files/eudralex/vol-2/2018_packaging_guidelines_en.pdf

2. Skogman-Lindqvist C, Lapatto-Reiniluoto O, Sirviö M, Sivén M 2023. Benefits and challenges of ePL (electronic package leaflet)-Review of ePL pilots in hospital settings in Europe. Eur. J. Pharm. Sci., 191, 106605. https://doi.org/10.1016/j.ejps.2023.106605

3. European Commission (EC) 2023, 2023. Proposal for a regulation of the European Parliament and the Council, COM(2023) 193 final, 2023/0131(COD). https://health.ec.europa.eu/medicinal-products/pharmaceutical-strategy-europe/reform-eu-pharmaceutical-legislation_en

5. European Commission (EC), 2023. Europe's Digital Decade. https://digital-strategy.ec.europa.eu/en/policies/europes-digital-decade

6. European Commission (EC), 2020. Pharmaceutical Strategy for Europe 25 November 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0761

7. Joint Statement on Electronic Product Information (ePI), CPME, PGEU, BEUC, AGE, HOPE, AIM, EFN, EAHP. 15.11.2025 https://www.pgeu.eu/publications/joint-statement-on-electronic-product-information-epi/

8. Australian Government, Therapeutic Goods Administration (TGA), 2020 https://www.tga.gov.au/resources/resource/reference-material/improved-consumer-medicine-information-template

9. Nagaoka M, Takamine T, 2022. E-labelling system in prescription medicines in Japan: measures and perspectives in the pharmaceutical industry. Translat. Regulat. Sci. 4 (1),12–19. https://www.jstage.jst.go.jp/article/trs/4/1/4_2022-001/_pdf/-char/en

10. European Medicines Agency (EMA) 2025. Reflection paper on linking to electronic product information (ePI) from EU medicine packages. EMA/95076/20252. https://www.ema.europa.eu/en/documents/other/draft-reflection-paper-linking-electronic-product-information-epi-eu-medicine-packages_en.pdf

3.8 Disposal of medicinal products

3.8.1 Origins and Handling of Unused or Expired Medicines in the EU

Medical waste has multiple origins and can be generated at any stage of the medicine lifecycle, but primarily at the consumer level, i.e., via excretion after consumption or as unused or expired medicines (UEM). The demographic and lifestyle changes, for example, the ageing of the population and the rise of chronic diseases, can lead to increased pharmaceutical usage and consequently, increased likelihood for UEM. There are several ways medicines can end as UEM: patients may not complete their prescribed courses due to recovery, changes in treatment, or nonadherence. Preventive stockpiling of over-the-counter (OTC) drugs that expire before use is another significant contributor to this issue. Additionally, the dispensing of more-than-needed prescriptions, errors, and discontinued refills can lead to the accumulation of unused medicines in households. Studies suggest that a notable percentage of dispensed medicines remain unused; for example, estimates range from 3% to 8% of medicinal products sold in Europe. [1]

Household disposal practices for these UEM vary across the EU because their handling is regulated at the Member State level. Standard methods include returning to the collection point, disposing of it in the household bin, and flushing it down the sink or toilet. Liquid medications are more frequently disposed of in sinks or toilets, while solid and semi-solid forms are often placed in household waste. The improper disposal methods can lead to pharmaceutical leakage into the environment, potentially harming aquatic organisms and contributing to antimicrobial resistance. Concerns also exist regarding the risk of accidental ingestion or intentional misuse of unused medicines left unsecured in homes. [1] [2]

To address environmental pollution and public health risks associated with UEM, many EU countries have implemented collection schemes and take-back systems, with on-site containers at pharmacies being the most common. These systems can be voluntary, with pharmacies and the pharmaceutical industry taking the initiative, or mandatory, often driven by Extended Producer Responsibility (EPR) legislation [1].

Several EU member states have established national collection programs. For instance, France has a mandatory EPR scheme managed by PRO Cyclamed, which achieves a high participation rate among pharmacies and patients, with collected medicines being incinerated for energy recovery. Spain and Portugal also have national EPR schemes (SIGRE and SIGREM, respectively), which are financed by the pharmaceutical industry and utilise pharmacies as collection points. In Sweden, retail pharmacies commonly act as collection sites under a mandatory EPR scheme, and some pharmacies even offer bonus points for returning unused medicines. While some countries, such as Finland and Denmark, classify all unused medicines as hazardous waste and require high-temperature incineration, others do not. The EU List categorises cytotoxic and cytostatic medicines (18 02 07) and other medicines (18 02 08) as dangerous waste (2000/532/EC). [1]

The EU Directive 2007/83/EC (Article 127b) requires Member States to ensure that appropriate collection systems are in place for unused or expired medicinal products. Additionally, Articles 54 and 11 of the same directive require that the outer packaging and the summary of product characteristics of medicinal products refer to any appropriate collection system. Despite these

regulations, the implementation and effectiveness of collection schemes vary across the EU. Some countries consider disposal via mixed solid household waste environmentally sound in certain conditions. [1]

Efforts are also underway to prevent the generation of unused medicines through measures such as improved disease prevention, personalised medicine, and more appropriate packaging sizes. Marketplaces and redistribution platforms for unused, near-expiry-date medicines are being explored in some EU countries, such as the Netherlands, to reduce waste and achieve economic savings. However, concerns about counterfeits and quality assurance often limit the widespread adoption of resale or re-dispensing practices. [1]

Awareness campaigns play a crucial role in educating the public about the proper disposal routes for unused medicines. Initiatives like the #MedsDisposal campaign, a European collaboration, aim to inform consumers about available take-back systems. Nudging techniques, such as reward systems, are also used in Sweden to encourage the return of unused medicines to pharmacies. [1]

The revised Urban Waste Water Treatment Directive (UWWD) in the EU introduces Extended Producer Responsibility for certain products, including those used for human medicinal purposes. This means that producers will be required to contribute financially to cover the costs of additional treatment needed to remove micropollutants, including pharmaceutical residues, from urban wastewater. This legislative development signifies a growing focus on addressing pharmaceutical pollution at its source and throughout the waste management process in the EU.

3.8.2 Treatment of Wastewater Containing Pharmaceuticals in the EU

Wastewater containing pharmaceuticals in the EU may originate from various sources, including manufacturing facilities, hospitals, and households. Untreated or inadequately treated wastewater containing active pharmaceutical ingredients (APIs) and their metabolites poses significant risks to the environment and human health. The release of antimicrobials can contribute to the development of antibiotic resistance in environmental organisms. Pharmaceutical residues can also have toxic effects on aquatic organisms. [1]

The EU is addressing this issue through several regulatory frameworks and initiatives. The revised Urban Wastewater Treatment Directive (Directive (EU) 2024/3019 of the European Parliament and of the Council of 27 November 2024 concerning urban wastewater treatment, UWWD) introduces new requirements for wastewater treatment, including quaternary treatment specifically targeting micropollutants, such as pharmaceuticals. This advanced treatment is mandated for urban wastewater treatment plants (WWTPs) serving agglomerations with a population equivalent (p.e.) of 150,000 or more by 2045, with interim targets. Member States must also establish lists of areas sensitive to micropollutant pollution, for which WWTPs with a population equivalent (p.e.) of 10,000 or more will require quaternary treatment, based on risk assessments. [3]

The UWWD also introduces the concept of Extended Producer Responsibility (EPR) for pharmaceuticals and cosmetics. This means that producers placing these products on the EU market

will be financially responsible for the additional costs of quaternary treatment needed to remove their residues from urban wastewater. The contributions of producers should be proportionate to the quantities and hazardousness of the substances in their products. [3]

For industrial pharmaceutical wastewater, the WHO provides guidance on wastewater and solid waste management for antibiotic manufacturing. [4] This guidance emphasises the need for at least pre-treatment, and ideally complete treatment, at the manufacturing plant to reduce the pollutant load before discharge. [5] It outlines technology targets for liquid effluent and solid waste, including stringent targets for fermentation-based processes (≥ 99% API removal for solid waste) and other processes (≥ 80% API removal for solid waste). The guidance also discusses assessment methods and advanced treatment technology options for both wastewater and solid waste. Examples of treatment technologies mentioned include enhanced hydrolysis, chemical or enzymatic treatment, incineration, and secure landfill for solid waste. For sewage treatment, advanced technologies such as membrane filtration (ultrafiltration, nanofiltration, and reverse osmosis) and enhanced hydrolysis are highlighted.

Urban WWTPs in the EU utilise various treatment stages. While conventional secondary treatment is not always sufficient to remove pharmaceutical residues, tertiary treatment, often focused on nutrient removal (nitrogen and phosphorus), can offer some reduction. However, the new quaternary treatment specifically aims to remove micropollutants. Technologies for quaternary treatment include ozonation, activated carbon filtration, and advanced oxidation processes. The selection of appropriate technologies depends on the specific pharmaceuticals present and the desired removal efficiency. [3]

The Environment Agency in England and Wales has also conducted research on the causes and consequences of feminisation of male fish in rivers, highlighting the impact of endocrine-disrupting substances, including pharmaceuticals, in sewage effluent. This underscores the environmental necessity for improved wastewater treatment. [6]

Monitoring and assessment are crucial aspects of managing pharmaceutical wastewater. The UWWD mandates monitoring of WWTP inlets and outlets for various pollutants. [3] Mass-balance calculations and chemical analyses are used to quantify antibiotic concentrations in industrial effluents. [4]

Despite progress, challenges remain in the effective treatment of pharmaceutical wastewater across the EU. The EFPIA (European Federation of Pharmaceutical Industries and Associations) has expressed concerns about the potential impact of the UWWD on the pharmaceutical industry's competitiveness and access to medicines, calling for an urgent review. [7]

Overall, the UWWD seeks to balance responsibility for the treatment of pharmaceutical residues between producers and national authorities through a shared-funding model. This approach aims to ensure the financial sustainability of advanced wastewater treatment while safeguarding the

availability and affordability of essential medicines. A collaborative approach among the pharmaceutical industry, policymakers, and the public is necessary to strike a balance between environmental protection and ensuring access to critical drugs.

3.8.3 Socio-Economic Factors of Pharmaceutical Pollution in the EU

Demographic and lifestyle changes, such as population ageing and the rise of chronic diseases, are key drivers of increased pharmaceutical use. This higher consumption naturally increases the potential for UEM in households. The availability of generic treatments has also contributed to increased pharmaceutical usage.

Household disposal practices of UEM, which vary across socio-economic groups and regions, significantly contribute to pharmaceutical pollution. Factors such as awareness of proper disposal methods, convenience of collection schemes, and access to information influence whether UEMs are returned to pharmacies or improperly discarded into household waste or sewage systems. [1]

The implementation of Extended Producer Responsibility (EPR) schemes for UEM in several EU countries, such as France, Spain, Hungary and Portugal, places the financial and organisational burden of collecting and disposing of UEM on pharmaceutical companies. This shift in responsibility aims to reduce the economic impact on taxpayers.

Regarding wastewater treatment, the pharmaceutical industry, as represented by EFPIA, has raised concerns that the arbitrary selection of the pharmaceutical and cosmetic industries to fund the cleanup of micropollutants could disproportionately affect their competitiveness and potentially lead to supply disruptions of critical medicines, especially in the off-patent sector. They argue that the "polluter pays" principle should be applied more broadly across all industries that contribute to micropollutant emissions. [7] The revised UWWD mandates EPR for pharmaceuticals and cosmetics to cover a significant portion of the costs associated with quaternary treatment, which is necessary to remove micropollutants. The financial contributions of producers are intended to be proportionate to the quantities and hazardousness of the substances in their products. The European Parliament has emphasised that this producer responsibility should be complemented by national funding, recognising the high societal value of medicines. However, this national funding should not exceed 20% to uphold the "polluter pays" principle. [3]

While a global study indicates that the highest cumulative API concentrations in rivers are observed in lower-middle-income countries, where wastewater and waste management infrastructure is poor, this underscores the crucial role of economic development and infrastructure in managing pharmaceutical pollution. Within the EU, variations in socio-economic conditions across member states might influence the effectiveness of waste management systems and the extent of pharmaceutical pollution. For instance, countries with more robust waste management infrastructure and higher public awareness might exhibit lower levels of environmental contamination from pharmaceutical household waste. [2]

The UWWD acknowledges the potential impacts of EPR requirements on the accessibility, availability, and affordability of medicines and mandates the Commission to analyse these aspects. This reflects a concern that environmental regulations should not compromise public health access to necessary medications.

Furthermore, awareness campaigns and nudging techniques are employed in some EU countries (e.g., Sweden) to encourage the return of unused medicines. The success of these initiatives can be influenced by the socio-economic characteristics of the target populations, such as their level of education, access to information, and motivation to participate in environmental programs.

3.8.4 Impact of Medicine Waste on Wildlife in the EU

Pharmaceutical waste poses a significant threat to wildlife in the EU. Pharmaceuticals and their metabolites can enter the environment through various pathways, including wastewater treatment plant (WWTP) effluent, household disposal, and potential landfill leakage. These substances can have adverse effects on a wide range of organisms. [1] [5]

Direct toxic effects have been observed in aquatic organisms exposed to pharmaceutical residues. For example, diclofenac and ibuprofen, common analgesics, have been shown to cause organ damage and reduced hatching success in fish, as well as genotoxicity and neurotoxicity in molluscs. Certain pharmaceuticals can also disrupt hormones in frogs. Studies have documented the acute and chronic ecotoxicological effects of various drugs on the cladoceran Daphnia magna. Even at low concentrations, pharmaceuticals can elicit undesired responses in aquatic or terrestrial biota. [1] [8]

Endocrine-disrupting substances, including pharmaceuticals, present in sewage effluent have been linked to the feminisation of male fish in English rivers. Research programs have evaluated the effects of candidate contaminants and their pathways to the environment. Ethinylestradiol, a synthetic estrogen, has caused reproductive failure in fish and reproductive effects in zebrafish. Long-term exposure to environmental concentrations of ethinylestradiol can affect the life cycle of the fathead minnow. Pharmaceuticals that act on endocrine systems may require additional evaluation due to their potential for population-level effects. [1] [6] [9]

The discharge of antibiotics into the environment is a significant concern due to the risk of antimicrobial resistance (AMR) in bacteria. [1] [5] [10] Pharmaceutical waste from antibiotic production can facilitate the emergence of new drug-resistant bacteria, which can spread globally. [11] Even short exposures to antibiotics can be considered chronic from a bacterial perspective, given their short life cycle. [4] The presence of antibiotics in the environment, even at parts-per-trillion levels, can exert selective pressure on bacteria, leading to the development of resistance. [8] This resistance can subsequently be transferred to human pathogens, posing a risk to public health. [5]

A notable example of a pharmaceutical causing adverse population-level impacts is diclofenac in South-East Asia, where its veterinary use led to the poisoning and significant decline of vulture populations that fed on treated livestock carcasses. While this specific event did not occur in the EU, it highlights the potential for pharmaceuticals to have devastating effects on wildlife populations. [9]

3.8.4 Recommendations for Environmentally Friendly Pharmaceutical Waste Management

Recommendations for environmentally friendly pharmaceutical waste management can be implemented throughout the pharmaceutical lifecycle, from production to disposal. [1]
For pharmaceutical manufacturing, the WHO guidance emphasises controlling emissions at the source. [4] [5]
Key recommendations include:

- Establishing and consistently meeting targets for antibiotic concentrations and antibiotic-resistant bacteria in liquid effluent. Two acceptable levels (Good and Stringent) are defined to facilitate progressive adoption.
- Implementing wastewater treatment at the manufacturing plant, ideally complete treatment, to reduce the pollutant load before discharge.
- For solid waste, especially from fermentation-based processes, incineration or disposal in a secure landfill is recommended. If alternative disposal methods are used, stringent performance targets for API removal should be met (≥99% for fermentation-based, ≥80% for other processes). Validated hydrothermal, chemical, or enzymatic treatments can be applied.
- Conducting environmental risk assessments.
- Ensuring proper storage of products and wastes to prevent accidental releases.
- Regular monitoring of waste streams (liquid and solid) to quantify API residues.
- Considering zero liquid discharge (ZLD) strategies.

For household pharmaceutical waste, the OECD guidance highlights the need for a multi-faceted approach: [1]

- Prevention of pharmaceutical waste through measures like improved disease prevention, personalised medicine, and better dimensioning of packaging sizes.
- Establishing collection schemes and take-back systems, often at pharmacies, to avoid improper disposal. These systems can be mandatory or voluntary.
- Conducting awareness campaigns to educate the public about proper disposal routes and the environmental risks of improper disposal (e.g., flushing or discarding in household waste). These campaigns should clearly communicate the availability of take-back systems and discourage flushing liquids and creams down the toilet. Visible sorting instructions on packaging can aid awareness.
- Considering marketplaces and redistribution platforms for unused, close-to-expiry-date medicines to match supply and demand better.

- Providing clear instructions on medicine packaging regarding disposal, referencing collection systems where available.

Both manufacturing and household waste management should prioritise environmentally sound treatment methods, such as incineration (especially for antibiotic manufacturing waste) [4] [5], and potentially advanced wastewater treatment technologies in WWTPs to remove micropollutants, including pharmaceuticals. Landfilling of untreated pharmaceutical waste should be avoided due to the risk of leaching. [1]
Overall, a holistic approach that integrates regulatory frameworks, industry responsibility, public awareness, and appropriate waste management infrastructure is crucial to minimising the environmental impact of pharmaceutical waste and combating antimicrobial resistance.

References

[1] OECD (2022), Management of Pharmaceutical Household Waste: Limiting Environmental Impacts of Unused or Expired Medicine, OECD Publishing, Paris, https://doi.org/10.1787/3854026c-en.
[2] J.L. Wilkinson et al., Pharmaceutical pollution of the world's rivers, Proc. Natl. Acad. Sci. U.S.A. 119 (8) e2113947119, https://doi.org/10.1073/pnas.2113947119 (2022)
[3] Directive (EU) 2024/3019 of the European Parliament and of the Council of 27 November 2024 concerning urban wastewater treatment https://eur-lex.europa.eu/eli/dir/2024/3019/oj
[4] World Health Organisation, Guidance on wastewater and solid waste management for manufacturing of antibiotics, 2024
[5] Tim Sandle, PhD, WHO Guidance Seeks To Reduce Antimicrobials In Pharmaceutical Liquid Waste (2024) https://www.pharmaceuticalonline.com/doc/who-guidance-seeks-to-reduce-antimicrobials-in-pharmaceutical-liquid-waste-0001
[6] Gross-Sorokin MY, Roast SD and Brighty GC. Causes and consequences of feminisation of male fish in English rivers. Science Report SC030285/SR. 2004.
[7] EFPIA position on the Urban Wastewater Treatment Directive. 2024. https://www.efpia.eu/news-events/the-efpia-view/statements-press-releases/the-urban-wastewater-treatment-directive-will-run-counter-to-the-commission-s-and-member-states-work-on-competitiveness-and-critical-medicines/
[8] Han, J., He, S. & Lichtfouse, E. Waves of pharmaceutical waste. Environ. Chem. Lett. 21, 1251–1255 (2023). https://doi.org/10.1007/s10311-022-01491-0
[9] Holm G, Snape JR, Murray-Smith R, Talbot J, Taylor D, Sörme P. Implementing ecopharmacovigilance in practice: challenges and potential opportunities. Drug Saf. 2013 Jul;36(7):533-46. https://doi.org/10.1007/s40264-013-0049-3
[10] Janik-Karpinska, E.; Brancaleoni, R.; Niemcewicz, M.; Wojtas, W.; Foco, M.; Podogrocki, M.; Bijak, M. Healthcare Waste—A Serious Problem for Global Health. Healthcare 2023, 11, 242. https://doi.org/10.3390/healthcare11020242
[11] World Health Organisation. 2024. https://www.who.int/news/item/03-09-2024-new-global-guidance-aims-to-curb-antibiotic-pollution-from-manufacturing

4. The contribution of the industrial pharmacist

Due to their academic training, industrial pharmacists possess knowledge applicable to the stages of a medicine's development, from research and pharmaceutical development through industrial production and distribution to clinical development and commercialisation. This diverse knowledge gives him a unique professional profile, potentially enabling him to fit into various roles in the pharmaceutical sector.

Furthermore, because of his hybrid knowledge, which spans both chemical and biological domains, the industrial pharmacist can readily assess the environmental impact of medicines and industrial activities.

Based on the above, the industrial pharmacist can contribute to managing the various aspects of environmental sustainability that the pharmaceutical industry must address by leveraging his knowledge and skills.

In the coming years, we can expect significant changes in how the pharmaceutical industry operates, driven not only by the introduction of new technologies (such as AI/ML) but also by the progressive implementation of new requirements for environmental impact management. This will lead to a cultural shift, necessitating the development of new knowledge and skills. In the face of increasing technological complexity and the constraints that must be respected, operating in teams with diverse skills will become increasingly essential. In this context, the industrial pharmacist will need to interact more closely with other professionals and technicians specialised in new technologies, and will be able to make a key contribution by understanding how to develop a medicine suitable for therapeutic use.

Alongside technological advancements, a significant increase in the development and marketing of advanced therapy medicinal products (ATMPs) is anticipated. From an environmental perspective, this change will reduce the ecological impact of these products, as they are either biodegradable or inactivated through simple chemical or physical treatments, unlike small molecules. However, these products will increase the energy required to conserve and maintain the cold chain.

In general, the interventions required of the pharmaceutical industry to reduce the environmental impact of its activities will involve significant investments in new technologies and increased management costs for the development, production, and distribution of medicines, thereby affecting the prices of the finished product. This prospect must be reconciled with the need to maintain the competitiveness of European medicinal products in the global market, given the presence of products from countries where environmental regulations are not yet in place.

However, as the European pharmaceutical industry undergoes a gradual transformation to comply with regulatory requirements on environmental impact, it should improve its image by better recognising its key role in supplying a product essential to health.