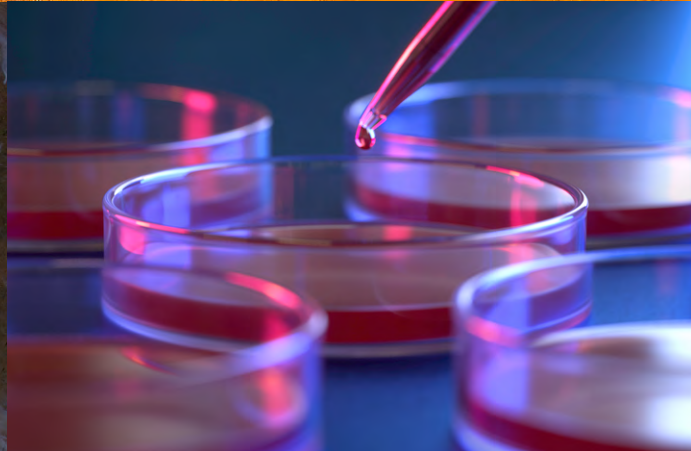
Sustainable Medicines

Use through EcoPV

Capgemini invent



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Executive Summary

The growing environmental impact of pharmaceuticals – from production to disposal – poses serious risks to ecosystems and public health, including antimicrobial resistance (AMR) and water contamination. This whitepaper presents a comprehensive framework for integrating Ecopharmacovigilance (EPV) across the pharmaceutical value chain to promote sustainable use of medicines within a One Health context.

EPV encompasses the detection, assessment, understanding, and prevention of adverse environmental effects caused by medicines. It is positioned not as a regulatory burden but rather as a catalyst for innovation, risk mitigation, and resilience across the healthcare and pharmaceutical sectors. Key upstream strategies include green chemistry, eco-design, and advanced manufacturing aimed at reducing waste, energy use, and environmental toxicity. Midstream interventions focus on precision prescribing, optimized supply chains, and digital innovations to minimize medication waste and improve clinical outcomes. Downstream efforts emphasize take-back programs, public education, and robust environmental monitoring of pharmaceutical residues.

A standardized EPV Key Performance Indicator (KPI) model is proposed to help measure progress across manufacturing, packaging, prescribing, waste management, and AMR surveillance. Industry leaders such as Novartis, AstraZeneca, and Sanofi are already embedding EPV into their Environmental, Social, and Governance (ESG) strategies, resulting in measurable improvements in sustainability.

Capgemini's sustainability services offer strategic and operational support to pharmaceutical companies, enabling them to implement EPV through lifecycle assessments, ESG reporting, and circular economy practices. The paper concludes by identifying research gaps and policy innovations needed to advance EPV and ensure long-term environmental and human health protection.

1 Introduction

The escalating global consumption of pharmaceuticals has inadvertently led to widespread environmental contamination by active pharmaceutical ingredients (APIs), their metabolites, and other residues. This pharmaceutical pollution contributes to significant ecological and public health threats, including antimicrobial resistance (AMR), wildlife endocrine disruption, and broader ecosystem toxicity. Ecopharmacovigilance (EPV), a systematic approach to monitoring the environmental impacts of medicines, provides a critical framework for mitigating these risks. EPV refers to the scientific discipline and associated activities focused on identifying, evaluating, understanding, and preventing the unintended effects of pharmaceuticals on ecosystems and human as well as animal health.

This whitepaper outlines a framework for achieving sustainable medicine use by integrating EPV across the entire pharmaceutical value chain. It proposes collaborative action among industry, regulators, healthcare professionals (HCPs), and patients. The framework addresses upstream prevention through green chemistry, midstream clinical optimization, and downstream waste management, all underpinned by robust EPV monitoring and measurable outcomes. It also highlights the role of new technologies and proposes a set of key performance indicators (KPIs) to measure progress toward a more sustainable pharmaceutical supply chain. The paper concludes by identifying key challenges and outlining future research directions needed to advance sustainable medicine use within a "One Health" context.

2 Ecopharmacovigilance: Monitoring Across the Lifecycle

Pharmaceutical Value Chain
Hotspots for Ecopharmacovigilance

Eco-friendly Design
Using green chemistry to create biodegradable APIs or drugs with lower persistent, bioaccumulative, and toxic (PBT) properties.

Emission Minimization
Implementing Environmental Risk Management Plans (ERMPs) to reduce active pharmaceutical ingredients (APIs) in industrial wastewater.

Eco-Procurement
Auditing supplier waste management practices and selecting GMP-certified suppliers to ensure compliance with waste management standards.

Rational Use & Education
Reducing “irrational use” (over-prescription) and educating patients to prevent excretion of unneeded metabolites into water systems.

Take-back Programs
Establishing pharmaceutical return programs to prevent consumers from flushing unused or expired medicines.

2.1

Green Chemistry & Eco-Design: Upstream Prevention

This section focuses on minimizing environmental harm during the earliest stages of a drug's lifecycle.

Design for Minimal Hazard and Waste (Green Chemistry):

Green chemistry reduces the environmental impact of pharmaceuticals by designing APIs that safely degrade and pose minimal ecological risk. Early ecotoxicity assessments prevent ecosystem harm, while metrics such as E-factor and Process Mass Intensity (PMI) track waste generation and resource use. Advanced manufacturing techniques including biocatalysis, flow chemistry, and green solvents enhance sustainability through improved yields and reducing energy consumption and waste.

Eco-Design in Product and Packaging:

Eco-design promotes sustainable packaging using recycled and bio-based materials to lower energy, water use, and emissions. Circular systems such as closed-loop packaging repurpose waste, while biodegradable dosage forms and personalized medicine help reduce environmental persistence.

Innovation in Trials and Patient Engagement:

Virtual clinical trials minimize carbon emissions and waste through remote participation. Digital tools and wearables improve research accessibility while reducing environmental impact. Replacing paper leaflets with electronic product information (ePI) improves patient experience and reduces emissions (estimated at 700,000 tons across the EU[1]).

Table 1: Upstream Interventions in Sustainable Pharmaceuticals

Intervention Area	Key Strategies	Environmental Benefits
Green Chemistry	• Design APIs for biodegradability • Early ecotoxicity assessment	• Reduced environmental exposure • Lower risk to ecosystems
Efficiency Metrics	• Track E-factor, PMI, solvent intensity • Optimize synthesis routes	• Less manufacturing waste • Improved resource efficiency
Advanced Manufacturing	• Use biocatalysis, flow chemistry, green solvents	• Lower energy use • Reduced hazardous waste
Eco-Design in Packaging	• Use recycled/bio-based materials • Adopt closed-loop systems	• Reduced fossil fuel use • Lower GHG emissions • Circular material reuse
Biodegradable Dosage Forms	• Develop less persistent delivery systems • Lower therapeutic doses	• Reduced pharmaceutical residues in environment
Virtual Clinical Trials	• Remote monitoring, telehealth, wearables	• Lower carbon footprint from travel • Reduced operational waste
Digital Product Information	• Quick Response (QR) codes for ePI • Replace paper leaflets	• Saves paper • Cuts emissions • Enhances access

2.2

Responsible Use and Disposal of Medicines

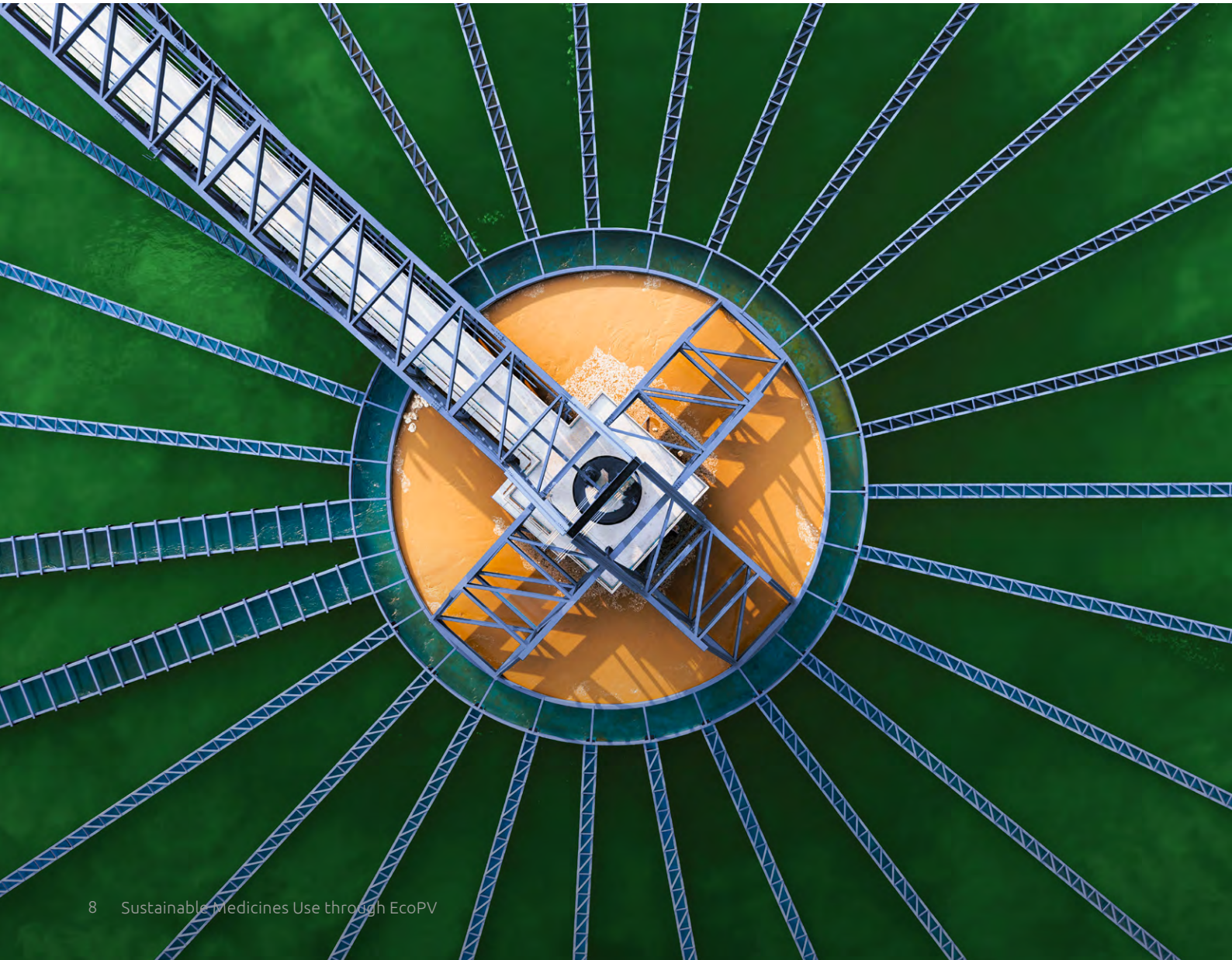
This section focuses on optimizing medication use to improve patient outcomes while reducing environmental impact.

Precision Prescribing:

Precision Prescribing ensures patients receive the appropriate medication, dose, and duration based on clinical guidelines and individual needs. This approach reduces waste and improves outcomes. Healthcare professionals use decision-support tools and patient education to enhance adherence [2,3,4]. Efficient supply chains, supported by digital inventory systems and First-Expiry-First-Out (FEFO) protocols, help align medicine availability with demand, minimizing expired drug waste. Taken together, these practices enhance safety, effectiveness, and sustainability across healthcare systems.

End-of-Life Control:

End-of-Life Control ensures proper disposal of medicines through accessible take-back programs supported by digital tools such as QR codes and RFID tags for traceability. Clear legislation on financial responsibility supports these initiatives. Public education by healthcare professionals promotes awareness of environmental risks and responsible behavior. Convenient return options and informed prescribing help further reduce pharmaceutical waste and contamination.



3 Common Key Performance Indicator (KPI) Model

A unified KPI model for EPV tracks environmental and public health impacts across the pharmaceutical lifecycle from manufacturing to waste management. Standardized KPIs enable benchmarking, accountability, and continuous improvement, while also enhancing transparency and regulatory efficiency. This framework promotes green innovation and more efficient use of resources by encouraging environmentally conscious drug development.

Table 2: EPV KPI Metrics and Targets Across the Pharmaceutical Lifecycle

Category	KPI	Metric Description	Suggested Target
Manufacturing (Energy, Water, Waste)	Waste Generation Rate	kg waste per unit of output	↓ 30% by 2030
	Hazardous Waste Compliance	% compliance with disposal regulations	100% compliance
Plastic Footprint	Plastic Packaging Weight	kg plastic per unit of product	↓ 25% by 2026
	Recycled Content in Packaging	% of packaging from recycled materials	≥ 50% by 2030
	Biodegradable Packaging Adoption	% of products with biodegradable packaging	≥ 30% by 2026
	Packaging Recyclability Rating	% of packaging that is recyclable	≥ 90% by 2030
Pharmaceuticals in the Environment (PiE)	API in Wastewater	µg/L of API in discharge	< 0.1 µg/L for high-risk APIs
	Wastewater Treatment Efficacy	% of API removed	≥ 95% removal efficiency
	API in Surface Water	µg/L in rivers/lakes near sites	< 0.01 µg/L
	Contamination Events	Number per year	Zero incidents annually
Prescribing Metrics	Prescription Duration Adherence	% prescriptions following guidelines	≥ 95% adherence
	Unused Medication Discard Rate	% of issued meds returned/wasted	↓ 50% by 2030
	Antibiotic Prescription Rate	Prescriptions per 1,000 patients	↓ 20% in high-prescribing regions
	Informed Disposal Rate	% of patients educated on disposal	≥ 80% by 2026
Return of Unused Medicines	Medication Return Volume	kg of meds collected	↑ 20% annually
	Return Program Utilization	% of authorized locations used	≥ 75% utilization
	Patient Participation Rate	% of households returning meds	≥ 50% by 2030
	Awareness of Take-Back Programs	% of population aware	≥ 70% by 2026
AMR Indicators	Environmental ARG Prevalence	% of samples with resistance genes	↓ 30% by 2030
	Indicator Bacteria Concentration	CFU/ml in wastewater	↓ 50% from baseline
	Antibiotic Use vs Resistance	Correlation coefficient	↓ to < 0.5 (weaker correlation)
	Hospital Effluent Monitoring	Rate of ARGs in hospital wastewater	↓ 50% by 2030

While a universal EPV framework is still evolving, leading pharmaceutical companies are already embedding EPV into their ESG and risk management practices. Novartis aims for net-zero environmental impact through initiatives such as eliminating PVC packaging and setting ambitious climate targets[5]. AstraZeneca implements Environmental Risk Management Plans (ERMPs) to assess drug lifecycle risks, showcasing its science-based approach to stewardship[6]. Sanofi uses Life Cycle Assessment and its Eco-Design Digital intelligence (EDDi) tool to reduce emissions, water use, and resource consumption across its product portfolio[7].

4 Future Research Directions and Challenges

Methodological Gaps:

There is a need for advanced analytical tools to detect pharmaceutical contaminants and metabolites in complex environments.

Addressing Data Scarcity:

Global harmonization and open-access sharing of environmental monitoring data are crucial to overcome fragmented datasets.

Socio-Economic Research:

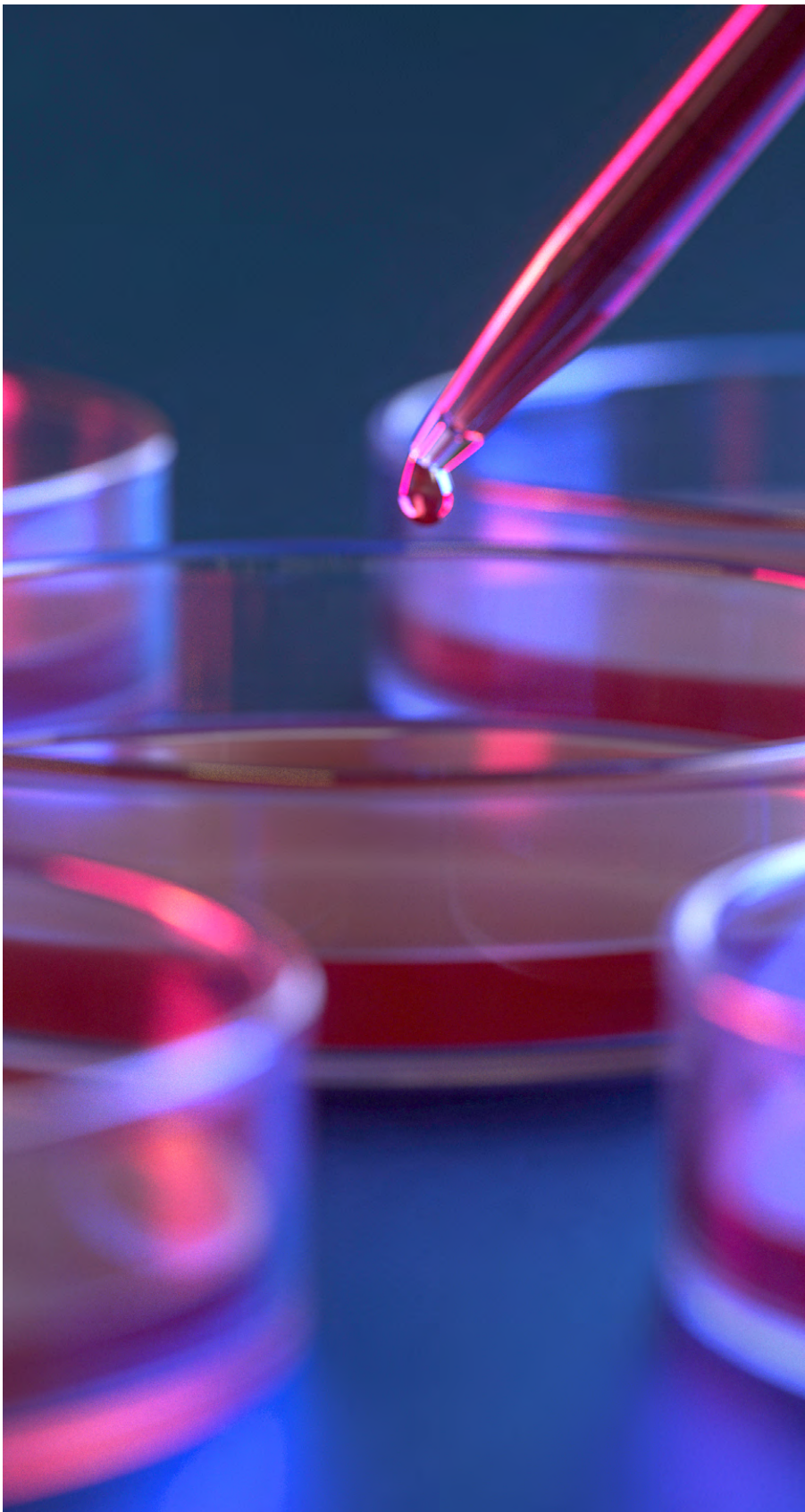
Investigate behavioral, social, and economic factors influencing sustainable medicine use, prescribing practices, adherence, and disposal behaviors.

Policy and Regulation Innovation:

Integrate environmental data into drug approval processes, and revise regulations to include ecotoxicological and sustainability metrics.

Novel Green Technologies:

Explore and assess emerging solutions such as Advanced Oxidation Processes (AOPs), phycoremediation, and advanced wastewater treatments for scalability and impact.



5 Capgemini: Pioneering Sustainable Solutions for the Pharmaceutical Industry

Organizations are entering a pivotal moment in their sustainability transformation, as highlighted in Capgemini's A world in balance 2025 report[8]. Despite persistent geopolitical and economic pressures, most enterprises continue to advance their environmental agendas, increasing sustainability investments and maintaining their net-zero commitments. However, limited transition planning and rising stakeholder scrutiny continue to challenge credibility, underscoring the need for measurable, near-term action and stronger data-driven governance.

Capgemini enables pharmaceutical and life sciences organizations to operationalize sustainability through our Business-to-Planet philosophy, embedding EPV principles across strategy, operations, and technology. Our sustainability framework provides a structured pathway from vision to execution, integrating circular economy practices and sustainable technology choices while ensuring transparent ESG data management. This approach supports compliance with evolving regulatory requirements and strengthens trust through clear impact measurement aligned to both business value and environmental performance.

Effective sustainability transformation within pharmaceutical enterprises hinges on addressing key environmental hotspots across research and development, production processes, facility operations, supply chain activities, and international logistics. Capgemini's services address these challenges through sustainable operations and supply chain optimization, lifecycle assessments, green-lean digital factories, carbon impact modelling, and automated tracking of Scope 3 emissions. These capabilities are complemented by eco-design, sustainable packaging, green chemistry, water and waste management, reverse logistics, and energy-efficient infrastructure improvements, each designed to reduce environmental footprint without compromising product safety, quality, or regulatory integrity.

Digital enablement plays a central role in advancing sustainability outcomes. Capgemini leverages AI, IoT, blockchain, and advanced analytics to enhance predictive maintenance, traceability, resource optimization, and environmental performance monitoring. Recognizing the organizational dimension of sustainable transformation, the offering also incorporates workforce upskilling, structured change enablement, cross-industry collaboration, and sustainability maturity assessments to define actionable, evidence-based roadmaps. Together, these capabilities help pharmaceutical organizations accelerate their transition to low-carbon, compliant, resilient, and future-ready value chains.

Capgemini's Sustainability Framework

Capgemini's "Commit, Act, Monitor & Report" Framework

Commit

Net zero strategy & new business models

To get from climate pledge to tangible strategies – helping you achieve a minimum 45% cut in CO_2e emissions by 2030 and become net zero by 2050

#vision #roadmap #governance #renewablesourcing #carbonpricing #offsetting

To truly shift businesses towards a regenerative future – looking at both current and future possibilities, to have a 360-degree approach in building the future

#sustainableexperience #ventures #brand #team

Act

Sustainable products & services

To incorporate sustainability into the product and services development process, ensuring innovative opportunities are explored and saving costs processes are implemented

#ecodesign #lowcarbon #customerexperience

Sustainable operations & supply chain

To enhance your brand's commitments by tackling end-to-end supply chain & operations ambitions, including procurement and circular economy

#procurement #greenlean #transparency #lifecyclemanagement #circulareconomy

Sustainable IT

To assess and reduce the footprint of IT capabilities to limit its growing share in the total global CO_2e emissions which account for 4% today

#strategy #greenIT #rationalization #awareness #ITforgreen

Monitor & Report

Data for net zero

To help you seamlessly collect and make the best of data to secure your net zero performance

#strategy #datahub #ESG #dataperformance

6 Conclusion

As pharmaceutical consumption continues to rise globally, so does its environmental impact across the production-to-disposal lifecycle, posing risks such as AMR and ecosystem contamination. The "One Health" framework emphasizes the interconnectedness of human, animal, and environmental health, making environmental protection a prerequisite for long-term well-being. EPV offers a strategic approach to address these challenges by integrating sustainability into every stage of the pharmaceutical lifecycle. Going beyond regulatory compliance, EPV drives innovation, resilience, and circular economy practices across the healthcare and pharma sectors.

7 Abbreviations

Abbreviation	Full Form
AMR	Antimicrobial Resistance
API	Active Pharmaceutical Ingredient
AOPs	Advanced Oxidative Processes
ARG	Antibiotic Resistance Gene
CFU	Colony-Forming Unit
EDDi	Eco-Design Digital Intelligence
EPV	Ecopharmacovigilance
EPI	Electronic Product Information
ERMP	Environmental Risk Management Plan
ESG	Environmental, Social, and Governance
FEFO	First-Expiry-First-Out
FDA	Food and Drug Administration
GHG	Greenhouse Gas
HCP	Healthcare Professional
KPI	Key Performance Indicator
PET	Polyethylene Terephthalate
PMI	Process Mass Intensity
QR	Quick Response
RFID	Radio-Frequency Identification

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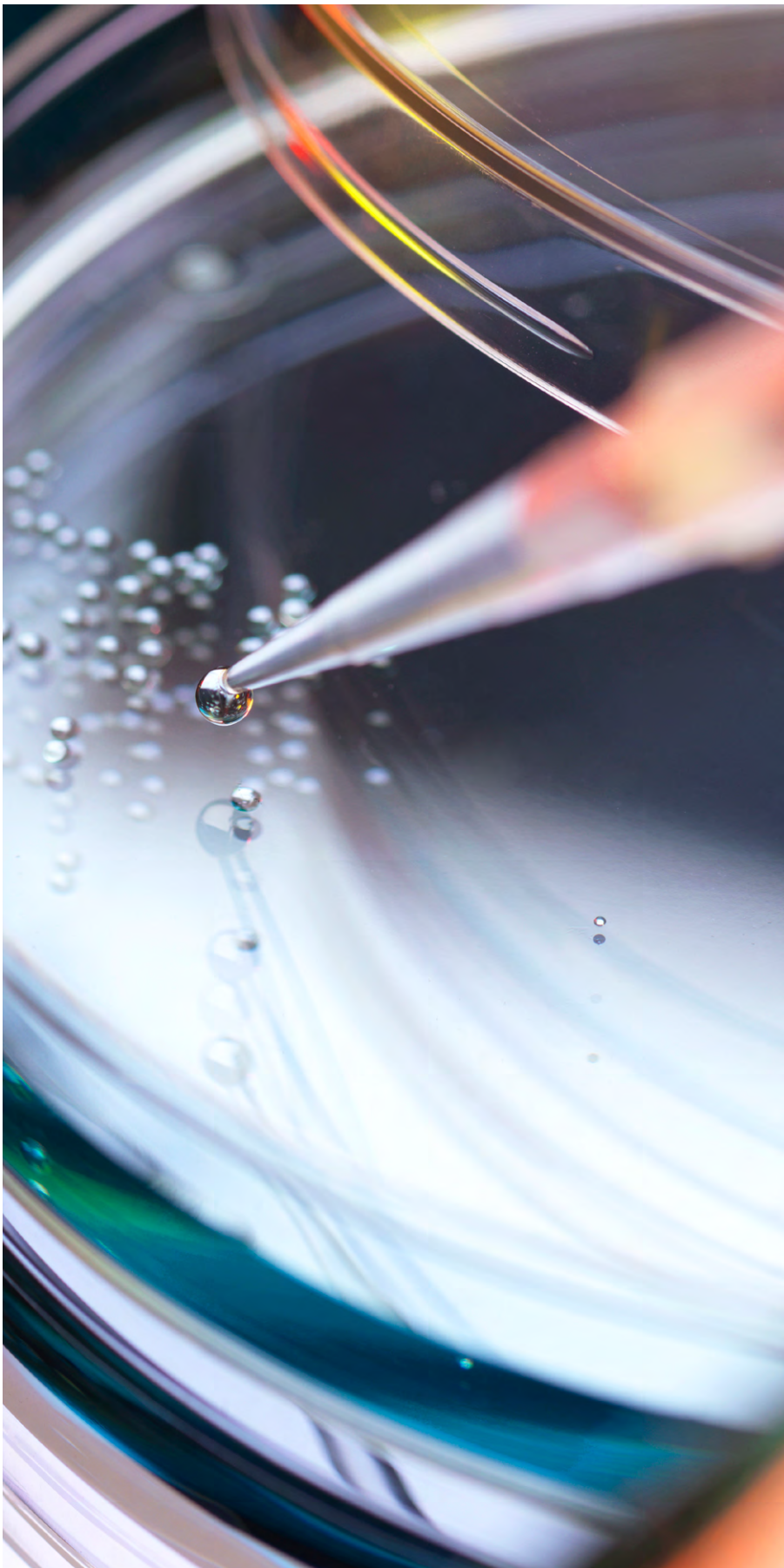

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