



D1.4: Sustainability Impact Assessment. Environmental Impacts of Innovative Wastewater Treatment Technologies

Task 1.3: Sustainability Impact Assessment

WP1: Societal Actions for the Reduction of Chemical Pollution

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ABSTRACT	The study presents the environmental impacts and benefits resulting from the application of the iMERMAID wastewater treatment technologies during the use cases. It highlights both the beneficial and detrimental environmental effects related to the technologies developed within the project, the four Use Case facilities, and the pilots. Although additional treatment increases environmental burdens worldwide, mainly through electricity and chemicals, handprint results show local benefits from contaminant removal, so sustainability depends on balancing.

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Executive Summary

Executive summary

Project context. The iMERMAID project develops and demonstrates advanced wastewater treatment technologies to address chemical pollution in the Mediterranean region. This study evaluates the environmental sustainability of these technologies in four use cases by examining both the additional environmental burdens associated with their deployment and the potential remediation benefits related to the removal of contaminants of concern. The assessment is intended to support technology development, inform implementation decisions, and contribute to broader EU objectives on pollution prevention, water protection, and sustainable innovation.

Methodological approach and study design. The study combines life cycle assessment (LCA), water footprint, and environmental handprint approaches to assess the environmental implications of integrating innovative tertiary treatment technologies into existing wastewater and leachate treatment systems. The assessment covers Use Cases 1, 2, 3 and 5 and compares a baseline scenario, representing the existing treatment configuration, with an iMERMAID scenario that includes the innovative treatment step. The functional unit is 1 m³ of treated wastewater. The analysis follows ISO 14040, ISO 14044 and ISO 14046, and applies the Environmental Footprint 3.1 method to quantify midpoint environmental impacts, while the handprint approach is used to assess the remediation value of contaminant removal in relation to the burdens of technology production and operation.

Results. Across the assessed use cases, the main environmental hotspots are consistently linked to electricity consumption during operation. Depending on the use case, additional relevant contributors include direct process emissions, chemical use, sludge management, and selected high-impact components such as electronics, pumps, ion exchangers, instrumentation, and high-purity materials. In the baseline systems, electricity is the dominant contributor to climate change and fossil resource use, which represent the main impact categories. In the iMERMAID scenarios, the additional treatment steps generally increase environmental burdens because they add electricity demand and, in some cases, chemicals- and component-related impacts. At the same time, the handprint assessment shows that the innovative technologies can deliver meaningful local environmental benefits through the removal of contaminants of concern, particularly in relation to freshwater ecotoxicity and water quality protection. The results therefore show that remediation benefits must be interpreted together with life cycle burdens, and that the sustainability of the technologies depends on the balance between treatment performance and operational demand.

Outlook. The interpretation of the results must take into account important data and methodological limitations, including the pilot-scale nature of the demonstrations, assumptions required for modelling novel or custom-made components, and the incomplete regional specificity of some background datasets. For these reasons, the study should be understood primarily as a hotspot-oriented assessment rather than as a comparison or a definitive prediction of future full-scale performance. Nevertheless, the results provide robust evidence to guide eco-design improvements, energy optimisation, and future scale-up of the technologies.

The study as well as the technology applications were considered beneficial by the interviewed iMERMAID partners. The assessment conducted at the end of the use cases show that **KPI 1.4: At least 3 no-regret, low-regret and win-win adaptation actions implementations discussion** was reached.

They are also relevant in relation to EU policy goals, including the Zero Pollution Action Plan, the Water Framework Directive, the Marine Strategy Framework Directive, and the Chemical Strategy for Sustainability, by showing both the remediation potential of advanced wastewater treatment technologies and the areas where further improvement is needed.

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Acronyms

Al	Aluminium
ASP	Activated Sludge process
AWARE	Available Water Remaining
BPA	Bisphenol A
CD	Compact Disc
CFC-11 eq	Trichlorofluoromethane
CH ₄	Methane
CML	Centrum voor Milieuwetenschappen
CO ₂	Carbon Dioxide
CO ₂ eq	CO ₂ equivalent
CoEC	Contaminants of Emerging Concern
CTUe	Comparative Toxic Unit for ecosystems
Cu	Copper
EF	Environmental Footprint
EPD	Environmental Product Declaration
EU	European Union
GES	Good Environmental Status
GHG	Greenhouse Gas
H ⁺	Hydrogen Ion
kBq U235 eq	kilobecquerel Uranium 235 equivalent
km	kilometres
IPCC	Intergovernmental Panel on Climate Change

ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MBR	Membrane bioreactors
Mm ³	Million cubic meter
MSFD	Marine Strategy Framework Directive
MW	Megawatt
N	Nitrogen
N ₂ O	Nitrous Oxide
NF	Nanofiltration
NH ₃	Ammonia
NMVOc	Non-Methane Volatile Organic Compounds
NO _x	Nitrogen Oxides
P	Phosphorus
PA12	Polyamide 12
PDP	Pulse Discharge Plasma
PVC	Polyvinyl Chloride
RO	Reverse Osmosis
SETAC	Society of Environmental Toxicology and Chemistry
SO _x	Sulphur Oxides
TRACI	Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts

UC	Use Case
UNEP	United Nations Environment Program
USEtox	UNEP/SETAC consensus toxicity characterization model
WAF	Water Availability Footprint
WDF	Water Degradation Footprint
WEEE	Waste electrical and electronic equipment
WFD	Water Framework Directive
WSF	Water Scarcity Footprint
WULCA	Water Use in LCA
WWTP	Wastewater treatment plant
WWTT	Wastewater treatment technology
Zn	Zinc
UF	Ultrafiltration
US EPA	United States Environmental Agency
μ Pt	Micropoints (measure for environmental impact, dimensionless)
3D	three-dimensional

1.0 Introduction

The Mediterranean region is subject to increasing environmental pressures related to water quality and chemical pollution. Multiple anthropogenic activities, including industrial processes, urban wastewater discharge, and the use of chemicals in agriculture and households, contribute to the release of contaminants of emerging concern (CoECs) into aquatic environments. These substances include pharmaceutical residues, pesticides, personal care product constituents, and industrial chemicals, many of which are persistent, bioaccumulative, and insufficiently regulated. Their presence in water bodies poses documented risks to aquatic ecosystems and may affect human health through direct or indirect exposure pathways (Gómez-Navarro et al., 2024; Haydous et al., 2025).

In this context, there is a growing need to implement water treatment and monitoring solutions that effectively target such pollutants while maintaining a low environmental burden.

The iMERMAID project aims to address these challenges by developing and demonstrating advanced and potentially scalable technologies designed to monitor, prevent, and remediate chemical pollution in the Mediterranean basin. These technologies include electrochemical sensors, microfluidic water treatment modules, and plasma-based degradation processes targeting CoECs that are typically resistant to removal in conventional wastewater treatment plants. However, introducing new technologies without a comprehensive evaluation of their full life cycle may result in unintended trade-offs.

The application of Life Cycle Assessment (LCA) provides a structured and scientifically robust framework for quantifying environmental impacts associated with both existing and emerging treatment systems. By considering material inputs, energy use, emissions, and end-of-life aspects, LCA enables a system-wide assessment of environmental performance and supports informed technology selection and deployment. Related methods with a focus on water-related impacts (water footprint and water handprint) allow to investigate the water-related impacts of these technologies, including their remediation effect.

The assessment focuses on four distinct Use Cases (UC1, UC2, UC3 and UC5), each characterized by specific technological configurations, operational contexts, and treatment objectives. UC 4 is not taken into account in this deliverable, since its focus lies on pollution detection and measurement and it does not foresee pollution removal.

To ensure methodological robustness, each Use Case is modelled and evaluated independently. The results are therefore not intended for direct comparison but rather for understanding the life cycle environmental performance of each system within its respective boundary conditions.

The goal is to identify environmental hotspots, benchmark performance, and ensure that pollutant mitigation efforts are aligned with broader sustainability goals, including the objectives of the EU Zero Pollution Action Plan, the Marine Strategy Framework Directive (MSFD), and the Water Framework Directive (WFD), the Chemical Strategy for Sustainability and the Convention for the Protection of the Mediterranean Sea against pollution. The contribution of the sustainability assessment of the iMERMAID wastewater treatment technologies to these policies are illustrated in Table 1.

The findings are intended to inform about both the environmental impacts of iMERMAID technologies and their potential contribution to improved environmental performance of water management systems. From a systemic perspective, the knowledge generated aims at supporting decision-making related to the mitigation of chemical pollution risks in the Mediterranean region.

Table 1: Contribution of the sustainability assessment of iMERMAID wastewater treatment technologies to relevant EU policy objectives

EU Policy	Policy objectives (selection)	Demonstration of policy alignment through iMERMAID sustainability assessment
EU Zero Pollution Action Plan	<p>Reduce air, water, and soil pollution to levels no longer harmful to health and natural ecosystems.</p> <p>Achieve a 50% reduction in nutrient losses and pesticide risk by 2030.</p> <p>Phase out harmful chemicals and reduce plastic litter and microplastics.</p>	<p>Calculation of environmental impacts for 16 different impact categories related among others, to emissions to water, air and soil</p> <p>Assessment of the consequences of chemicals use in wastewater treatment systems</p>
Marine Framework (MSFD) Strategy Directive	<p>Achieve or maintain Good Environmental Status (GES) of marine waters.</p> <p>Concentrations of contaminants are at levels not giving rise to pollution effects.</p> <p>Monitor bioaccumulation and pollution-related effects on marine biota.</p>	<p>Detailed water footprint and handprint to evaluate the environmental benefits of iMERMAID technological solution and assess eventual trade-offs</p> <p>Inclusion of water ecotoxicity in LCA analysis</p>
Water Framework Directive (WFD)	<p>Achieve good chemical and ecological status of surface and groundwater</p> <p>Monitor and control priority substances and priority hazardous substances.</p> <p>Encourage pollution prevention at source and development of less polluting technologies.</p>	<p>Calculation of pollutant effects on water (acidification, eutrophication, toxicity).</p> <p>Technology-related assessment of environmental impacts</p>
Convention for the protection of the Mediterranean Sea against pollution	<p>Eliminate pollution deriving from land-based sources and activities</p> <p>Effluents monitoring</p>	<p>Provides insights in the environmental impact of water pollution at plant effluent</p>
Chemical Strategy for Sustainability	<p>Bans the most harmful chemicals in consumer products</p> <p>Boosts the investment and innovative capacity for production and use of chemicals that are safe and sustainable by design, and throughout their life cycle</p>	<p>Investigates the environmental impacts of technologies that aim at reducing the use of chemicals in wastewater and leachate treatment</p> <p>Highlights environmental hotspots of technologies thus allowing improvement by re-design</p>

The report is structured as follows. First, the methods applied in the study (Life Cycle Assessment, Water Footprint and Environmental Handprint) and their applications to wastewater treatment and membrane technologies in particular are presented in Chapter 2. Chapter 3 illustrates the environmental sustainability assessment results by Use Case, describing the demonstrated technology and system context, defining scenarios and modelling choices, and providing results for the baseline scenario (plant operation) and the iMERMAID scenario (including also technology production, operation and end-of-life). The water quality footprint and handprint for the environmental impact related to the contaminants of concern are presented and discussed as well. In Chapter 4, results are discussed according to the main environmental hotspots identified in the Use Cases, limitations of the studies, and the alignment of the technologies with policy goals. The assessment of benefits, drawbacks and trade-offs of the Use cases by the involved partners is also presented in Chapter 4. It demonstrates that **KPI 1.4: At least 3 no-regret, low-regret and win-win adaptation actions implementations discussion** was reached.

2.0 Methods

This study applies a Life Cycle Assessment (LCA) framework consistent with ISO 14040 and ISO 14044 standards (ISO, 2006a, 2006b) to quantify the environmental impacts associated with the development and implementation of the iMERMAID water treatment technologies. The approach enables a systematic evaluation of material and energy use, emissions, and related environmental burdens across defined life cycle stages.

This chapter presents the methodological structure common to all case studies, including the goal and scope definition, system boundaries, functional unit specification, allocation procedures, and assumptions underpinning the analysis. The potential environmental benefits of the technology use for water quality are assessed via the water footprint and water handprint methods, in accordance with ISO 14046 (ISO, 2014) and the Environmental handprint approach (Vatanen et al., 2021). This ensures transparency and methodological consistency across the case studies and support comparative assessment of the iMERMAID solutions against conventional water treatment systems.

2.1 Life Cycle Assessment

LCA is a scientifically established methodology used to quantify the environmental impacts and resource use associated with a product, process, or system throughout its entire life cycle. It systematically evaluates environmental exchanges and potential burdens from raw material extraction through manufacturing, use, and end-of-life treatment. Internationally standardized within the ISO 14040 and ISO 14044 standards, LCA provides a structured approach to support decision-making in both policy and industrial contexts.

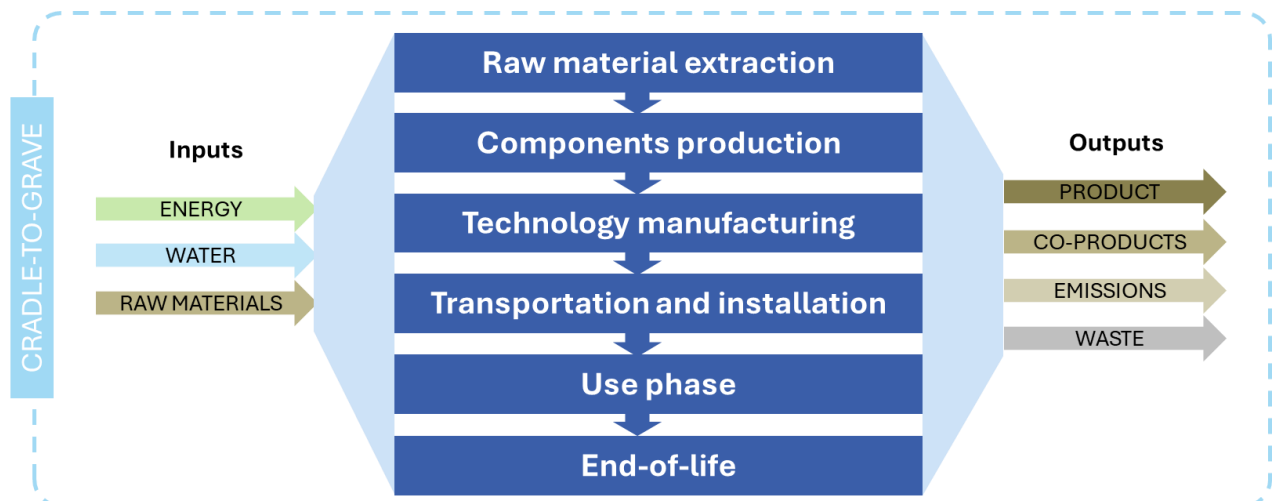


Figure 1: Typical inputs, outputs and life cycle stages of a product.

The methodology supports a life cycle thinking perspective, ensuring that improvements made in one part of the system do not result in burden-shifting elsewhere. Through the evaluation of a broad range of environmental indicators, such as climate change, freshwater use, resource depletion, and ecotoxicity, LCA allows for the identification of trade-offs and synergies within complex systems. This is particularly relevant for water treatment technologies, where multiple environmental dimensions intersect.

- The LCA framework comprises four interlinked phases as defined by ISO 14040: Goal and Scope Definition: Establishes the purpose, intended application, and target audience of the study. It also

defines the system boundaries and the functional unit, which serves as a reference for all input and output flows.

- Life Cycle Inventory Analysis (LCI): Involves data collection and modelling to quantify energy use, material inputs, emissions to air, water, and soil, and waste generation throughout the life cycle.
- Life Cycle Impact Assessment (LCIA): Translates inventory data into environmental impact indicators using characterization models. This phase evaluates the significance of environmental issues across selected impact categories.
- Interpretation: Integrates findings from the previous phases to draw conclusions consistent with the goal and scope, highlighting limitations and supporting recommendations.

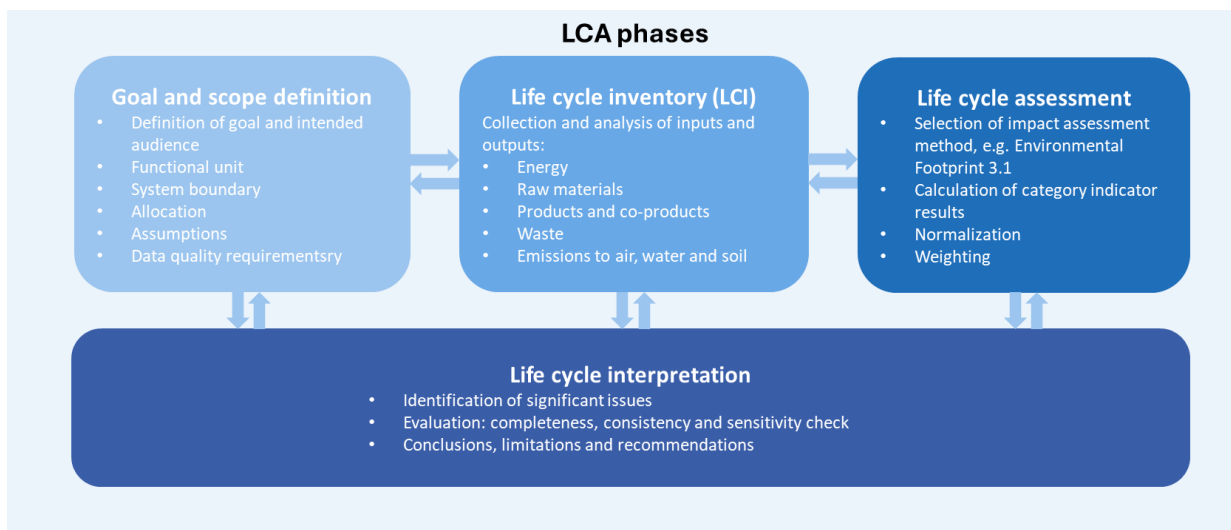


Figure 2: Phases of LCA as defined by the ISO 14040 and ISO 14044 standards.

The quantitative nature of LCA supports rigorous comparisons between alternative systems. For instance, evaluating a novel water treatment technology may reveal trade-offs between reduced pollutant loads and increased energy consumption. These insights support environmentally sound innovation and informed policy design. Within iMERMAID, LCA is used to assess the environmental performance of innovative water treatment technologies under development, ensuring their deployment contributes to pollution reduction goals without generating unintended environmental consequences.

In the following, the general methodological setup applied in the Use Cases is explained in detail according to the four phases illustrated above: Goal and Scope Definition, Life Cycle Inventory Analysis, Life Cycle Impact Assessment, Interpretation.

2.1.1 Goal and Scope of the Environmental Assessment

The objective of this assessment is to quantify the environmental impacts of iMERMAID’s water treatment technologies. The study evaluates resource consumption, emissions, and their effects on human health and the environment across relevant life cycle stages. The results are expected to show the prevalent environmental impacts across the life cycle and reveal which life cycle stages, materials and processes contribute consistently to the technology’s environmental profile. These findings are intended to support the future development of the technologies from an eco-design perspective and to benchmark their performance to conventional alternatives.

The scope of the assessment is defined by the system boundaries and the selected functional unit.

The system boundaries adopt a cradle-to-grave perspective, encompassing:

- Upstream processes: Raw material extraction and energy production for manufacturing system components.
- Core processes: Operation of the treatment systems, including energy and material use and associated emissions.
- Downstream processes: End-of-life treatment of equipment and residual materials (e.g., disposal or recycling).

The geographical focus is the Mediterranean region, in line with iMERMAID's implementation context, and is further specified for each Use Case. The temporal scope aligns with current operating practices and technology life spans. Activities assumed to take place in the future are extrapolated from current data, following the conservative assumption that no technological development takes place.

The functional unit is defined as 1 cubic meter of treated wastewater using a technology that addresses the contaminants of concern identified for each Use Case. This provides a consistent reference for quantifying impacts across all technologies and Use Cases. All data (inputs and outputs) are scaled to the treatment of 1 m³ of wastewater, aligned with the primary function of the systems.

No co-products or by-products are present within the defined system boundaries. Environmental burdens are therefore fully attributed to the treatment systems.

The cut-off allocation method is applied, in line with ISO 14044. This assigns all upstream and operational impacts, such as material use and emissions, to the iMERMAID technologies, reflecting a direct attribution model. This approach ensures that system boundaries remain clearly defined and impacts are not redistributed beyond the technologies under assessment.

The assessment follows a structured and standardized methodology. However, certain limitations are expected:

- System Boundaries: The scope excludes the production, installation and dismantling of the plant infrastructure and further WWTP operations not directly influenced by iMERMAID technologies.
- Data Specificity: Background datasets may not fully reflect local conditions, introducing uncertainty where regional data are unavailable.
- Temporal and Geographical Scope: The study reflects operational data from 2024-2026 and may not account for future developments or conditions outside the Mediterranean region.
- Pilot-Scale Focus: The analysis reflects pilot-scale implementation of the iMERMAID technologies and does not cover their full deployment.

These constraints are documented to support appropriate interpretation of results and reinforce the transparency and scientific robustness of the study.

2.1.2 Life Cycle Inventory

The Life Cycle Inventory (LCI) phase consists of the systematic quantification of material and energy flows associated with the manufacturing and operational phases of iMERMAID's water treatment technologies. The collected data supports the subsequent Life Cycle Impact Assessment (LCIA), enabling the evaluation of environmental burdens linked to each system component and life cycle stage. Different data sources are used to compile the inventory:

- Foreground system: Collected from technology developers and implementation partners, covering manufacturing and operational parameters.

- Background system: Secondary datasets from Ecoinvent v3.10 and v3.11, Environmental Product Declarations (EPDs) and component specific technical data sheets were used to model upstream and auxiliary processes where primary data were unavailable.
- Data collection focused on the specific technological solutions demonstrated at the four pilot sites. Primary data was collected directly from the technology developers and implementation partners, covering the following aspects:
 - Material composition and manufacturing requirements of each technology (e.g., microfluidic systems, 4D scavenger modules, and plasma discharge units).
 - Operational parameters during the use phase, such as electricity consumption, treatment efficiency, and emissions.
 - Infrastructure and supporting processes related to integration into pilot wastewater treatment plants.

All data were scaled to the functional unit of 1m³ of wastewater treated, ensuring consistency across technologies and locations. Where primary data were unavailable or incomplete, secondary datasets were sourced from Ecoinvent v3.10 and v3.11, ensuring that upstream and auxiliary processes (e.g., raw material extraction, energy supply, manufacturing infrastructure) were adequately represented. Priority was given to datasets aligned geographically with the Mediterranean region when available.

To ensure reliability and consistency, the following data quality criteria were applied:

- Consistency: Harmonized procedures were followed across Use Cases to support comparability.
- Completeness: All relevant input and output flows were identified and quantified, with uncertainties documented where applicable.
- Precision: Data were validated through technical specifications, laboratory reports, or direct communication with technology developers.
- Representativeness: Primary data reflect operational conditions from the demonstration activities carried out during the relevant phases of the project (2024-2026). Secondary data were selected to match the temporal, geographical, and technological context of each Use Case.

The resulting LCI captures all significant flows contributing to the environmental performance of the iMERMAID technologies, providing a robust foundation for transparent, reproducible, and policy-relevant environmental assessments.

2.1.3 Life Cycle Impact Assessment

The Life Cycle Impact Assessment (LCIA) phase converts the inventory of material and energy flows into environmental impacts, such as climate change, toxicity or water scarcity. This phase applies scientifically validated environmental impact models to quantify how emissions and resource use contribute to various environmental issues across defined impact categories.

This is carried out in two steps. The first one, called classification, assigns each input and output inventoried in the LCI to the related impact category or categories. For example, while the use of metals as raw materials in a product system can be related to the impact category “Resource depletion, minerals” (as exemplified by the inventory flow silver in Figure 3), other substances can be related to more impact categories, such as nitrogen oxides, which lead to particulate matter pollution if emitted to air and acidification in case of soil or water emissions.

In a second step, inputs and outputs are multiplied by the related characterization factor, which express the magnitude of the impact per unit of input or output. The best-known example therefore are

characterization factors for the climate change category, measured as CO₂-equivalent. In this context, the characterization factor used for CO₂ is 1, while other gases with a stronger climate change impact per mass unit are assigned higher characterization factors, e.g., 29.8 for fossil methane and 273 for nitrous oxide (Andreas Bassi et al., 2023). The calculated input- or output-specific impacts are then aggregated by impact category through summation.

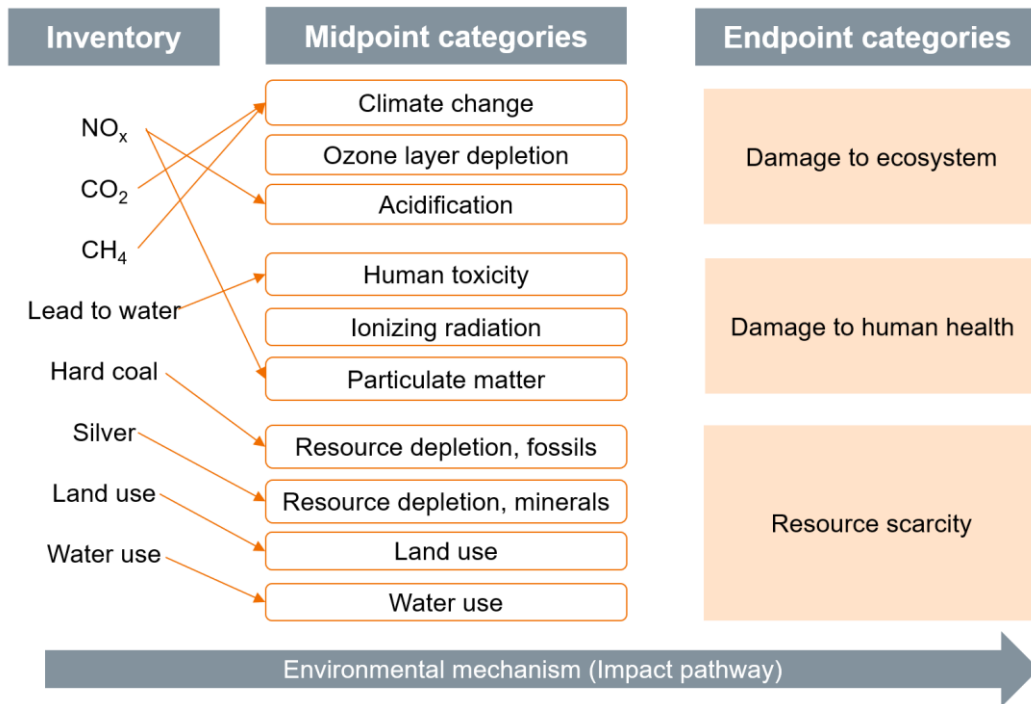


Figure 3: Simplified example of the classification step in LCIA. Based on the ILCD Handbook (European Commission Joint Research Centre, 2010).

This study adopts, as LCIA framework, the Environmental Footprint (EF) method, version 3.1., developed by the European Commission, the EF method provides a harmonized and policy-aligned approach to environmental impact assessment (Andreas Bassi et al., 2023). Its selection reflects both the geographical focus of the iMERMAID project within the European Union and the methodological requirements for supporting EU sustainability goals, including those articulated in the Zero Pollution Action Plan, the Water Framework Directive (WFD), and the Marine Strategy Framework Directive (MSFD).

The EF method applies midpoint categories to capture the potential environmental burdens associated with emissions and resource use. These indicators quantify impacts in terms of cause-effect relationships, using standardized characterization factors derived from scientifically peer-reviewed models. The impact categories included in the EF method are briefly described in Table 2.

Table 2: List and description of the impact categories included in the Environmental Footprint Method (European Commission, 2021).

Impact category	Unit	Description
Acidification	mol H ⁺ eq.	Describes impacts due to acidifying substances in the environment. Emissions of NO _x , NH ₃ and SO _x lead to releases of hydrogen ions (H ⁺) when the gases are mineralised. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low, resulting in forest decline and lake acidification.

Climate change, total	kg CO ₂ eq	All inputs or outputs that result in greenhouse gas emissions, which increase average global temperatures and sudden regional climatic changes.
Ecotoxicity, freshwater	CTUe	Potential toxic impacts on an ecosystem, which may damage individual species as well as the functioning of the ecosystem. Ecotoxicity is a result of a variety of different toxicological mechanisms caused by the release of substances with a direct effect on the health of the ecosystem
Eutrophication, marine	kg N eq	Eutrophication impacts ecosystems due to nutrients (mainly nitrogen or phosphorus) from sewage outfalls and fertilized farmland that accelerate the growth of algae and other vegetation in water. The degradation of organic material consumes oxygen, resulting in oxygen deficiency and, in some cases, fish death.
Eutrophication, freshwater	kg P eq	
Eutrophication, terrestrial	mol N eq	
Human toxicity, cancer	CTUh	Describes adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin – cancer category insofar as they are related to cancer, and the non-cancer category insofar as they are related to non-cancer effects that are not caused by particulate matter/respiratory inorganics or ionising radiation.
Human toxicity, non-cancer	CTUh	
Ionising radiation, human health	kBq U235 eq	The exposure to ionising radiation (radioactivity) can have impacts on human health.
Land use	Dimensionless (pt)	Describes the impacts on soil quality related to land use (occupation) and conversion (transformation) due to agriculture, roads, housing, mining or other purposes
Ozone depletion	kg CFC-11 eq	The degradation of stratospheric Ozone (O ₃) layer is caused by emissions of long-lived chlorine and bromine containing gases.
Particulate Matter	disease incidence	The adverse impacts on human health caused by emissions of Particulate Matter (PM) and its precursors (e.g. NO _x , SO ₂).
Photochemical ozone formation - human health	kg NMVOC eq	Ozone on the ground (in the troposphere) is harmful: it damages organic compounds in animals and plants. It is caused by photochemical oxidation of volatile organic compounds (VOC) and carbon monoxide in the presence of nitrogen oxides and sunlight.
Resource use, fossils	MJ	Addresses the use of fossil natural resources like coal, oil and gas.
Resource use, minerals and metals	kg Sb eq	Addresses the use of non-renewable abiotic natural resources (minerals and metals).
Water use	m ³ world eq of deprived water	Water use represents the relative available water remaining per area in a watershed, after demand from humans and aquatic ecosystems has been met. It assesses the potential for water deprivation, to either humans or ecosystems, based on the assumption that the less water remaining available per area, the more likely it is that another user will be deprived.

After the classification and characterization steps, the EF method includes also two optional steps, i.e., normalization and weighting.

Normalization converts the midpoint impact results into dimensionless scores by dividing them by a reference information (for the EF method, the average per capita environmental burdens in the European

Union). The purpose of normalization is to provide context for the relative significance of each impact category, supporting clearer interpretation of the results and prioritization of environmental hotspots. This enhances comparability across categories and Use Cases and aligns the assessment with recommended practices for policy-relevant environmental analysis within the EU framework.

Weighting consists in multiplying the normalized results for each impact category by the category-specific weighting factor, which reflects the societal importance of the impact category. Weighting is therefore based on value choices and not on natural science as classification, characterization and normalization are. The weighting step of the EF 3.1 method is based on a hybrid evidence- and judgement-based weighting set that accounts for both the relevance of the impact category and the robustness of the related factor, which depends on the uncertainty of the characterization model and the completeness of the dataset used for the normalisation inventory. As a result, impact categories considered less robust are attributed a lower weighting factor, i.e., their relevance is “discounted” (Sala et al., 2017).

2.1.4 Interpretation

In this phase, the LCI and LCIA results are interpreted according to the goal and scope of the study.

ISO 14044 highlights the following processes as relevant for the interpretation of the results of an LCA study:

- Assessing the suitability of the functional unit and system boundary to reach the goal of the study.
- Identifying the significant issues based on the LCI and LCIA results, e.g., inventory data, impact categories, processes or process groups, including the impact of methodological choices (e.g., system boundary, allocation) or value choices on the results.
- A data quality assessment following criteria set in the goal and scope phase, such as consistency, completeness, precision, representativeness.
- A completeness check, to ensure that all relevant information is available and complete.
- A sensitivity check, to investigate the dependency from specific parameters such as energy mix or end-of-life fate.
- Conclusions, limitations and recommendations based on the case setup and results.

2.2 Water footprint

The water footprint method builds upon the principles of life cycle assessment and is focused on water-related environmental impacts. Water footprint is defined as the metric or metrics “that quantifies the potential environmental impacts related to water” (ISO, 2014), and a water footprint assessment as the “compilation and evaluation of the inputs, outputs and potential environmental impacts related to water used or affected by a product, process or organization” (ISO, 2014).

Water footprint is standardized in ISO 14046 (ISO, 2014), which foresees an application to products, processes and organizations following the four-steps approach (goal and scope, inventory analysis, impact assessment, interpretation) that is common to LCA studies. In addition, ISO/TR 14073 (ISO, 2017) provides practical examples for the method application.

Differently than LCA, which helps identifying trade-offs between different environmental impacts and supports comprehensive environmental decision-making, water footprint is used to understand water dependency and risks to production and value chains related to water scarcity and water pollution.

Within the water footprint framework, the environmental focus can be narrowed down to a water scarcity footprint or a water degradation footprint.

A water scarcity footprint studies focus on the amount of water consumed in each step of the value chain

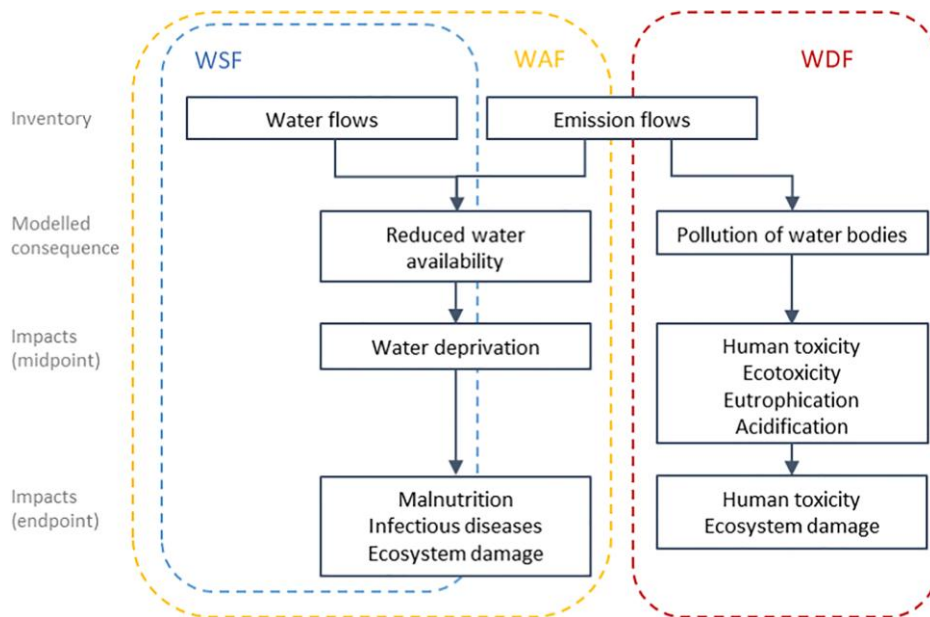


Figure 4: Impact pathways schematically describing the environmental mechanisms accounted for in water footprinting. WSF=water scarcity footprint; WAF=water availability footprint; WDF=water degradation footprint. From (Mikosch et al., 2021).

and the related impact on water availability. This depends on the location in which the water consumption takes place. In general, the water scarcity footprint of a process is higher if the process takes place in a water-scarce region. Different impact assessment methods have been developed to investigate the consequences of water scarcity. The current consensus method Available Water Remaining (AWARE) was developed between 2013 and 2018 by the Water Use in LCA (WULCA) expert group and provides characterization factors at a watershed level as well as average factors to be applied at the national and regional level (Boulay et al., 2018). A more recent version including updated hydrological data was released in 2025 (Seitfudem et al., 2025). Further methods that build upon AWARE focus on the protection of natural resources (Pradinaud et al., 2019) or ecosystems (Núñez et al., 2016), and illustrate the application to large water inventories (Boulay et al., 2020; Forin et al., 2020).

Unlike water scarcity assessments, there is no scientific consensus on how water quality issues should be addressed in water footprinting. According to (Mikosch et al., 2021), two types of water pollution characterization models can be identified: water availability footprints and water degradation footprints (see Figure 4).

The first type consists in water availability footprints, which focus on the reduced availability of clean water due to pollutants, e.g. agricultural water deprivation due to contamination, which potentially leads to malnutrition, or domestic water deprivation, which causes infectious diseases.

The second category of footprint addressing water quality encompasses water degradation footprints, which assess the “negative change in water quality”, i.e., in the “physical (e.g., thermal), chemical and biological characteristics of water with respect to its suitability for an intended use by humans or ecosystems” (ISO, 2014).

Water degradation can be quantified multi-dimensionally via a water degradation footprint profile that includes distinct impact categories such as acidification, eutrophication and water ecotoxicity, or aggregating different environmental aspects in indices like pollution-induced water scarcity (Zeng et al., 2013) and the pollution water indicator (Lovarelli et al., 2018). Though facilitating communication through

their simplicity, single score results that include several impact pathways make results interpretation rather difficult. Therefore, for the assessment of water degradation, impact categories standardized at the level of the EF method (eutrophication, acidification, and ecotoxicity) are used and considered together within a water footprint profile. In the following, the main characteristics of these impact categories are illustrated.

Eutrophication poses significant challenges to aquatic ecosystems, primarily resulting from elevated levels of environmental nutrients, such as nitrogen and phosphorus. Phosphorus predominantly affects freshwater habitats, while nitrogen is more influential in marine environments. Nevertheless, they both contribute to accelerated algal and vegetative growth in water bodies. The decomposition of organic matter depletes oxygen, leading to hypoxic conditions that may cause fish mortality (Grassle, 2001). Anthropogenic sources of these nutrients include sewage discharge and the runoff from fertilized agricultural land. Moreover, eutrophication can impact terrestrial systems, as alterations in soil composition may decrease biodiversity and disrupt ecological equilibrium, ultimately diminishing soil fertility. Soil erosion resulting from storms or natural disasters can further exacerbate aquatic eutrophication (Kobetičová & Černý, 2019).

In LCA impact assessment, nitrogen oxides and phosphorous compounds are converted in nitrogen and phosphorus equivalents (kg or mol P/N eq.) through characterization factors based on nutrient fate and transport models in order to allow for comparison and aggregation (Morelli et al., 2018).

The **acidification** potential quantifies how far airborne emissions, mainly sulphur dioxide, nitrogen oxides, and ammonia, affect the increase of hydrogen ion concentration in terrestrial and aquatic environments. This process leads to detrimental effects such as forest decline, due to the deposition of airborne emissions on vegetation, which causes damages to leaves and needles, and elevated fish mortality, due to acid stress and toxicity in lakes (Rosenbaum et al., 2018). Besides freshwater basins, also oceans are affected by acidification through the absorption of increasing amounts of atmospheric CO₂ (Bach et al., 2016).

Two main factors affect the acidification potential: “the potency of the emitted gas and the sensitivity of the receiving environment in terms of buffering capacity of the soils and sensitivity of the ecosystems to acidification as expressed by their critical load” (Rosenbaum et al., 2018). While the variation in acidification potency among different gases is relatively moderate, typically within one order of magnitude, the environmental sensitivity can differ by several orders of magnitude. This is due to site-specific characteristics such as geological composition and soil quality.

The primary sources of acidification are sulphur oxides (SO_x) and nitrogen oxides (NO_x) emissions originating in combustion processes in electricity generation, thermal power plants, and combustion engines (European Commission, 2025). Ammonia is also an important contributor to acidification in certain regions. The main sources are related to agriculture, such as the use of NH₃ as a fertiliser, and to animal husbandry, with ammonia emissions from stables and dispersion of manure. The effect of these substances is typically expressed as moles of hydrogen ion equivalents, allowing for consistent assessment in life cycle analyses.

Ecotoxicity impacts are caused by chemical emissions into the environment. Depending on the place and time of the emissions and the substance characteristics, chemical emissions can affect human health and ecosystems in different ways, leading to “increased mortality, reduced mobility, reduced growth or reproduction rate, mutations, behavioural changes, changes in biomass or photosynthesis, etc” (Rosenbaum et al., 2018).

To provide a faithful estimate of the potential ecotoxicity impact at the midpoint level, toxicity methods account for three main variables: fate, exposure and effect:

- The fate indicates the concentration increase in a specific medium (air, water, soil) caused by the emissions quantified in the life cycle inventory.
- The exposure quantifies to which extent the emissions reach, and damage, living organisms.
- The effect indicates the fraction of species within an ecosystem that are affected by the emissions being examined, e.g., through increased mortality, mutations, reduced growth or changes in biomass and photosynthesis.

When considering water ecosystems, standardized methods are available for freshwater ecotoxicity, which consider three different trophic levels: organisms that perform photosynthesis, thus converting light into biomass (e.g., algae), their primary consumers, e.g., zooplankton and invertebrates, and organisms at the upper end of the aquatic food chain such as piscivorous fish.

Though accounting for several aspects of the complex environmental mechanisms behind toxicity impacts, the use of water-related toxicity assessment in LCA has two main limitations. First, it accounts only for a limited share of the tens of thousands of different chemicals released to the environment, which have a potentially toxic effect on living organisms. Current LCIA models cover around 3000 substances for aquatic ecotoxicity, about 1800 thereof being standardized in the EF 3.1 method, according to the UNEP/SETAC consensus toxicity characterization model (USEtox).

The second limitation regards the scope of standardized methods, that include only freshwater ecotoxicity. Characterization factors for the assessment of marine ecotoxicity, though available, are not part of standardized impact assessment procedures because the available ones are not considered mature enough (Carvalho et al., 2024).

The unit of measurement is Comparative Toxic Unit for ecosystems (CTUe). This is based on toxicity models such as the USEtox model.

2.3 Environmental handprint method

The environmental handprint method (Vatanen et al., 2021) was developed to address the growing need for companies to highlight the positive environmental consequences of their offerings, especially in the context of urgent climate action. Traditional methods of environmental performance assessment, such as LCA and footprints, have focused primarily on quantifying negative impacts across a product's or service's life cycle. However, organizations that have optimized their own environmental footprint often lack robust means to demonstrate the benefits their products or services can enable for their customers.

The environmental handprint concept builds on the previously established carbon handprint approach (Grönman et al., 2019; Pajula et al., 2021; Tuppurä et al., 2024), expanding its focus beyond climate impacts to include a broader range of environmental aspects. An environmental handprint is defined as **the beneficial environmental impacts that organizations can achieve and communicate by offering products and services that reduce the environmental footprints of others.**

Both the carbon and the environmental handprint method were developed at LUT University and VTT (Finland) between 2016 and 2021, within different projects involving producing companies, LCA tool providers, research institutions and the public sector. The handprint approach takes ISO 14040 and ISO 14044 as a starting point and complements them through specific guidelines for calculating beneficial impacts.

The handprint approach is structured in four main stages: handprint requirements, additional LCA requirements, quantification and communication. Their main contents are summarized in Figure 5.

Stage 1	Define the scope of the studied solution	Product (goods, service, material, component)	Organisation (product or service portfolio)	Project (a non-recurrent activity to reach the preferred outcome in a defined time frame)	
	Identify potential handprint contributors	Description, how the studied solution may achieve footprint reductions			
	Identify the environmental impacts in question and their potential indicators	Climate change GHG emissions	Resources e.g. ADP (elements and fossil fuels), cumulative energy demand	Water e.g. scarcity, eutrophication, acidification, toxicity	Nutrients N/P/K balance and eutrophication, in addition e.g. toxicity, acidification
	Identify users and beneficiaries of the studied solution	Identify potential or actual customers or other parties that may benefit from the studied solution			
	Define the baseline	Reference case that best represents the conditions (most likely) to occur in the absence of the studied solution			
Stage 2	Define the functional unit	The measure of the function the studied solution delivers in a relevant time frame in the use <input type="text"/>			
	Define the system boundaries	The relevant and similar life cycle stages of the studied and the baseline solution			
	Define data needs and sources	Identifying representative and accessible data of the studied and the baseline solution representing the similar geographical and time-related coverage			
Stage 3	Calculate the footprints	Calculate footprints of the studied and the baseline solution based on relevant ISO-standards where applicable			
	Calculate the handprint	Difference of the footprints calculated			
Stage 4	Identify the relevant indicators to be communicated	Confirmation of the most relevant indicators that accurately and justly represent the results and should thus be communicated			
	Consider critical review of the handprint	Recommended in B2C communications, and mandatory if the results are intended for comparative assertions to be disclosed to the public as instructed in the ISO standards 14044 and 14026.			
	Communicate the results	Communicating the results respecting appropriateness, clarity, credibility, and transparency			

Figure 5: Methodological framework for the environmental handprint assessment. From (Vatanen et al., 2021).

For the specific case of tertiary wastewater treatment systems such as the ones tested within the iMERMAID project, which are incremental technologies, i.e., technologies applied after a technology already in place, specifications to the method are necessary, as introduced in (Forin et al., 2025).

First of all, for the case of technologies used for environmental remediation, the definition of handprint needs to be adapted. The original definition, in fact, focuses on the reduction of environmental footprints of others, thus assuming that the technologies under analysis (both the baseline and the solution) have a harmful impact on the environment. This does not apply for environmental remediation technologies, which are designed to improve the condition of the natural environment. Therefore, the following definition will be applied: **the handprint of environmental remediation technologies is the beneficial environmental impact that organisations can achieve and communicate by offering products and services that enable environmental remediation.**

The remaining methodological elements illustrated in Figure 5 (Stage 1 and 2) are applied as follows in this study. Given the focus on water quality related impacts, the general term water quality handprint will be used in the following, whereby the specific water quality related impact category of interest (e.g., ecotoxicity, eutrophication or acidification) will be specified case by case according to the identified contaminants of concern.

- The **scope** of the studied solution is the wastewater treatment technology as a product. The assessment of the existence and magnitude of the environmental remediation requires to

consider additional inputs and outputs and therefore a broader **system boundary**. The use phase accounts for the consumptive inputs and outputs of the technology in place (the wastewater treatment plant the technology is applied to relative to the functional unit, excluding their construction and dismantling) and for the pollutant input and output flows. The system boundary is exemplified in Figure 6.

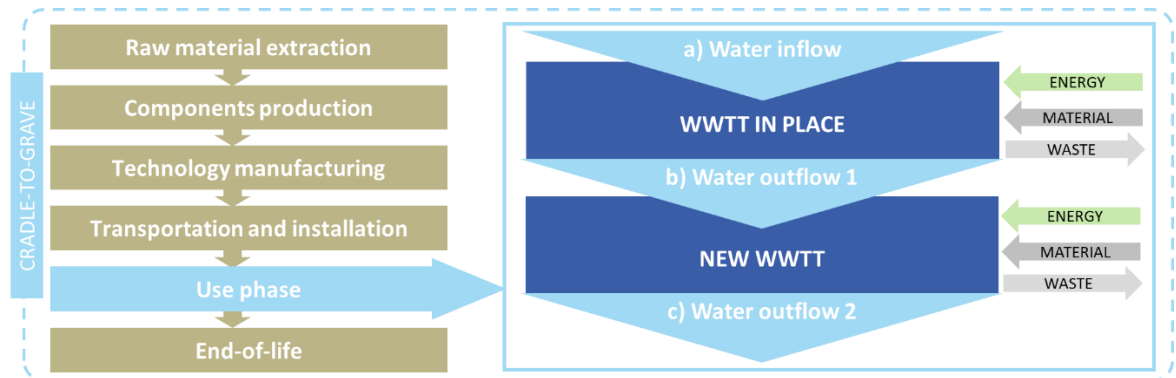


Figure 6: System boundary for the water handprint assessment of incremental wastewater treatment technologies.

- The **potential handprint contributors** are selected based on the emissions of concern identified for each Use Case. The **environmental impact categories** are selected based on the availability of characterization models and characterization factors linking the specific emissions to LCA midpoint categories according to the EF 3.1 method. Particular attention is set on spotting potential trade-offs originating from the supply chain of the new WWTTs and their use phase (material and energy consumption of waste generation), considering the different geographical locations of the different impacts.
- **Potential users** in the iMERMAID case studies are the wastewater treatment plants where the technologies are tested. **Beneficiaries** are, besides the above-mentioned plants, the local community and other stakeholders that profit from an improvement in water quality in the plant's surroundings and in the Mediterranean Sea.
- The **baseline scenario** is represented by the current technology at the plant's location (WWTT in place), without the additional tertiary technology applied in the Use Case, and is juxtaposed to the iMERMAID scenario, which includes the innovative technology.
- The **functional unit** is 1 m³ of treated water.
- The **data needed** for the analysis are the components, materials, waste, water, energy and emissions flows related to the production of the technologies and the operation of the plants (the latter for both the baseline and the iMERMAID scenario), the distance between production and installation locations and the mode of transport used.

2.4 State of the art: LCA and water footprint studies for selected wastewater treatment technologies

Life Cycle Assessment (LCA) has become an established tool to evaluate the environmental performance of wastewater treatment plants (WWTPs), offering insights into trade-offs between pollutant removal, resource use, and environmental burdens. Recent applications, supported by case studies and reviews published between 2018 and 2025, reveal both a growing LCA methodological maturity and persistent heterogeneity in how studies select system boundaries, and impact categories, and to a lesser extent how

they select functional units (FUs). Following the analytical structure proposed by (Corominas et al., 2020), this section synthesises the state of the art and situates the approach adopted in iMERMAID within this context. A structured overview is provided in Table 3.

A central methodological choice in wastewater LCAs is the FU. The literature shows a strong convergence around volume-based units, most frequently defined as one cubic metre of treated wastewater. In some cases, the FU is further specified as effluent meeting regulatory discharge requirements, a refinement noted in (Corominas et al., 2020). For sludge-oriented assessments, mass-based units are more common, with one kilogram of dry solids at a given volatile solids content (Alyaseri & Zhou, 2024; Prateep Na Talang et al., 2022). Review studies confirm that this alignment towards either volumetric or mass-based FUs facilitates comparability across systems (Rashid et al., 2022). For iMERMAID, this trend supports the decision to adopt one cubic metre of treated wastewater as the reference FU across demonstration sites, ensuring methodological consistency while maintaining flexibility to capture effluent quality requirements relevant to contaminants of emerging concern.

System boundaries remain more fragmented across studies. Operation is consistently included, covering electricity consumption, chemical inputs, and direct process emissions (Samsami et al., 2025; US EPA, 2023; Viotti et al., 2024). Sludge treatment is also widely addressed, either integrated into the WWTP system, (Samsami et al., 2025) or evaluated in dedicated assessments of treatment and disposal alternatives (Alyaseri & Zhou, 2024; Prateep Na Talang et al., 2022). Construction and infrastructure are sometimes included (Bałazińska et al., 2024; Lopes et al., 2018), but often remain excluded, especially in operation-focused studies. Transportation is treated inconsistently, included in sludge-focused LCAs but neglected in many plant-level analyses. End-of-life aspects of facilities and equipment are rarely assessed. For iMERMAID, this landscape underlines the importance of setting clear and consistent boundaries. The project focuses on the operational phase and sludge management across all cases, while also capturing cradle-to-grave impacts of the new technologies implemented in the demonstrations. Construction of existing WWTP infrastructure will not be considered, in line with the project's scope and objectives.

The reviewed studies apply a range of life cycle impact assessment (LCIA) methods. The Centrum voor Milieuwetenschappen method (CML) remains common, particularly in studies emphasising classical midpoint categories such as climate change, eutrophication, and acidification (Lui et al., 2025; Rashid et al., 2022; Viotti et al., 2024). ReCiPe has become the most widely adopted framework in recent years, supporting both midpoint and endpoint indicators and allowing results to be aggregated into damage to human health, ecosystems, and resources (Bałazińska et al., 2024; Samsami et al., 2025). The Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) is applied in North American contexts, as in the United States Environmental Protection Agency (US EPA) nutrient removal study (US EPA, 2023). The toxicity model by the United Nations Environmental Program (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC), called UNEP-SETAC toxicity model (USEtox) is increasingly used when pharmaceutical removal and toxicity impacts are under investigation (Surra et al., 2024; US EPA, 2023), although toxicity impacts are also covered by ReCiPe and Environmental Footprint (EF) impact method. Stepwise2006 was employed in a study integrating LCA and cost assessments (Prateep Na Talang et al., 2022). Notably, none of the studies reviewed adopt the EF method, despite its growing importance in the European regulatory context. This highlights a gap between academic practice and policy requirements. For iMERMAID, EF is applied to ensure consistency with EU guidance and comparability with related initiatives, while methodological insights from the existing literature will inform interpretation and scenario design.

Impact categories also show convergence. Climate change is universally included and is the most emphasised indicator across the reviewed studies (Rashid et al., 2022; Samsami et al., 2025; Viotti et al., 2024). Eutrophication and acidification are almost equally often selected, reflecting the nutrient removal

function of WWTPs (Mehmeti & Canaj, 2022; US EPA, 2023). Toxicity categories, including human toxicity and freshwater or marine ecotoxicity, are analysed in many cases but are often not prioritised in the interpretation, despite their relevance for wastewater containing pharmaceuticals and emerging contaminants (Surra et al., 2024). Resource depletion and energy demand are receiving increased attention, particularly in studies linking treatment technologies to energy neutrality and circularity goals (Bałazińska et al., 2024; US EPA, 2023). Endpoint indicators, such as damage to human health, ecosystems, and resources, are consistently applied in ReCiPe-based studies, offering a more integrative perspective. In this context, iMERMAID will place particular emphasis on climate change and water-related impacts, namely water use, eutrophication, and ecotoxicity. The analysis will also be explicitly connected to water footprint and handprint concepts, addressing a gap identified in the reviewed literature.

Overall, the state of the art demonstrates that LCA of wastewater treatment has matured significantly but still lacks harmonisation. Functional units are relatively consistent, but boundary choices and category selection remain heterogeneous, limiting comparability across studies. Most critically, toxicity categories remain underrepresented, even though contaminants of emerging concern are increasingly relevant. At the same time, the application of LCA to novel treatment technologies shows the adaptability of the framework to emerging challenges in wastewater management. For iMERMAID, this review underscores the opportunity to advance the field by applying robust, EU-aligned methods while explicitly addressing toxicity and water-related impacts, ensuring that the assessment responds to both scientific gaps and policy priorities. In summary, the collective body of research firmly supports a standardised and harmonised LCA approach aligned with iMERMAID’s objectives: the use of a volumetric functional unit for comparability, system boundaries consistently covering operational and sludge phases, and the adoption of LCIA methods capable of capturing multi-dimensional environmental impacts.

Table 3: Summary of literature review on LCA studies of wastewater treatment, detailing study scope, functional units, LCIA methods, impact categories, and system boundaries to illustrate methodological tendencies relevant for iMERMAID. Stars (★) highlight the focus of the study.

Name of Study	Author(s)/Year	Short Description	Functional Unit (FU)	LCIA Method	Impact categories (★ = focus)	System Boundary
Life Cycle Assessment Methodology Applied to a Wastewater Treatment Plant	(Viotti et al., 2024)	LCA of a municipal WWTP in Italy; compares conventional activated sludge, membrane bioreactor (MBR), and anaerobic digestion + photovoltaic scenarios.	1 m ³ /d of influent	CML 2001	Climate change (★),	Cradle-to-gate; infrastructure less detailed
					Energy consumption	
Environmental impact assessment of southern Tehran wastewater treatment plant using life cycle assessment (LCA)	(Samsami et al., 2025)	Full-scale LCA; compares discharge vs reuse (irrigation); uses ReCiPe 2016 midpoint + endpoint.	1 m ³ treated wastewater	ReCiPe (endpoint)	Damage to Human health,	Cradle-to-grave; excludes construction

					Damage to Ecosystems,	to	
					Damage to Resources availability		
Life Cycle and Cost Assessments of Nutrient Removal Technologies in Municipal Wastewater Treatment Plants	(US EPA, 2023)	Compares nine nutrient-removal configurations; integrates LCIA + life-cycle cost assessment.	1 m ³ wastewater	TRACI, ReCiPe, USEtox	2.1, and	Midpoint categories	Cradle-to-gate; decommissioning excluded
Environmental Assessment of Wastewater Treatment and Reuse for Irrigation: A Mini-Review of LCA Studies	(Mehmeti & Canaj, 2022)	Review of 59 LCA studies on wastewater treatment and reuse; synthesizes FU, boundaries, and LCIA choices.	The common functional unit analyzed is volume-based, i.e., the volume of water treated	ReCiPe, CML (mainly)		Global warming (★), Eutrophication (★), Acidification (★), Ecotoxicity (★),	Summarizes multiple studies; notes many exclude infrastructure and EoL
					Others		
Life Cycle Assessment of an Innovative Combined "Wetland®" Technology vs Conventional Wastewater Treatment Technology	(Batazińska et al., 2024)	Compares novel Wetland® vs conventional WWTP; applied to pesticide-contaminated water.	1 m ³ treated water	ReCiPe (endpoint)		Damage to Human health, Damage to Ecosystems,	Cradle-to-gate
						Damage to Resources availability	

<p>Handling Uncertainties Inherited in Life Cycle Inventory and Life Cycle Impact Assessment Method for Improved LCA of Wastewater Sludge Treatment</p>	<p>(Alyaseri & Zhou, 2024)</p>	<p>Methodological study of sludge treatment (incineration vs digestion); focus on uncertainty in LCI/LCIA.</p>	<p>1 kg dry sludge (70% VS)</p>	<p>ReCiPe</p>	<p>Mid and endpoint categories</p>	<p>Gate-to-grave</p>
<p>The review of toxicity emission from municipal wastewater treatment by life cycle assessment</p>	<p>(Rashid et al., 2022)</p>	<p>Review of toxicity-related emissions in WWTP LCAs; highlights methodological gaps.</p>	<p>1 m³ treated wastewater (most common FU)</p>	<p>CML 2001 (most frequently applied)</p>	<p>Abiotic depletion (fossil fuels), Eutrophication, Global warming (★), Acidification, Ozone depletion, Human toxicity</p>	<p>Literature-based; shows most studies cover operation, some include infrastructure and sludge management</p>
<p>Life cycle assessment applied to wastewater treatment: State of the art</p>	<p>(Corominas et al., 2020)</p>	<p>Comprehensive review of methodological advances and challenges in wastewater LCA.</p>	<p>1 m³ treated wastewater (most common FU in literature); sometimes 1 m³ treated effluent meeting standards</p>	<p>ReCiPe, CML, TRACI, others (varies across reviewed studies)</p>	<p>Global warming, Eutrophication, Acidification, Human toxicity, Ecotoxicity, Resource depletion, Water use</p>	<p>Variable boundaries, mostly cradle-to-grave including treatment plant construction and operation</p>
<p>Environmental performance of a full-scale wastewater treatment plant</p>	<p>(Lopes et al., 2018)</p>	<p>LCA of WWTP construction and operation phases using CML 2 baseline 2000 method.</p>	<p>1 m³ treated effluent</p>	<p>CML 2 baseline 2000</p>	<p>Abiotic depletion, Global warming, Acidification, Eutrophication</p>	<p>Cradle-to-grave</p>
<p>Comparative life cycle assessment of non-thermal plasma for pharma removal</p>	<p>(Surra et al., 2024)</p>	<p>LCA of plasma and membrane technologies for pharmaceutical removal.</p>	<p>1 m³ treated or pollutant</p>	<p>ReCiPe and USETOX</p>	<p>18 categories of impact (ReCiPe method)</p>	<p>Cradle-to-gate</p>

Life cycle assessment of urban wastewater treatment plants	(Rebello et al., 2020)	Review of 111 LCA studies addressing variability; commonly analyzed: GHG, eutrophication, toxicity.	Usually 1 m ³ wastewater	CML and ReCiPe (mainly)	GHG, Eutrophication, Toxicity, Acidification	Cradle-to-grave; varying scopes
Life cycle impact assessment and life cycle cost of sludge treatment	(Prateep Na Talang et al., 2022)	Combined environmental and cost assessment for sludge treatment with ReCiPe impact assessment.	1 kg treated effluent	Stepwise2006	14 categories of impact (Stepwise2006 method)	Gate-to-gate
Life cycle assessment of drinking water and wastewater treatment	(Lui et al., 2025)	LCA of drinking and wastewater plants with focus on energy use and greenhouse gases using ReCiPe and IPCC methods.	1 m ³ drinking water and 1 m ³ treated wastewater	CML 2001	Global warming	Cradle-to-gate

2.5 State of the art: LCA applications to reverse osmosis (RO) and membrane-based water treatment systems

The number of LCA studies addressing membrane technologies for wastewater treatment has increased substantially over the past decade, in parallel with the broader integration of sustainability principles into the design of water treatment systems. An overview is provided in Table 4.

As observed, the period between 2011 and 2020 marks a significant rise in publications, reflecting growing interest in quantifying the environmental performance of membrane-based systems (Razman et al., 2022). This upward trend has continued, expanding the application of LCA to processes such as reverse osmosis (RO), ultrafiltration (UF), nanofiltration (NF), and membrane bioreactors (MBR), thereby supporting a more holistic understanding of their environmental implications.

Recent literature addressing LCA in RO and other membrane-based water treatment systems reflects a progressive shift from isolated technology evaluations to comprehensive system-level environmental analyses. Studies highlight how LCA has evolved from identifying hotspot processes in desalination and filtration systems toward integrating methodological harmonisation and resource recovery aspects (Bello et al., 2021; Razman et al., 2022). Comparative assessments demonstrate the growing use of LCA for benchmarking operational performance across treatment technologies (Banti et al., 2020; Fayyaz et al., 2023; Yang et al., 2020). Similarly, other studies (Jährig et al., 2025) extend the discussion to high-salinity and hybrid systems, incorporating brine management, energy use, and carbon footprint considerations. Collectively, these studies show significant methodological maturity but persistent inconsistencies in boundary definition, functional unit formulation, and impact coverage.

The reviewed literature exhibits a consistent preference for volumetric functional units, typically 1 m³ of treated or produced water (Banti et al., 2020; Fayyaz et al., 2023; Yang et al., 2020). In some cases, the FU extends to brine or product water streams (Bello et al., 2021; Jährig et al., 2025), while (Razman et al., 2022) report that volume-based units remain the dominant approach across 57 membrane-related LCA studies. The volumetric basis allows performance comparisons across technologies differing in configuration and treatment objective, from wastewater reclamation to seawater desalination. Within iMERMAID, the same volumetric FU will be maintained to ensure cross-comparability among pilot systems and alignment with established scientific practice.

System boundaries in the examined studies are predominantly cradle-to-gate, covering feedwater abstraction, pre-treatment, membrane operation, and effluent or product-water generation. Studies (Aleisa, E. et al., 2022; Fayyaz et al., 2023) explicitly delimit the scope to operational energy, chemical inputs, and brine management, while excluding infrastructure and end-of-life stages due to their limited contribution to overall impacts, while authors (Banti et al., 2020; Yang et al., 2020) include final disposal of sludge. This diversity underscores a common trade-off between completeness and data availability. For iMERMAID, a cradle-to-gate system will be applied, encompassing the entire operational chain and by-product management while excluding infrastructure construction to maintain focus on operational performance and comparability across demonstration sites. The use and-of-life phase will be accounted for in the cradle-to-gate iMERMAID scenario and considered as an integral part of the plant-technology system.

Table 4: Summary of literature review on LCA studies of reverse osmosis and membrane-based technologies, detailing study scope, functional units, LCIA methods, impact categories, and system boundaries. Stars (★) highlight the focus of the study.

Name of Study	Author(s)/year	Short Description	Functional Unit (FU)	LCIA Method	Impact Categories Analysed (★= focus)	System Boundaries
An overview of brine management: Emerging desalination technologies, life cycle assessment, and metal recovery methodologies	(Bello et al., 2021)	Review of brine management strategies in desalination, including emerging technologies, LCA applications, and metal recovery approaches. Discusses environmental impacts of desalination and brine disposal, particularly aquatic ecotoxicological potential.	1.0 m ³ of raw brine input	USEtox	Aquatic ecotoxicological potential	Cradle-to-gate, up to and including brine treatment or disposal
An overview of LCA applied to various membrane technologies: Progress, challenges, and harmonization	(Razman et al., 2022)	Comprehensive review of 57 LCA studies on membrane-based technologies (RO, FO, NF, UF). Discusses methodological challenges, progress, and harmonization needs for applying LCA to membrane systems.	1 m ³ of treated wastewater	CML, ReCiPe, TRACI, EDIP, Impact 2002+, EDP 2013, or CED (as reported among 37 studies)	Global Warming Potential, Eutrophication Potential, Acidification Potential	Cradle-to-gate, typically including construction and operation phases; infrastructure impacts considered negligible, and end-of-life or dismantling rarely assessed.
LCA of a Membrane Bioreactor Compared to Activated Sludge System for Municipal Wastewater Treatment	(Banti et al., 2020)	Comparative LCA of a membrane bioreactor (MBR) and a conventional activated sludge (CAS) system treating municipal wastewater with identical influent characteristics and effluent quality. The study evaluates environmental impacts based on real plant data from Northern Greece.	1 m ³ of effluent (treated wastewater)	CML 2001	Acidification potential (★), Eutrophication potential (★), Global warming potential (★), Ozone depletion potential, Photochemical ozone creation potential	Cradle-to-gate, covering influent treatment, all process operations, effluent production, and by-products such as sludge and membrane module disposal, including energy consumption.

<p><i>Treatment of Textile Wastewater by CAS, MBR, and MBBR: A Comparative Study from Technical, Economic, and Environmental Perspectives</i></p>	<p>(Yang et al., 2020)</p>	<p>Experimental comparison of three biological treatments—conventional activated sludge (CAS), membrane bioreactor (MBR), and moving bed biofilm reactor (MBBR)—for textile wastewater. Includes technical, economic, and LCA-based evaluation of pilot-scale plants.</p>	<p>1 m³ of treated effluent</p>	<p>ReCiPe, H</p>	<p>Midpoint and endpoint (★)</p>	<p>Cradle-to-gate, encompassing influent treatment, treatment processes, energy consumption, and effluent production. Sludge generation impact excluded; focus on operational phase.</p>
<p><i>Innovative pre-treatments for reverse osmosis to reclaim water from biotech and municipal wastewater for the industrial symbiosis in Kalundborg</i></p>	<p>(Jährgig et al., 2025)</p>	<p>Study conducted within the EU H2020 ULTIMATE project assessing pilot-scale water reclamation from biotech and municipal wastewater using different pre-treatment membranes (UF, ultra-tight UF, and NF) combined with RO. Compares energy demand, water recovery, and carbon footprint under various scenarios including biocide dosing, UV treatment, and brine management.</p>	<p>1 m³ of water</p>	<p>IPCC 2023 (for GWP 100a) and AWARE (for direct Water Availability Footprint)</p>	<p>Global Warming Potential, Marine Eutrophication Potential, Water use</p>	<p>Cradle-to-gate, encompassing the entire municipal WWTP and novel tertiary treatment with pre-filtration, membrane pre-treatment (UF, u-t UF, NF), and RO, including brine treatment and background processes for electricity, chemicals, fuels, and construction materials. Transport and sludge valorisation excluded.</p>
<p><i>Environmental Impacts of Reverse Osmosis in Wastewater Treatment versus Desalination to Mend the Water Cycle: A Life Cycle Assessment</i></p>	<p>(Aleisa, E. et al., 2022)</p>	<p>Comparative LCA of reverse osmosis applied to seawater desalination (SWRO) and wastewater treatment (WWRO) in Kuwait. The study evaluates environmental burdens following ISO 14040/44, using consequential open-loop modelling with field and literature data to identify the relative environmental profiles of SWRO and WWRO.</p>	<p>1 million cubic meter (Mm³) of permeate</p>	<p>ReCiPe Midpoint (H)</p>	<p>Climate change, Ozone depletion, Particulate matter formation, Fossil depletion, Metal depletion, Human toxicity, Marine ecotoxicity</p>	<p>Cradle-to-gate, including all processes, materials, energy, and chemical inputs during operation. Construction, decommissioning, and brine disposal phases excluded due to low significance.</p>
<p><i>Life Cycle Assessment of Reverse Osmosis for High-Salinity Seawater Desalination Process: Potable and Industrial Water Production</i></p>	<p>(Fayyaz et al., 2023)</p>	<p>Comprehensive LCA of seawater reverse osmosis (SWRO) producing potable and industrial-grade demineralized water in a petrochemical complex in the Persian Gulf. Includes detailed inventory of energy, chemicals, brine discharge, and solid waste, covering both passes of RO and ion exchange.</p>	<p>1 m³ of water</p>	<p>ReCiPe 2016, H</p>	<p>Midpoint and endpoint</p>	<p>Cradle-to-gate. Excludes infrastructure construction and transport.</p>

The methodological landscape is heterogeneous. Across the seven studies, ReCiPe, CML, and TRACI dominate as the preferred LCIA frameworks (Banti et al., 2020; Razman et al., 2022). The use of USEtox focuses on aquatic ecotoxicity (Bello et al., 2021), while ReCiPe is employed for midpoint and endpoint indicators (Aleisa, E. et al., 2022; Fayyaz et al., 2023), and IPCC (GWP 100) is integrated with AWARE to evaluate carbon and water availability footprints (Jährgig et al., 2025). Despite this methodological variety, none of the reviewed studies apply the Environmental Footprint (EF) method currently recommended within the European framework. To close this gap, iMERMAID will employ the EF method, ensuring methodological consistency with EU environmental policy and comparability with related European initiatives.

The literature converges on a limited yet recurrent set of impact categories. Climate change, eutrophication, and acidification remain the most frequently quantified impacts across studies. More comprehensive analyses, extend this scope to include resource depletion, water availability, and toxicity-related endpoints, or targeted evaluation of aquatic ecotoxicological potential linked to brine discharge. Overall, endpoint indicators addressing human health, ecosystems, and resource damage are also assessed, but water-related categories are still underrepresented. iMERMAID will address this by focusing on climate- and water-related impact categories, integrating water footprint and handprint metrics to bridge the methodological gap identified in the current literature.

The reviewed body of work demonstrates that LCA applications to RO and membrane-based systems have evolved toward greater methodological depth but still exhibit substantial divergence in impact coverage and system modelling., with principal focus on energy and chemical consumption. The findings highlight the need for harmonised methodological frameworks to support robust comparability across treatment technologies. In iMERMAID, these insights guide the adoption of a cradle-to-gate boundary, a volumetric functional unit, and EU-aligned LCIA methods based on the Environmental Footprint. By systematically integrating water-availability indicators and addressing operational and by-product phases, iMERMAID will extend the state of the art, delivering policy-relevant and scientifically robust LCA results for next-generation membrane and reverse-osmosis systems.

3.0 Results

The iMERMAID project demonstrates four advanced water treatment technologies across distinct Use Cases. This section presents the life cycle modelling and environmental impact results for each of these technologies and their application. Each Use Case is evaluated independently based on its specific system configuration, operational context, and available data.

For each Use Case, two scenarios are assessed:

- A **baseline scenario**, reflecting the existing operation of the WWTP without the iMERMAID technology.
- An **iMERMAID scenario**, representing the system after the integration of the demonstrated solution.

The assessment includes system descriptions, inventory data and modelling assumptions, and life cycle impact results, whereby quantitative data on the used material and electricity are not documented due to confidentiality reasons. Where applicable and after carrying out the complete assessment of the iMERMAID scenario, the latter is also compared to a relevant reference system, such as RO, to contextualize potential environmental benefits.

Each Use Case follows the same structure:

- Description of the demonstrated technology and system context.
- Definition of the assessment scenarios.
- Life cycle modelling and inventory overview.
- Environmental impact results and interpretation, including the water quality footprint and handprint related to the type of environmental impact caused by the contaminants of concern.

3.1 Use Case 1: Application of PDP technology at Socamex¹

3.1.1 Demonstrated technology and system context

This Use Case focuses on mitigating pollution from agricultural contaminants, particularly pesticides, in the region of San Esteban de Litera, Spain. The local wastewater treatment plant (WWTP) serves approximately 1,042 inhabitants and receives wastewater potentially influenced by agricultural runoff from surrounding areas.

The demonstrated technology is a Pulsed Discharge Plasma (PDP) system developed by IRIS and implemented as a tertiary treatment step within the existing WWTP configuration. The PDP unit is designed to degrade persistent organic pollutants through high-energy plasma oxidation without the addition of external chemical reagents. This approach aims to reduce chemical inputs, avoid the generation of secondary pollution, and improve removal efficiency for contaminants that typically persist through conventional biological processes.

The PDP system was integrated as an additional polishing stage downstream of biological treatment, targeting contaminants that are insufficiently removed by standard operations.

The treatment focuses on three selected CoEC representative of agricultural pollution and commonly detected in surface waters:

- Bisphenol A (BPA): an industrial chemical and endocrine disruptor.
- Isoproturon: herbicide widely used in cereal production, frequently detected in agricultural runoff.
- Terbutryn: triazine herbicide used for weed, and algae control, with recognized persistence and aquatic toxicity.

3.1.2 Scenario definition and inventory modelling

The life cycle inventory (LCI) for both baseline and iMERMAID scenarios was developed to reflect the specific operational setup and technical components of the San Esteban de Litera WWTP. Inventory inputs were based on a combination of primary data from technology providers and complementary assumptions, supported by background datasets sourced from Ecoinvent, as well as technical datasheets and material composition declarations.

A detailed breakdown of component-level inputs and transport assumptions is provided in the annexed inventory file.

UC1 Baseline Scenario: This scenario represents the current operation of the WWTP without the integration of the PDP system. It includes primary and secondary treatment processes typical of a small-scale municipal plant, with effluent discharged after conventional biological treatment. No advanced polishing step is included in this configuration. Inventory flows cover:

- Electricity use: Estimated based on operational data from the WWTP, scaled to 1 m³/day of treated wastewater.

¹ The partner originally referred to in the project documentation and Grant Agreement as Socamex is now named AQLARA Infraestructuras. For consistency with earlier project materials, figures, and use case references, the name Socamex has been retained in this report. All mentions of Socamex should therefore be understood as referring to AQLARA Infraestructuras.

- Sludge treatment: Includes typical municipal processes followed by application in agriculture as fertilizer. The process was modelled using the appropriate Ecoinvent datasets for sludge management with land application.
- Air emissions: Methane (CH₄) and nitrous oxide (N₂O) emissions from biological treatment processes were estimated using default emission factors from the 2019 IPCC Guidelines for Wastewater.

UC1 iMERMAID Scenario: This scenario builds on the baseline configuration by adding a PDP unit as a tertiary treatment step, designed to degrade selected organic contaminants. Key inventory elements and assumptions include:

- PDP reactor manufacturing: IRIS provided a detailed component list for the reactor, primarily consisting of electronic parts and accessories. Material composition data were retrieved from original technical declarations or proxy components with equivalent function and documented specifications. Combined with component weight data, this enabled calculation of the total material input for the assembled PDP unit.
- Transport: Includes international maritime transport of electronic components and domestic road transport to the installation site. Transport distances and modes were based on supplier origin and standard logistical assumptions.
- End-of-life treatment: Electronics were modelled as waste electrical and electronic equipment (WEEE). Plastic components were assumed to follow local mixed plastic recycling or incineration pathways.
- No chemical inputs: The PDP system operates without consumable reagents or catalysts, simplifying use-phase modelling and reducing input variability.
- No structural changes: The reactor is added as a standalone tertiary step downstream of the biological treatment, without modifying upstream process configurations.

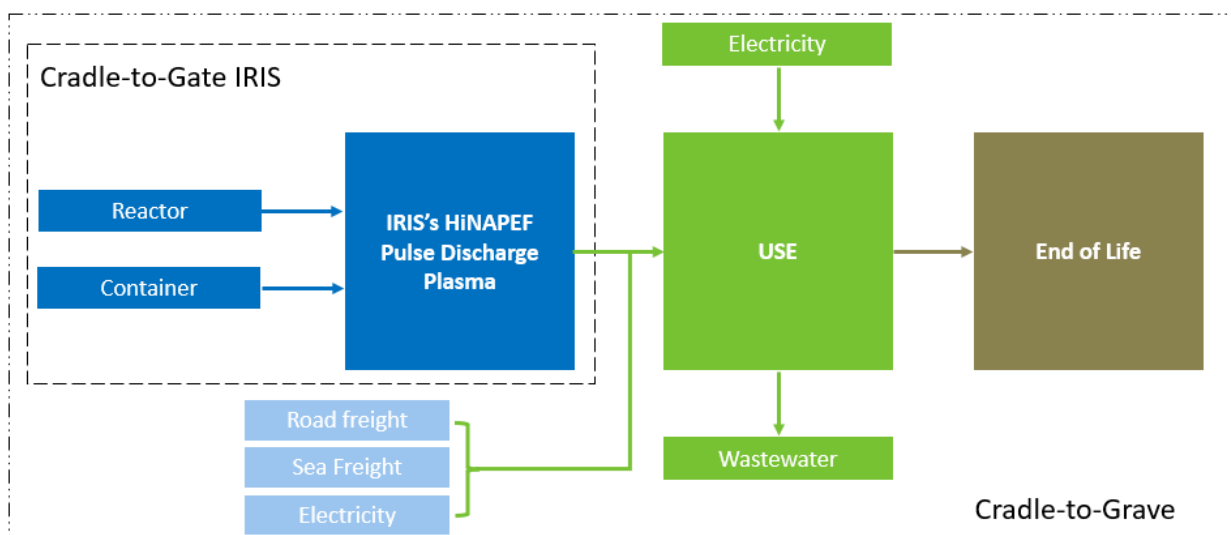


Figure 7: System boundaries for UC1, encompassing a cradle-to-grave assessment including device manufacturing, transport, use phase, electricity inputs, and end-of-life treatment.

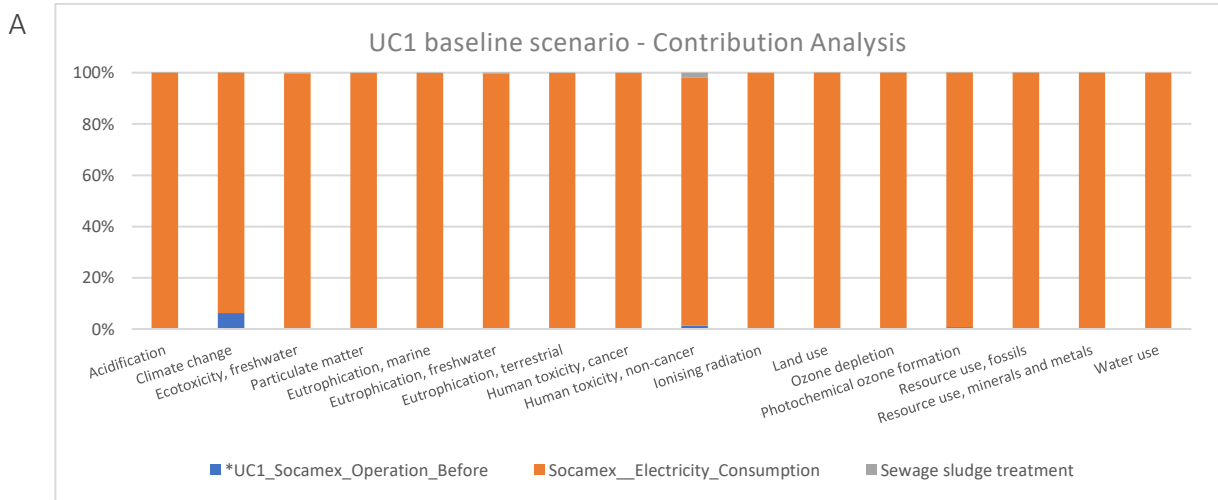
3.1.3 Baseline Scenario results

The baseline operation of the San Esteban de Litera WWTP is characterized by a strong dependency on electricity, which drives the majority of environmental impacts across all priority categories. Climate change, resource depletion (fossil), freshwater ecotoxicity, eutrophication (freshwater), and water use are almost entirely attributable to the electricity required for standard treatment processes.

In particular, climate change impact values reaches 183.86 μ Pt, with 93.6% linked to electricity consumption. The same pattern is evident for resource use (fossils), which totals 215.98 μ Pt, with nearly 100% from electricity, and water use, which amounts to 29.92 μ Pt, also dominated by electricity inputs. These results highlight the relatively simple inventory of the baseline system and the indirect footprint embedded in energy-intensive operations, particularly through upstream emissions and resource demands in the electricity mix.

Water-related impacts in the baseline scenario are non-negligible, with notable contributions from freshwater ecotoxicity (6.08 μ Pt), eutrophication (freshwater: 21.41 μ Pt; marine: 9.27 μ Pt), and water use (29.92 μ Pt). These impacts are also primarily driven by electricity consumption and, to a lesser extent, by sludge treatment, indicating that upstream burdens, rather than direct water withdrawals, are the main sources of pressure on aquatic ecosystems and water availability.

While sludge treatment is part of the overall configuration, its contribution remains minor across all categories, with slight relevance observed in freshwater ecotoxicity (0.02 μ Pt) and eutrophication (freshwater: 0.06 μ Pt; marine: 0.01 μ Pt) due to modelled end-of-life processes.



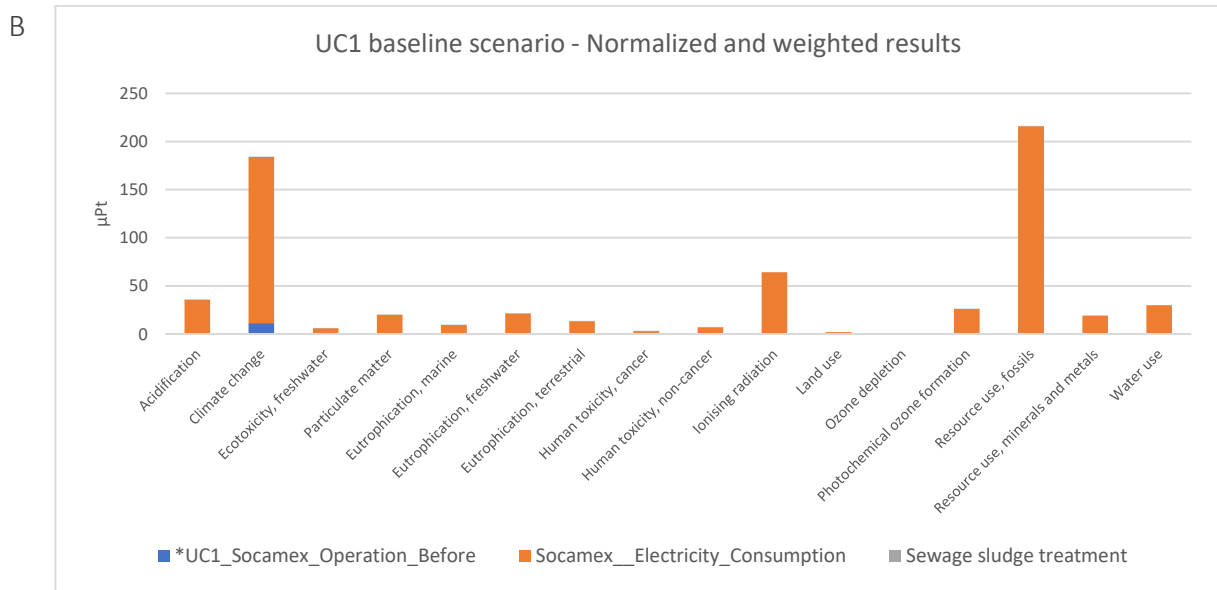


Figure 8: Environmental impact results for the UC1 baseline scenario. (A) Contribution analysis showing the relative share of individual processes to each impact category, expressed as a percentage of total impact per functional unit (1 m³ of treated wastewater). (B) Normalized and weighted results expressed in μPt, highlighting the relative importance of impact categories.

3.1.4 iMERMAID Scenario results

3.1.4.1 Cradle-to-gate impact: Pulsed Discharge Plasma Reactor

The total cradle-to-gate environmental impact associated with the IRIS PDP reactor amounts to 4.65 μPt, based on normalized and weighted midpoint indicators using the Environmental Footprint 3.1 method. The most significant contributors are Climate change (0.73 μPt, or 15.7%), Resource use: fossils (1.50 μPt, or 32.0%), and Water use (0.76 μPt, or 16.4%). These results reflect the embedded impacts of electronic components, polymers, high-purity materials, and associated freight transport, especially in the context of small but material-intensive devices.

The interpretation below focuses on selected midpoint categories to identify key contributors and link them to specific inventory drivers.

The Climate change category totals 0.73 μPt, representing 15.7% of the total cradle-to-gate impact. The main contributors are copper (0.015 μPt, or 2.1% of the category), epoxy resin (0.006 μPt, or 0.8%), and sea freight transport (0.077 μPt, or 10.6%). Additionally, electricity use during manufacturing contributes 0.001 μPt. These emissions are primarily driven by the production of metals and polymers, and the long-distance shipping of components from Asia to Europe. The presence of high-performance thermoplastics and epoxy composites further increases emissions due to their energy-intensive processing.

The Freshwater ecotoxicity category totals 0.12 μPt, contributing 2.6% to the total impact. Major contributors include cobalt oxide, nickel, and silver, all of which are components found in electronic subassemblies. These metals are associated with toxic releases into freshwater ecosystems during mining, extraction, and refining. Marginal contributions arise from polycarbonate and road transport due to upstream emissions linked to polymer and fuel production.

The Marine eutrophication category totals 0.040 μPt, accounting for 0.9% of the total impact. Sea freight and polypropylene components are key contributors, the former due to emissions of nitrogen compounds from marine fuels and the latter due to chemical processes associated with plastic manufacturing.

The Freshwater eutrophication category totals 0.056 μ Pt, or 1.2% of total impact. Main contributors include polycarbonate, polypropylene, and LED components, which are associated with phosphorus and nitrate discharges in the production of plastics and electronic assemblies. A smaller contribution from epoxy resin is also observed, reflecting emissions from the synthesis of resins and adhesives used in circuit boards or mechanical enclosures.

The Water use category amounts to 0.76 μ Pt, which is 16.4% of the total impact, the second highest among all categories. The largest single contributor is electronics-grade silicon (0.74 μ Pt, or 96.5% of the category), which reflects the high volume of water required during semiconductor fabrication. Other notable contributors include silver and LED components, both of which involve water-intensive manufacturing processes.

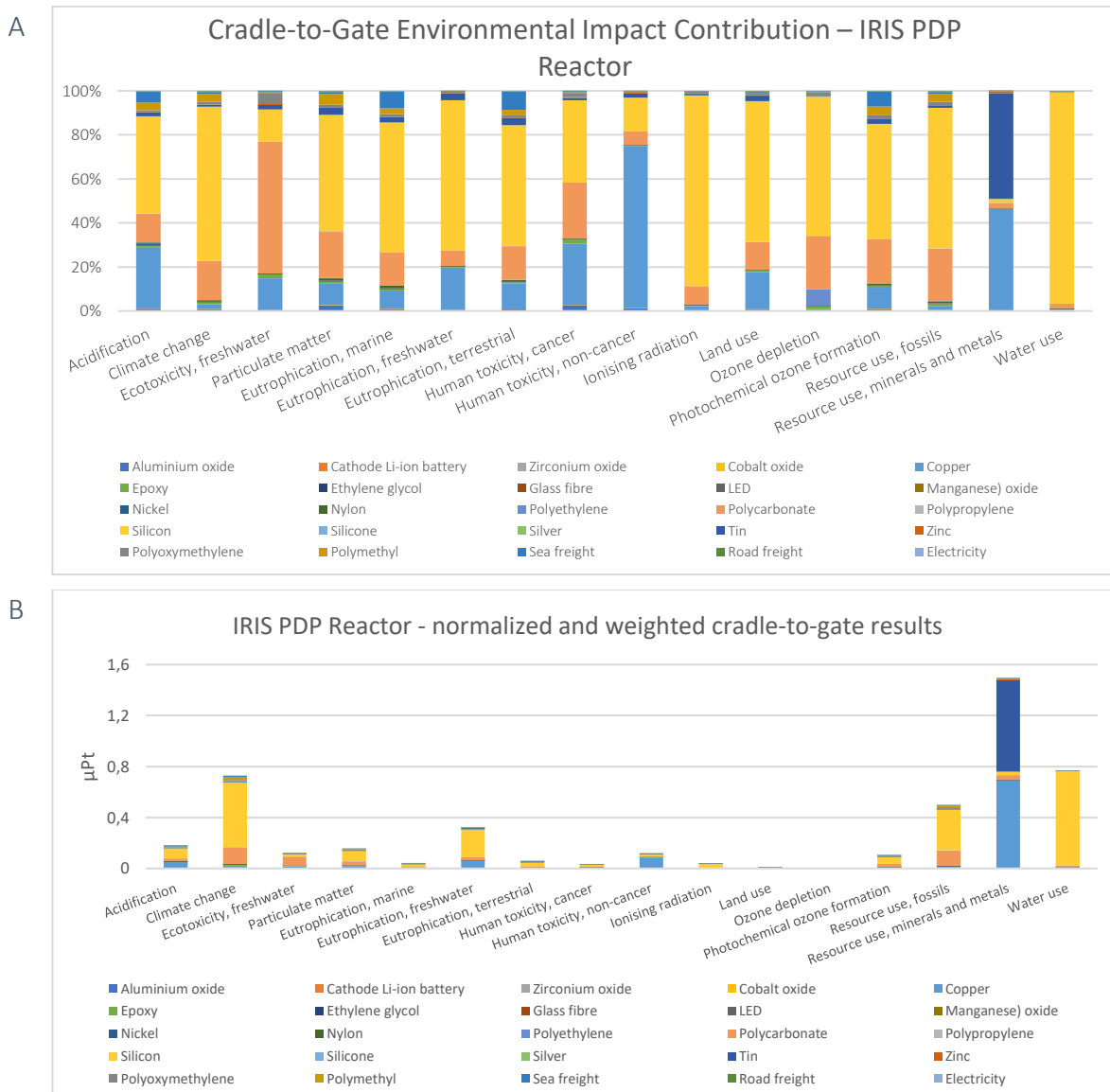


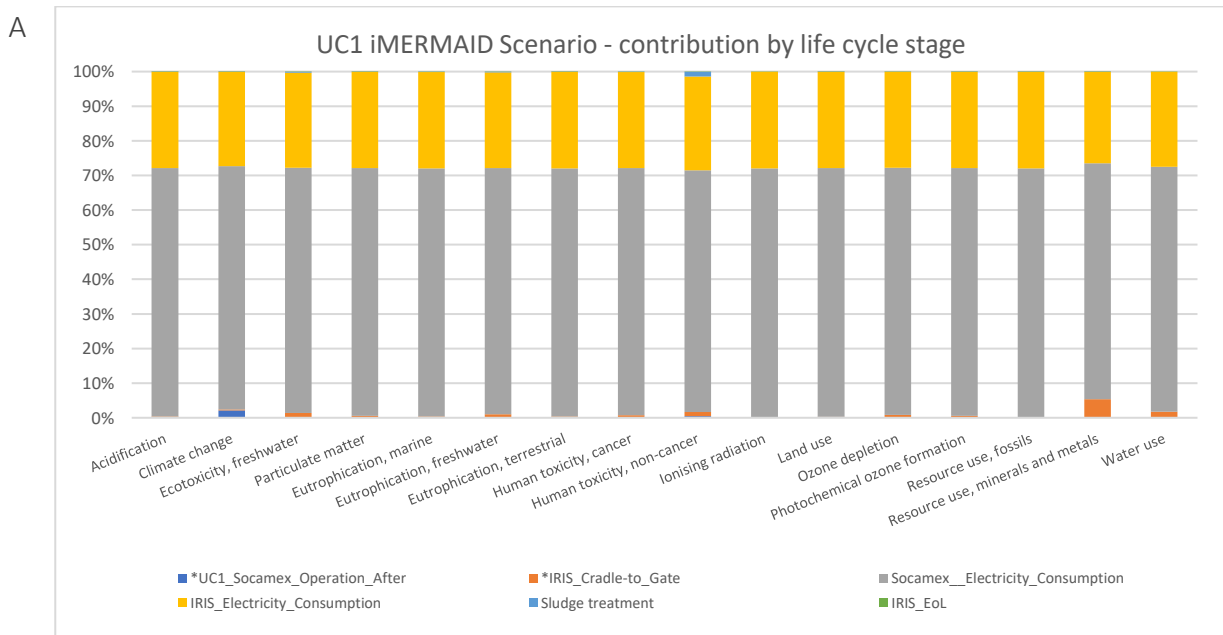
Figure 9: Cradle-to-gate environmental performance of the IRIS PDP reactor within the UC1 iMERMAID Scenario. (A) Relative contribution of individual components and materials to each midpoint impact category. (B) Normalized and weighted cradle-to-gate results showing the absolute contribution (μ Pt) of each impact category to the total environmental profile.

3.1.4.2 Cradle-to-grave results: Pilot application

The cradle-to-grave results describe the environmental profile of the iMERMAID scenario at the Socamex site, where the existing wastewater treatment configuration is complemented by the IRIS Pulsed Discharge Plasma reactor as an additional tertiary treatment step. The assessment integrates the operation of the current Socamex treatment system with the life cycle impacts associated with deployment of the PDP unit, including its production, additional electricity demand during operation, end-of-life treatment, and the existing sludge management processes. More specifically, the cradle-to-grave analysis includes:

- Socamex operation after implementation, representing the existing wastewater treatment process under the iMERMAID scenario, including reduced direct methane and nitrous oxide emissions associated with the assumed 55% reduction in total organic carbon (TOC)
- IRIS cradle-to-gate, including production of the PDP reactor and transport of its components
- Socamex electricity consumption, representing the baseline electricity demand of the WWTP
- IRIS electricity consumption, representing the additional electricity demand associated with operation of the PDP reactor
- sludge treatment, consistent with the baseline scenario
- IRIS end-of-life treatment, including recycling of plastic fractions and WEEE treatment of electronic parts

The contribution analysis by life cycle stage, shown in Figure 10, provides the basis for identifying the main drivers of the environmental profile of the iMERMAID scenario at the Socamex site across the impact categories considered.



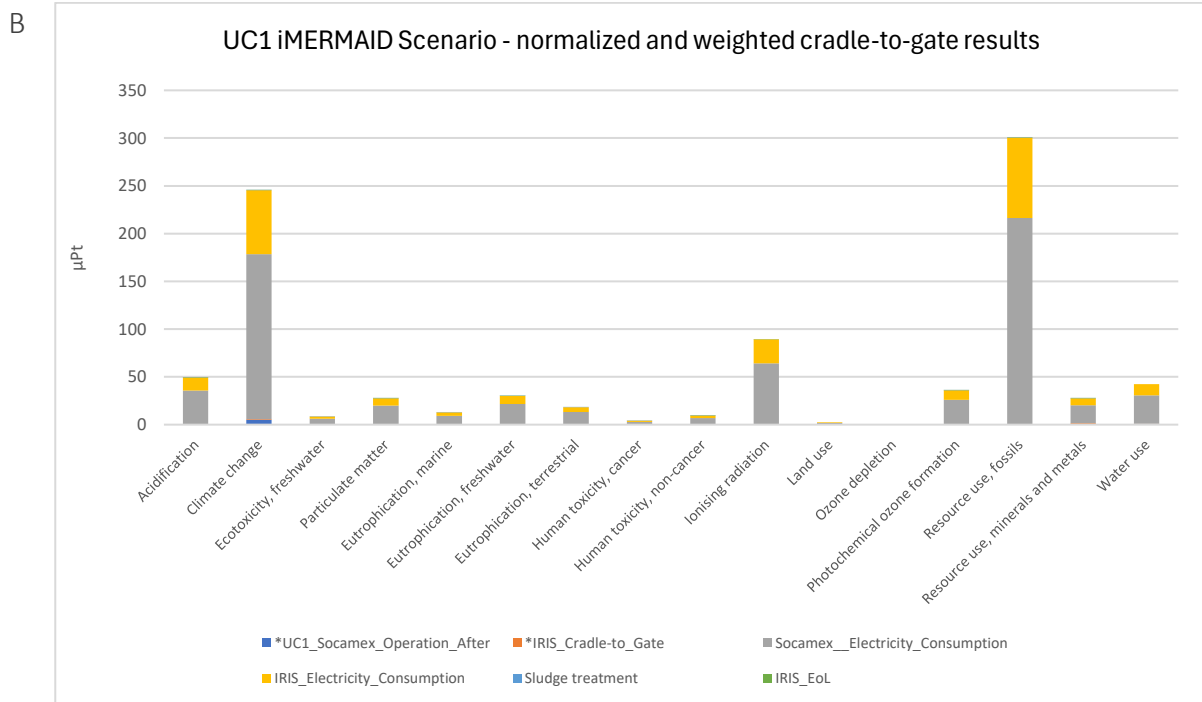


Figure 10: Environmental impact results for the UC1 iMERMAID scenario. (A) Contribution analysis showing the relative share of each life cycle stage to the impact categories considered, expressed as a percentage of total impact per functional unit (1 m³ of treated wastewater). (B) Normalized and weighted results expressed in µPt, highlighting the relative importance of impact categories and life cycle stages

In the cradle-to-grave iMERMAID scenario, the environmental profile is dominated by electricity use. Socamex electricity consumption and IRIS electricity consumption contribute 644 µPt and 250 µPt, respectively, corresponding to 71.2% and 27.7% of the total result. Together, these two stages account for 894 µPt, or about 98.9% of the overall environmental profile. By contrast, the direct contribution of Socamex operation after implementation amounts to 5.27 µPt and reflects residual process emissions from the biological treatment stage, mainly associated with degradation of organic matter and the resulting gaseous emissions to air. IRIS cradle-to-gate contributes 4.66 µPt, while sludge treatment and IRIS end-of-life remain negligible. This distribution indicates that the environmental burden of the post-implementation scenario is shaped almost entirely by operational electricity demand, while the direct contribution of reactor manufacturing and end-of-life treatment remains limited.

The environmental profile of the UC1 iMERMAID scenario is mainly defined by resource use, fossils, climate change, and ionising radiation, which contribute 300 µPt, 245 µPt, and 89.3 µPt, respectively. Together, these three categories account for about 70.2% of the total result. Resource use, fossils is almost entirely driven by electricity consumption, with Socamex electricity and IRIS electricity contributing 216 µPt and 84 µPt, respectively. A similar pattern is observed for climate change, where Socamex electricity contributes 172 µPt and IRIS electricity 67 µPt, together accounting for about 97.6% of the category total. Ionising radiation follows the same logic, with nearly the entire impact also linked to electricity supply. This pattern is consistent with the electricity mix represented in the Ecoinvent database for Spain, where the supply profile combines natural gas with nuclear and renewable sources such as wind, solar, and hydropower. As a result, electricity use contributes not only to climate change and fossil resource use, but also to ionising radiation and other upstream categories linked to power generation. Overall, these results show that the

additional tertiary treatment step increases the environmental burden primarily through higher electricity demand rather than through the material requirements of the PDP reactor itself.

The direct contribution of Socamex operation after implementation remains limited across most categories, with its main relevance observed in climate change, where it contributes 5.13 μPt . This contribution reflects the residual direct process emissions associated with wastewater treatment after application of the assumed 55% reduction in COT, mainly linked to degradation of organic matter and the corresponding methane and nitrous oxide emissions. In the present modelling approach, this stage represents the direct operational burden of the treatment process itself, while electricity use, sludge management, and the PDP system are accounted for separately. Compared with the dominant electricity-related burdens, however, these residual process emissions remain secondary in the overall environmental profile. The cradle-to-gate contribution of the IRIS reactor is also generally small, although it becomes more visible in resource use, minerals and metals, where it contributes 1.49 μPt , reflecting the material requirements of the electronic and high-purity components that make up the device.

From a project perspective, it is also relevant to consider the categories more directly associated with water systems, particularly water use, freshwater eutrophication, marine eutrophication, and freshwater ecotoxicity. Although these categories contribute a smaller share to the total result, they remain important in the context of wastewater treatment and the broader objectives of the iMERMAID project. Water use reaches 42.3 μPt , corresponding to 4.7% of the total result, while freshwater eutrophication contributes 30.0 μPt , marine eutrophication 12.9 μPt , and freshwater ecotoxicity 8.56 μPt . In all four categories, the contribution pattern remains overwhelmingly dominated by electricity consumption, with Socamex electricity and IRIS electricity together accounting for about 98 to 100% of the category totals. This indicates that water-related burdens in the UC1 iMERMAID scenario are driven mainly by upstream processes associated with electricity generation rather than by direct emissions or consumable inputs during operation.

The contribution of IRIS cradle-to-gate to these water-related categories remains limited but not negligible. It is most visible in water use, where it contributes 0.76 μPt , and in freshwater ecotoxicity, where it contributes 0.12 μPt . These impacts are associated with the upstream production of electronic-grade silicon, metallic components, and polymeric materials used in the PDP reactor, consistent with the cradle-to-gate results discussed previously. Sludge treatment plays only a marginal role, with minor contributions in freshwater ecotoxicity and freshwater eutrophication, while end-of-life remains negligible across all categories.

Overall, the cradle-to-grave iMERMAID scenario for UC1 remains strongly electricity-driven. The integration of the PDP reactor adds only a limited burden from manufacturing and end-of-life, while the main effect on the total environmental profile arises from the additional electricity required for operation. As a result, the environmental interpretation of the scenario depends primarily on the balance between increased electricity-related burdens and the remediation function delivered by the tertiary treatment step, the latter to be addressed through the comparative assessment and handprint analysis.

A note on updated electricity consumption data for the IRIS PDP system, communicated after completion of the main analyses, is provided in Technical Note I.

3.1.4.3 Comparative analysis of the LCA results of the baseline and iMERMAID scenarios

The comparison between the baseline and iMERMAID scenarios shows that the introduction of the PDP reactor as an additional tertiary treatment step increases the overall environmental burden of the system at the level of normalized and weighted LCA results. The total impact rises from 655.87 μ Pt in the baseline scenario to 904.41 μ Pt in the iMERMAID scenario, corresponding to an increase of 248.54 μ Pt, or about 38%. This result reflects the fact that the innovative configuration does not replace the existing Socamex treatment system but complements it with an additional polishing step that requires extra electricity during operation as well as the manufacture and end-of-life treatment of the IRIS reactor.

Table 5: Comparative normalized and weighted LCA results for the baseline and iMERMAID scenarios, with IRIS cradle-to-gate contribution shown for interpretation support

Damage category	Baseline scenario	iMERMAID scenario	Baseline vs. iMERMAID scenarios	IRIS cradle-to-gate contribution	Unit
Total	655.87	904.41	38%	5.271	μ Pt
<i>Acidification</i>	35.40	49.33	39%	0.007	μ Pt
<i>Climate change</i>	183.86	245.38	33%	5.126	μ Pt
<i>Ecotoxicity, freshwater</i>	6.08	8.56	41%	0.001	μ Pt
<i>Particulate matter</i>	19.87	27.74	40%	0.000	μ Pt
<i>Eutrophication, marine</i>	9.27	12.90	39%	0.005	μ Pt
<i>Eutrophication, freshwater</i>	21.41	30.03	40%	0.000	μ Pt
<i>Eutrophication, terrestrial</i>	13.19	18.35	39%	0.008	μ Pt
<i>Human toxicity, cancer</i>	2.89	4.04	40%	0.000	μ Pt
<i>Human toxicity, non-cancer</i>	6.97	9.65	39%	0.041	μ Pt
<i>Ionising radiation</i>	64.24	89.25	39%	0.000	μ Pt
<i>Land use</i>	1.81	2.52	39%	0.000	μ Pt
<i>Ozone depletion</i>	0.17	0.23	40%	0.000	μ Pt
<i>Photochemical ozone formation</i>	25.94	35.95	39%	0.083	μ Pt
<i>Resource use, fossils</i>	215.98	300.45	39%	0.000	μ Pt
<i>Resource use, minerals and metals</i>	18.87	27.69	47%	0.000	μ Pt
<i>Water use</i>	29.92	42.33	41%	0.000	μ Pt

The increase is mainly shaped by the same impact categories that dominate the iMERMAID scenario overall, namely resource use, fossils, climate change, ionising radiation, and water use. Resource use, fossils increase from 215.98 μ Pt to 300.45 μ Pt, corresponding to an increase of 84.47 μ Pt, or about 39%, while climate change rises from 183.86 μ Pt to 245.38 μ Pt, an increase of 61.52 μ Pt, or about 33%. Ionising radiation increases from 64.24 μ Pt to 89.25 μ Pt, or about 39%, and water use from 29.92 μ Pt to 42.33 μ Pt, or about 41%. In general, the increase across categories is remarkably consistent and reflects the additional electricity demand introduced by the IRIS reactor. In the iMERMAID scenario, the baseline electricity consumption of the Socamex plant is maintained and complemented by the electricity required for PDP operation. As both contributions are modelled through the Spanish electricity supply represented in Ecoinvent, the increase propagates across a broad set of impact categories with a similar relative magnitude.

The comparison also shows that the addition of the tertiary treatment step does not fundamentally change the structure of the environmental profile. Most impact categories increase by around 39 to 41%, which is broadly consistent with the increase in electricity demand associated with PDP operation. This indicates

that the additional burden of the iMERMAID scenario is primarily operational rather than material. The IRIS cradle-to-gate contribution remains limited, amounting to 5.27 μPt in total, or about 0.6% of the full iMERMAID scenario. Its influence is therefore secondary in comparison with the electricity-related burdens of the treatment system.

A slight deviation from this general pattern is observed in climate change, where the increase is lower, around 33%. This reflects the fact that the iMERMAID scenario includes not only the additional electricity demand of the PDP reactor, but also a reduction in direct methane and nitrous oxide emissions from the WWTP, linked to the assumed 55% decrease in COT. In this case, the added electricity burden is partially offset by lower direct process emissions from biological treatment, which moderates the relative increase in climate change compared with the other electricity-driven categories.

The category showing the highest relative increase is resource use, minerals and metals, which rises from 18.87 μPt in the baseline to 27.69 μPt in the iMERMAID scenario, corresponding to an increase of 8.82 μPt , or about 47%. Although the absolute increase remains moderate, this higher relative change indicates the influence of the additional material requirements associated with the PDP reactor. As discussed in the cradle-to-gate analysis, the IRIS unit includes electronic parts, metals, polymers, and high-purity materials whose upstream production contributes to this category. Even so, the overall contribution of reactor manufacturing remains limited in comparison with the dominant electricity-related burdens.

Beyond the dominant contributors to the total result, the water-related impact categories are particularly relevant for interpretation in light of the remediation purpose of the iMERMAID scenario. Freshwater ecotoxicity increases from 6.08 μPt to 8.56 μPt , freshwater eutrophication from 21.41 μPt to 30.03 μPt , marine eutrophication from 9.27 μPt to 12.90 μPt , and water use from 29.92 μPt to 42.33 μPt . These changes remain largely driven by the higher electricity demand of the integrated treatment configuration, rather than by consumable inputs or large infrastructure additions. In this case, the additional treatment step does not introduce chemical inputs, and the cradle-to-gate burden of the reactor is comparatively small. As a result, the water-related categories increase mainly through upstream burdens associated with electricity generation.

For this reason, the comparative LCA results should not be interpreted in isolation. The iMERMAID scenario introduces additional environmental burdens because it adds an energy-demanding tertiary treatment step to the existing system. At the same time, its environmental relevance lies in the expected improvement in water quality delivered by the PDP treatment. The comparative assessment should therefore be read together with the handprint analysis, which captures the beneficial effect of contaminant removal and provides the complementary perspective needed to assess the overall environmental value of the technology.

A note on updated electricity consumption data for the IRIS PDP system, communicated after completion of the main analyses, is provided in Technical Note I.

3.1.4.4 Water quality footprint and handprint

For UC1, the handprint assessment was developed to quantify the environmental benefit associated with the removal of the selected contaminants of concern, namely isoproturon, terbutryn, and bisphenol A, from the final treated effluent. In line with the project logic for remediation technologies, the handprint is expressed here in terms of freshwater ecotoxicity, since this is the impact category most directly linked to the selected contaminants and their potential effects on aquatic systems. Characterization factors for isoproturon and terbutryn were taken from EF 3.1, while the factor for bisphenol A was derived separately based on USEtox.

It should be noted that the LCA results and the handprint address different components of the environmental profile. The LCA quantifies the burdens associated with operation of the treatment system, reactor production, transport, sludge treatment, and end-of-life management, while the handprint focuses on the reduction of pollutant-related ecotoxicity in the discharged stream. In this way, the handprint complements the LCA results rather than duplicating them.

The remediation performance was calculated from the concentration of the selected contaminants at the Socamex WWTP outlet and at the outlet of the IRIS PDP system. The concentration at the Socamex WWTP outlet was based on six monitoring dates between 19 February and 24 March, from which average values were derived for each contaminant. For the IRIS outlet, the available pilot results indicate complete removal of all three substances under the tested conditions, corresponding to final concentrations equal to zero. The potential freshwater ecotoxicity intensity of the discharged stream was calculated by multiplying the mass of each contaminant per m³ by its freshwater ecotoxicity characterization factor. Table 6 presents the inventory data, characterization factors, and resulting ecotoxicity intensities used for the handprint assessment.

Table 6: Inventory data, freshwater ecotoxicity characterization factors, and resulting potential freshwater ecotoxicity impacts for the selected contaminants of concern at the Socamex WWTP outlet and after IRIS PDP treatment, used for the UC1 handprint assessment. Results are expressed in CTUe per m³ of treated wastewater.

CoCs		Socamex WWTP outlet		IRIS PDP Treatment System outlet	
Contaminantes of Concern	CF - Ecotoxicity freshwater (CTUe/kg)	Concentration at Final of Socamex treatment (kg/of SoC)	Potential freshwater ecotoxicity impact (CTUe)	Concentration at Final of IRIS treatment (kg/of SoC)	Potential freshwater ecotoxicity impact (CTUe)
<i>Isoproturon</i>	1.08E+04	0.000013	1.44E-01	0.00	0.00E+00
<i>Terbutryn</i>	6.15E+03	0.000027	1.64E-01	0.00	0.00E+00
<i>Bisphenol A</i>	2.17E+02	0.000617	1.34E-01	0.00	0.00E+00

The remediation performance of the IRIS PDP system amounts to 0.44 CTUe/m³, corresponding to the avoided freshwater ecotoxicity potential associated with the removal of isoproturon, terbutryn, and bisphenol A from the final effluent. Among the three contaminants considered, terbutryn contributes 0.16 CTUe/m³, representing about 37.1% of the total remediation performance, followed by isoproturon with 0.14 CTUe/m³, or about 32.6%, and bisphenol A with 0.13 CTUe/m³, or about 30.3%. Although bisphenol A is present at the highest concentration in the Socamex WWTP outlet, its contribution to the characterized result is moderated by its lower freshwater ecotoxicity characterization factor. By contrast, isoproturon and terbutryn contribute proportionally more to the remediation performance because of their higher characterization factors.

When this remediation performance is interpreted together with the freshwater ecotoxicity burden of the treatment configuration, the system-level balance changes. In the reference condition, the total freshwater ecotoxicity profile amounts to 18.41 CTUe/m³, including 17.97 CTUe/m³ from Socamex WWTP operation and 0.44 CTUe/m³ from the freshwater ecotoxicity potential of the selected CoCs in the discharged effluent. In the IRIS PDP configuration, the selected CoCs are removed from the final effluent, generating the remediation handprint described above. However, the PDP system also introduces an additional operational freshwater ecotoxicity burden of 7.31 CTUe/m³. As a result, the total freshwater ecotoxicity profile of the PDP configuration amounts to 25.72 CTUe/m³.

Under the specific conditions assessed for UC1, the avoided freshwater ecotoxicity potential associated with the selected CoCs is therefore lower than the additional operational burden introduced by PDP operation. This means that, although the PDP system provides a measurable remediation benefit by removing isoproturon, terbutryn, and bisphenol A from the discharged effluent, this benefit does not lead to an overall reduction in the system-level freshwater ecotoxicity profile for the assessed case.

At the same time, the result should not be interpreted as limited treatment capability of the IRIS PDP system. In the assessed experiment, the PDP system achieved full degradation of the selected CoCs, removing 100% of the freshwater ecotoxicity potential associated with isoproturon, terbutryn, and bisphenol A from the final effluent. This indicates that the system was technically effective for the contaminants and conditions evaluated in UC1.

Based on this demonstrated removal performance, it is reasonable to consider that the environmental relevance of the PDP system could be higher in wastewater contexts where CoC concentrations are higher, or where the contaminant-related freshwater ecotoxicity potential represents a larger share of the total freshwater ecotoxicity profile. However, this should be treated as a scenario-based consideration rather than a direct conclusion from the UC1 result. Additional assessment would be required to quantify whether higher CoC loads, different wastewater compositions, or different operating conditions would generate a larger net environmental benefit after accounting for the operational burdens of PDP implementation.

The UC1 result should therefore be understood as a case-specific balance between demonstrated treatment effectiveness and the environmental burden of implementation. Under the assessed Socamex conditions, the PDP system provides a clear targeted remediation benefit, but the selected CoC load in the effluent is not sufficient to generate an overall reduction in the system-level freshwater ecotoxicity profile. Future implementation assessments should consider removal efficiency together with contaminant load, ecotoxicity-weighted relevance, treatment capacity, operational energy demand, and the expected frequency of CoC occurrence in the treated effluent.

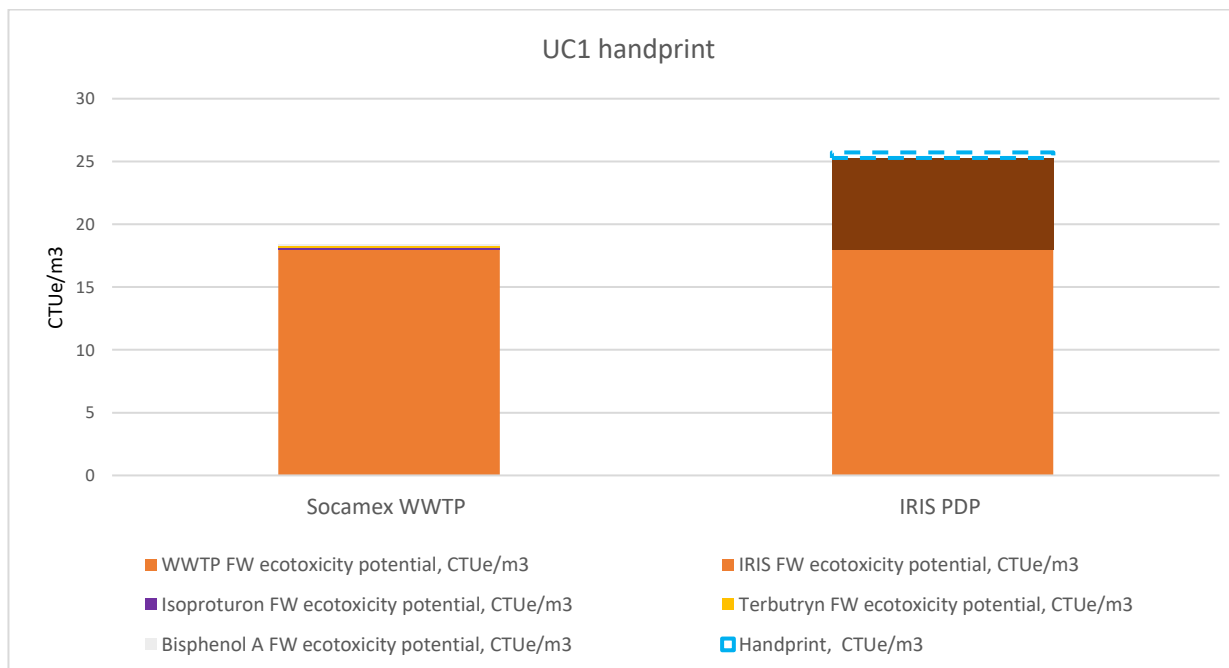


Figure 11: Handprint representation for UC1, showing the ecotoxicity potential associated with the selected contaminants at the Socamex WWTP effluent, the use-phase ecotoxicity burden associated with electricity consumption, the remaining potential after IRIS PDP treatment, and the resulting avoided potential. Freshwater (FW) ecotoxicity potentials are expressed in CTUe/m3.

3.2 Use Case 2: Application of Microfluidic System and reclaimed RO membranes at Opalia

3.2.1 Demonstrated technology and system context

This Use Case takes place in Kalaat Al Andalouss, Tunisia, where the pharmaceutical company Opalia operates an on-site WWTP using a conventional Activated Sludge Process (ASP). While effective for general organic matter and nutrient removal, the existing configuration shows limited capability in degrading persistent pharmaceutical contaminants.

To address this challenge, a novel microfluidic remediation system developed by EDEN was implemented as a tertiary polishing step downstream of the ASP. The system was demonstrated in collaboration with Opalia and ENIG. While EDEN provided the core treatment unit, ENIG contributed a pre-filtration system based on reclaimed RO membranes, designed to optimize influent quality and enhance the overall treatment performance.

EDEN's solution is a bioinspired treatment unit that mimics vascular networks found in nature. It circulates contaminated water through stacked microfluidic discs where photocatalysis occurs. Each disc is compact disc- (CD)-sized, etched with microchannels, and coated with a photocatalyst that activates under light. This enables the degradation of pharmaceutical residues without requiring external chemicals, offering a compact and energy-efficient technology. The upstream pre-filtration unit developed by ENIG, based on converted end-of-life RO membranes, provides particulate removal and sample preconcentration, supporting the efficiency and reliability of the downstream photocatalytic process and enabling circular membrane reuse in line with iMERMAID's goals.

The intervention targets the removal of three commonly detected pharmaceutical CoECs:

- Ibuprofen: a widely used anti-inflammatory drug.
- Ketoprofen: an analgesic and anti-inflammatory compound.
- Diclofenac: an environmentally persistent non-steroidal anti-inflammatory drug.

3.2.2 Scenario definition and inventory modelling

To support the environmental assessment of the Opalia case, a dedicated LCI was developed for both the baseline and iMERMAID-enhanced scenarios. The modelling reflects the actual configuration of the pharmaceutical wastewater treatment plant and accounts for the integration of EDEN's microfluidic remediation system as a tertiary step.

Inventory inputs were established through direct collaboration with technology providers, complemented by engineering-based estimations where necessary. All background processes were modelled using the Ecoinvent database, and the Tunisian electricity mix was applied to foreground operations to ensure regional consistency.

UC2 Baseline Scenario: This scenario represents the existing treatment configuration at the Opalia site, which consists of a conventional ASP designed for the removal of organic matter and nutrients. However, the current system demonstrates limited removal efficiency for micropollutants, particularly pharmaceutical residues. Key inventory components for the baseline scenario include:

- Electricity consumption: Estimated based on operational parameters of the ASP and normalized to the functional unit of 1 m³/day of treated wastewater.
- Sludge treatment: Includes typical municipal sludge handling processes such as thickening, dewatering, and disposal, modelled using representative Ecoinvent datasets.

- Direct emissions to air: Methane (CH₄) and nitrous oxide (N₂O) emissions resulting from the biological treatment stage were estimated using default emission factors from the 2019 IPCC Guidelines for Wastewater Treatment.

UC2 iMERMAID Scenario: In this scenario, the EDEN microfluidic remediation system is installed as a tertiary treatment step downstream of the ASP. Additionally, ENIG's pre-filtration unit, based on repurposed end-of-life RO membranes, is integrated upstream of the EDEN reactor to remove particulates and improve influent quality. The system is designed to enhance the removal of pharmaceutical micropollutants through a photocatalytic process embedded in bioinspired microfluidic discs. Inventory elements and modelling assumptions include:

- Manufacturing of the EDEN system: The microfluidic photocatalytic unit was modelled based on technical documentation and design inputs provided by EDEN. All components were included in the inventory, with material-level modelling aligned to available Ecoinvent datasets. For a limited number of custom or novel components, proxy datasets were applied and validated in consultation with EDEN:
 - UpPhoto Resin: Modelled using Bisphenol A production, due to its similar polymer backbone and functional role in photopolymer resins.
 - Trichloro (1H,1H,2H,2H-perfluorooctyl) silane: Approximated by generic inorganic chemical production, capturing the upstream impacts of halogenated synthesis.
 - Flexdym sheets: Represented by butyl acrylate production, a monomer used in soft, flexible polymers, serving as a close proxy for thermoplastic elastomers.
 - TiO₂-coated glass discs: Modelled using electronics-grade silicon production, reflecting the high purity and surface-treatment requirements of coated optical substrates.
 - Transport distances were estimated from manufacturer locations, including maritime and road freight, and assigned by mass and material type.
 - End-of-life scenarios assumed WEEE treatment for electronics and incineration or mixed-plastic recycling for polymers, based on standard EU and regional waste pathways.
- Manufacturing of the ENIG pre-filtration system: Modelled based on technical descriptions and inventory estimates of the repurposed membrane modules and support structures.
 - Reclaimed RO membranes: Assumed to undergo mild chemical treatment; modelled as reused polyamide membranes with no new polymer production.
 - Support materials: Included PVC tanks and valves, polypropylene filter housing and microfilter, and steel pump bodies, all modelled using corresponding datasets from the Ecoinvent database. Additional components such as level switches, pressure indicators, flowmeters, and conductivity sensors were represented using generic proxies for electronic instrumentation and sensor systems.
 - Lifespan: The reclaimed membranes and most filtration components were assumed to have a service life of 7 years, in line with typical operational performance of reused modules and auxiliary equipment. An exception was made for the water pump, which was modelled with a 10-year lifespan.
- Use-phase modelling assumptions: The use phase was modelled under an optimization-oriented scenario intended to represent a technically feasible integrated configuration rather than the provisional conditions of the laboratory experiments. The pilot tests were carried out at very small scale and required auxiliary inputs, including dilution water and alcohol, to enable prototype operation. However, these inputs were considered non-representative of the intended treatment configuration upon consultation with the technology developers. Alcohol was used to remove bubbles formed inside the microchannels, which increased hydraulic resistance, while dilution water was introduced as an interim experimental measure. According to the technology

developers, these conditions are linked to the current prototype setup and are not expected to remain necessary in future design iterations. Accordingly, no operational chemical or auxiliary liquid inputs were included in the use-phase inventory. Operational electricity demand: Under the assumptions adopted in this LCA, the use phase depends exclusively on electricity consumption. The electricity demand used in the model was estimated based on simulation results and technical input from technology developers. The selected value was adopted as a conservative reference for a realistic near-term operating configuration, while acknowledging that future design improvements may reduce energy demand further.

- System integration: In the model, ENIG and EDEN are represented as a sequential treatment train operating in series downstream of the activated sludge process, with ENIG acting as the pre-filtration step and EDEN as the final polishing stage. This configuration was considered more representative of the intended application than the separate operation of the two systems during the laboratory tests.

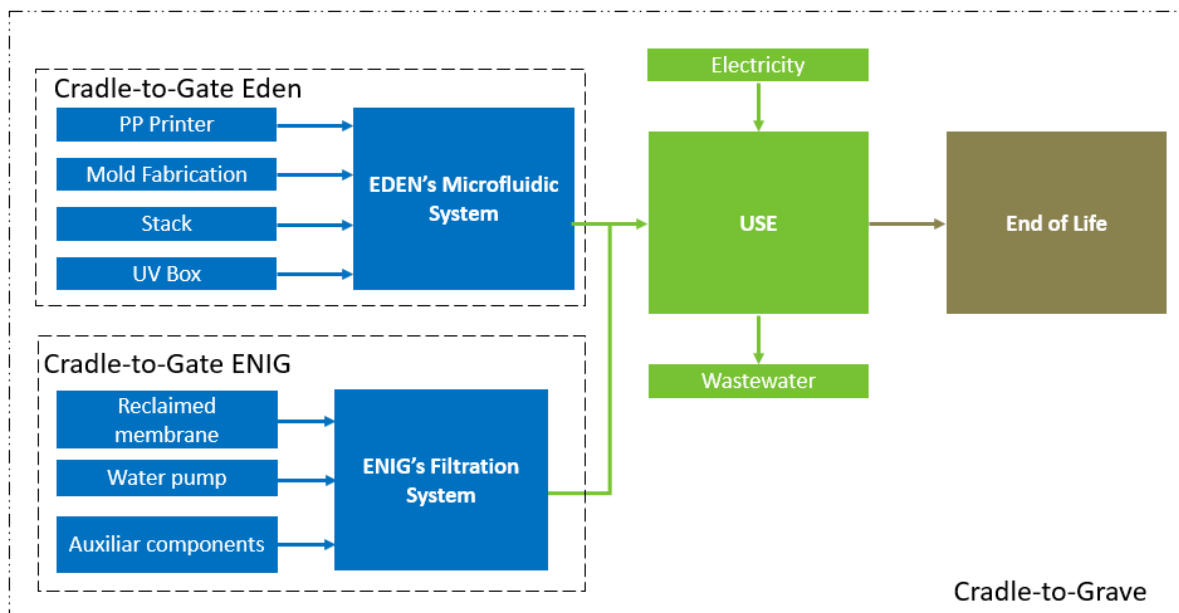


Figure 12: System boundaries for UC2, including cradle-to-grave modelling of EDEN's microfluidic system and ENIG's filtration system, use phase at the Opalia WWTP, electricity inputs, and end-of-life treatment.

3.2.3 Baseline Scenario results

The environmental profile of the current treatment configuration at the Opalia site, based on a conventional ASP, reveals a high dependency on grid electricity, which drives the majority of the system's environmental burden across impact categories.

Electricity consumption is the single largest contributor, accounting for 326.82 μ Pt, or 85.1% of the total weighted impact (383.72 μ Pt). The dominance of electricity is most evident in Climate change (142.63 μ Pt, 71.9%), Resource use – fossils (103.10 μ Pt, 97.3%), and Photochemical ozone formation (13.58 μ Pt, 94.6%). These categories shape the overall profile, highlighting the strong influence of upstream emissions and fossil fuel use in the Tunisian electricity mix.

Direct operational emissions, although smaller in magnitude, contribute significantly to Climate change (55.57 μ Pt, or 28.0%), Human toxicity – cancer (1.16 μ Pt, 96.1%), and Human toxicity – non-cancer (5.16 μ Pt, 91.0%). This reflects the role of direct wastewater-related emissions from the ASP process itself.

Sludge management, modelled as agricultural application of treated sludge, has only minor contributions across categories, with slight relevance in Freshwater ecotoxicity (0.34 μ Pt) and Eutrophication (freshwater: 0.01 μ Pt; marine: 0.03 μ Pt). Waste collection services account for negligible shares (<0.01% across categories).

Water-related impacts remain largely indirect. Water use totals 1.92 μ Pt (0.5% of the total), reflecting scarcity-adjusted upstream water use in electricity generation rather than local withdrawals at the Opalia site. Similarly, Freshwater ecotoxicity reaches 1.72 μ Pt (0.5% of the total), driven by electricity supply chains and sludge treatment processes.

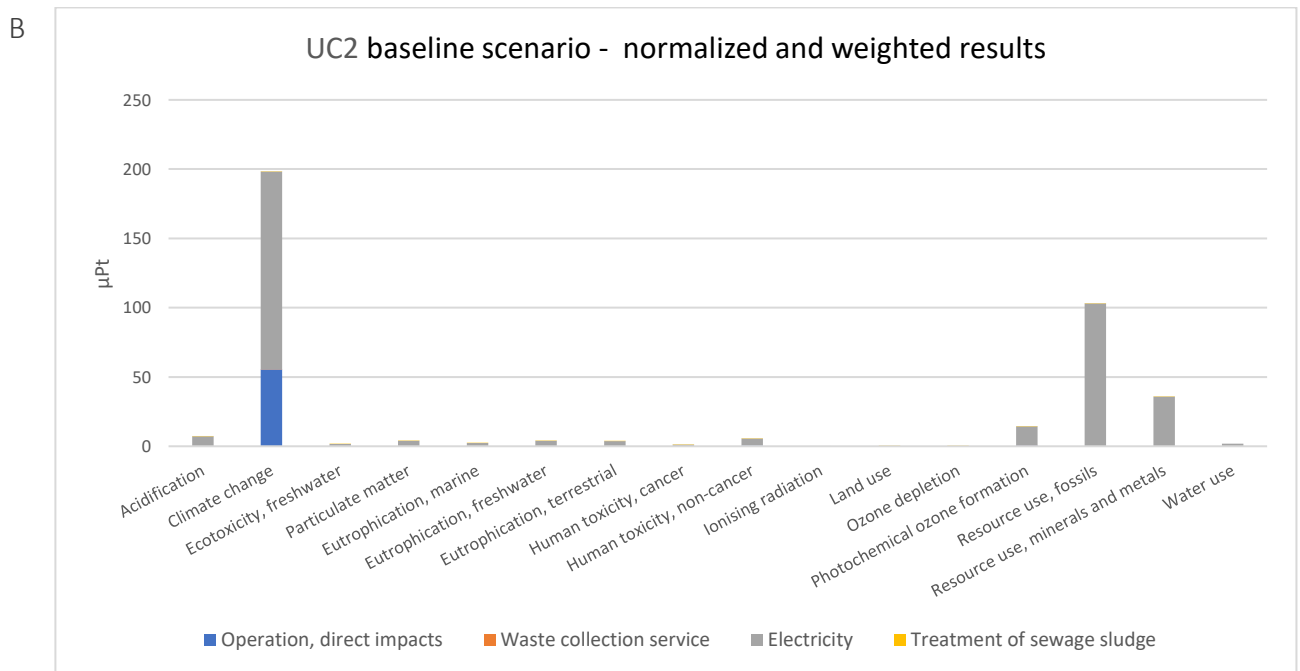
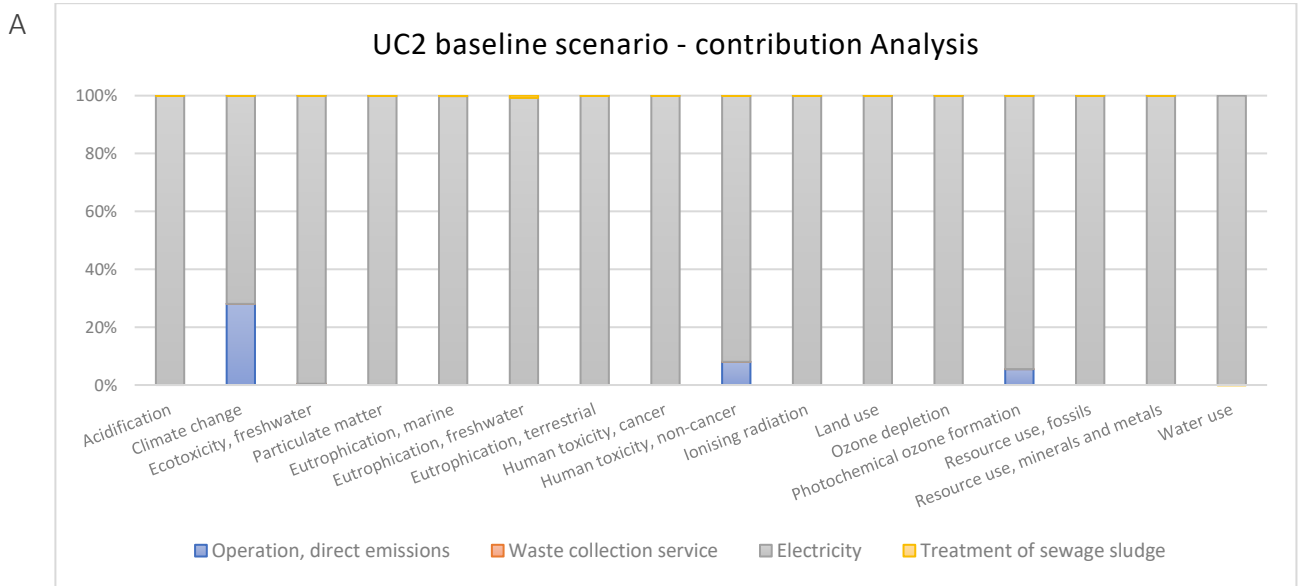


Figure 13: Environmental impact results for the UC2 baseline scenario. (A) Contribution analysis showing the relative share of individual processes to each impact category, expressed as a percentage of total impact per functional unit (1 m³ of treated wastewater). (B) Normalized and weighted results expressed in μPt , highlighting the relative importance of impact categories.

3.2.4 iMERMAID Scenario results

This subsection presents the environmental impact results associated with the iMERMAID-enhanced scenario for UC2 (Opalia). The analysis is structured in two stages. First, we assess the cradle-to-gate impacts of the technological solutions developed for this scenario, namely, the EDEN microfluidic photocatalytic reactor and the ENIG pre-filtration unit based on reclaimed RO membranes. These impacts reflect the burdens associated with material extraction, component manufacturing, and system assembly.

The second stage, presented in the subsequent subsection, will expand the system boundaries to include operational energy use and end-of-life treatment, allowing for a full cradle-to-grave comparison between the baseline and iMERMAID scenarios.

We begin here with the interpretation of cradle-to-gate results for the EDEN system, followed by the ENIG filtration unit. For each, the interpretation is based on normalized and weighted midpoint indicators calculated using the Environmental Footprint 3.1 method and supported by a detailed analysis of inventory composition and material contributions.

3.2.4.1 Cradle-to-gate impact: Microfluidic System

The total cradle-to-gate environmental impact of the EDEN microfluidic reactor amounts to 9.20 μPt , as calculated through normalization and weighting of EF 3.1 midpoint indicators. Among all evaluated categories, Climate change is the dominant contributor, representing 26.3% of the total impact. These impacts are primarily associated with the energy demand of high-purity electronics manufacturing and the use of resource-intensive materials such as electronics-grade silicon, LEDs, stainless steel, and polymeric resins. The remaining categories contribute smaller but non-negligible shares, underscoring the importance of both energy and material sourcing in the overall environmental profile of the technology.

The interpretation below focuses on selected midpoint categories, providing a detailed analysis of the main contributors and their underlying inventory drivers.

The cradle-to-gate contribution to the climate change impact category is 2.40 μPt . Within the Climate change category, the main contributing processes are the silicon production (1.5 μPt , or 63.1%), and LED components (0.36 μPt , or 14.9%). These contributions are primarily driven by the production of high-purity materials and electronic components with energy-intensive manufacturing processes. The electricity input, modelled with the French medium-voltage grid, further reinforces this impact due to upstream fossil fuel use in the national mix.

The Freshwater eutrophication category amounts to 1.2 μPt , representing 13.31% of the total impact. Major contributors are silicon (1.0 μPt) and LED components (0.12 μPt). This category is primarily linked to upstream phosphate-related emissions occurring along the supply chains of electronic materials and components. The dominance of silicon is explained by the highly processed nature of electronic-grade silicon, whose production requires energy-intensive purification and chemical treatment steps, supported by industrial background processes that can generate phosphorus-related emissions to water. Although these components are physically small, their production routes are technologically intensive and therefore carry disproportionately high freshwater eutrophication burdens per unit mass.

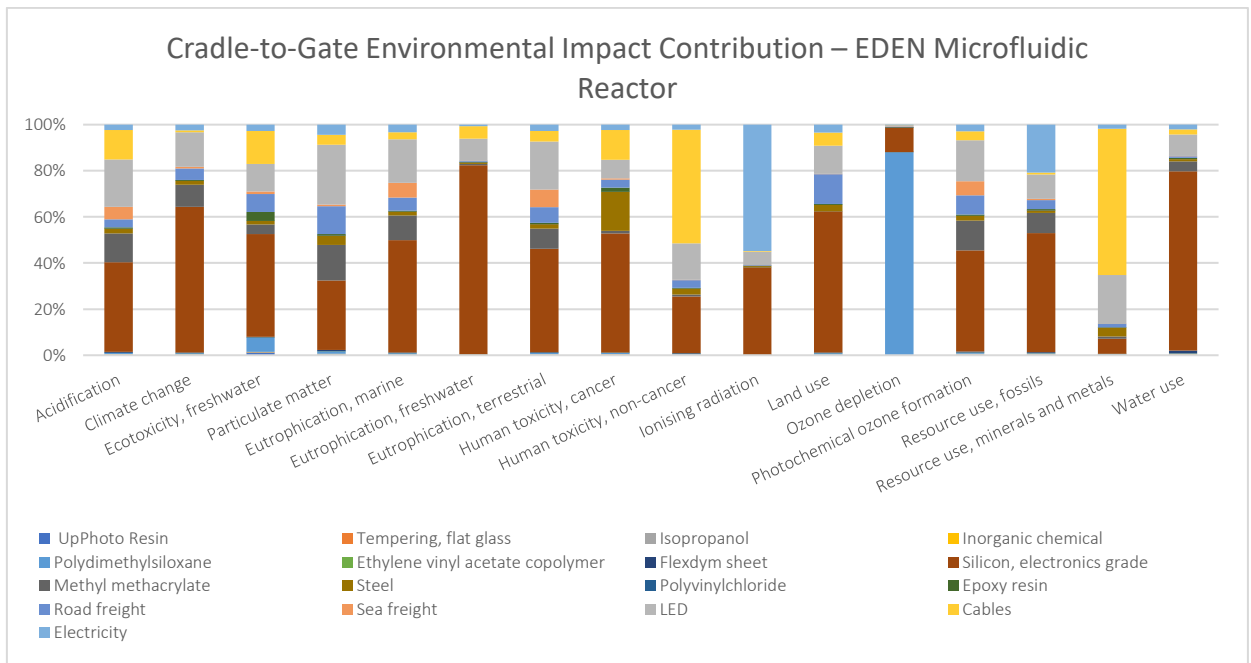
The total contribution to Freshwater ecotoxicity category totals 0.13 μPt , accounting for 1.4% of the total impact. The most significant sources are silicon production (0.06 μPt), cable production (0.02 μPt), and LED components (0.015 μPt). This pattern is mainly explained by the material and process intensity of electronic component manufacturing. Electronic-grade silicon production involves highly purified

feedstocks, multiple chemical treatment steps, and energy-intensive processing, all of which are associated with upstream emissions of substances relevant to aquatic ecotoxicity. Cable production also contributes due to the combined burden of conductive metals and polymer insulation materials, whose extraction, refining, and manufacturing stages are linked to emissions of metals and organic substances with ecotoxic potential. For LEDs, the contribution is related to the manufacture of semiconductor and electronic subcomponents, which typically rely on specialized materials, high-purity chemicals, and tightly controlled fabrication processes that generate upstream emissions relevant to freshwater ecotoxicity.

The Marine eutrophication category totals 0.12 μ Pt, contributing 1.3% of the total. Key contributors include silicon production (0.06 μ Pt), LEDs (0.02 μ Pt), and methyl methacrylate production (0.01 μ Pt). These impacts are associated mainly with nitrogen-related emissions released upstream during the production of electronic materials and specialty chemicals. Silicon and LED manufacturing depend on energy-intensive industrial processes and chemically complex supply chains, which are connected to wastewater discharges that ultimately contribute to nutrient enrichment in marine environments.

The impact related to Water use is 0.24 μ Pt, accounting for 2.7% of the total. The most significant contributors are silicon production (0.19 μ Pt), LEDs (0.02 μ Pt), and methyl methacrylate production (0.01 μ Pt). The dominance of silicon is expected, given that electronic-grade silicon production is both energy- and water-intensive, particularly because of repeated purification, cleaning, and processing steps required to achieve the necessary material quality. LED production also contributes due to the water demand associated with semiconductor fabrication and component assembly, where process water is used extensively in manufacturing and cleaning operations. Methyl methacrylate adds to the category through upstream petrochemical production, which also relies on water-consuming industrial processes.

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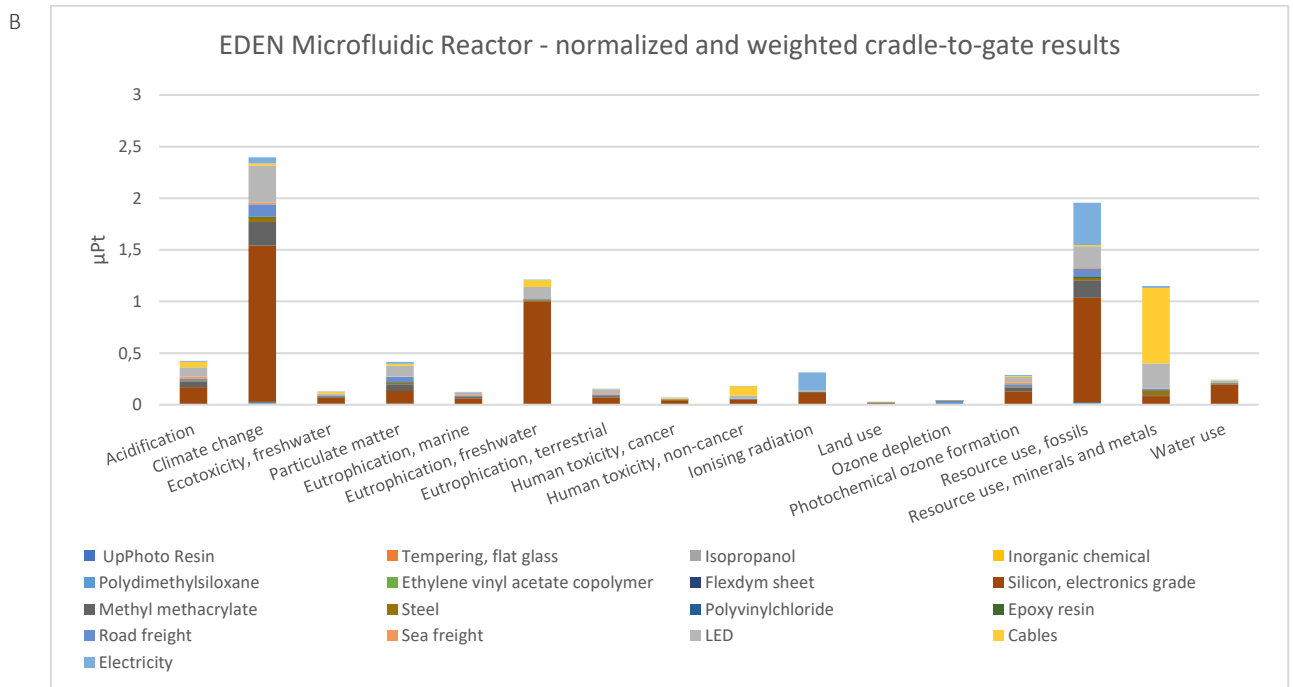


Figure 14: Cradle-to-gate environmental performance of the EDEN microfluidic reactor within the UC2 iMERMAID Scenario. (A) Relative contribution of individual components and materials to each midpoint impact category. (B) Normalized and weighted cradle-to-gate results showing the absolute contribution (μPt) of each impact category to the total environmental profile.

3.2.4.2 Cradle-to-gate impact: Reclaimed filtration unit

The total cradle-to-gate environmental impact associated with the ENIG filtration unit amounts to 364.00 μPt . The most significant contribution arises from Resource use, minerals and metals (214.00 μPt , 58.8% of the total environmental burden). This is followed by Climate change (37.00 μPt , 10.2%) and Resource use, fossils (26.10 μPt , 7.2%). Other relevant categories include Freshwater eutrophication (19.00 μPt , 5.2%), Acidification (12.10 μPt , 3.3%), Particulate matter (12.00 μPt , 3.3%), and freshwater ecotoxicity (11.10 μPt , 3.0%). This profile is primarily driven by instrumentation components, pump-related equipment, sodium hypochlorite, and PVC-based infrastructure used in the reclaimed membrane treatment system.

The interpretation below focuses on five selected midpoint categories, analysing the main contributors and linking them to specific inventory drivers.

Climate change totals 37 μPt , representing 10.2% of the overall environmental burden. The largest contributor to this impact category is water tank (8.98 μPt , 60.2%), followed by sodium hypochlorite (8.10 μPt , 21.9%) and the flowmeter (7.33 μPt , 19.8%). Other relevant components include the water pump (4.89 μPt , 13.2%), the butterfly valve (2.34 μPt , 6.3%), the pressure indicator (1.83 μPt , 4.9%), and the pressure transmitter (1.47 μPt , 4.0%). These impacts are mainly related to the production of PVC and metallic parts, the manufacture of instrumentation components, and the upstream energy demand associated with sodium hypochlorite production. Electricity contributes only a limited share, with 0.32 μPt (0.9%).

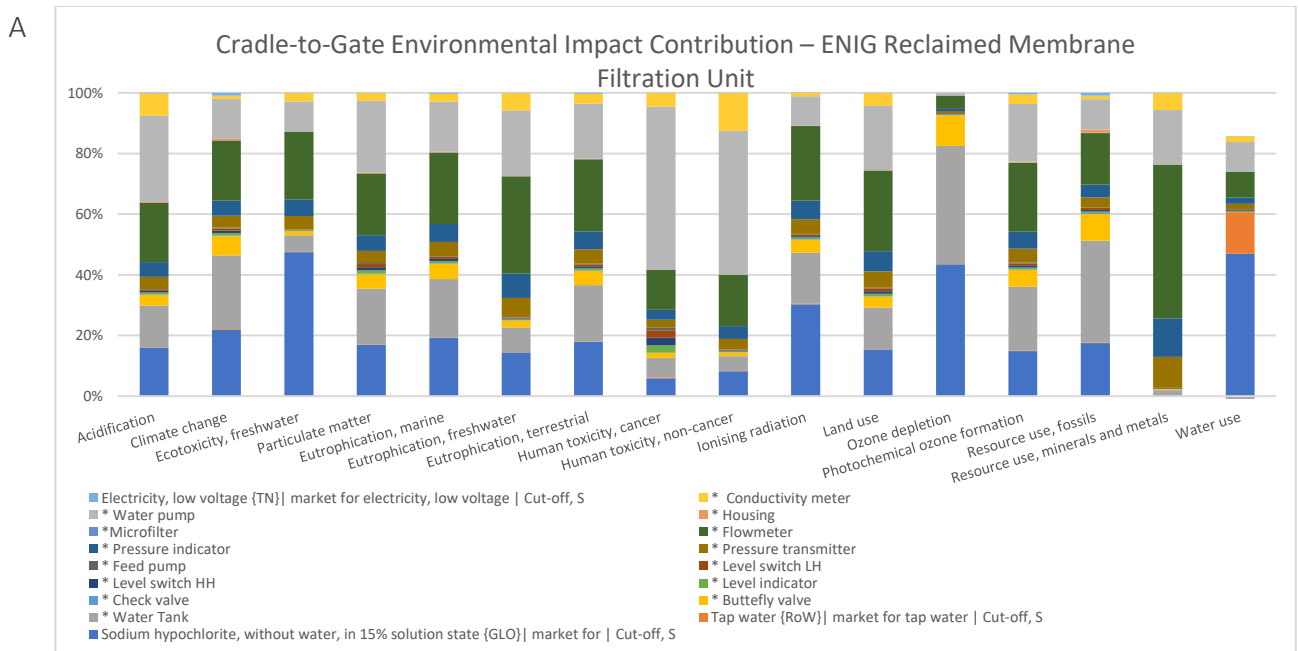
The Freshwater ecotoxicity category totals 11.10 μPt , accounting for 3.0% of the total environmental impact. The dominant contributor is sodium hypochlorite (5.26 μPt , 47.4%), followed by the flowmeter

(2.46 μ Pt, 22.2%) and the water pump (1.11 μ Pt, 10.0%). Additional contributions arise from the pressure indicator (0.62 μ Pt, 5.5%), the water tank (0.61 μ Pt, 5.5%), and the pressure transmitter (0.49 μ Pt, 4.4%). These impacts are mainly associated with upstream emissions from chemical production and from the manufacture of instrumentation and pump-related components, which include metals and electronic elements with known relevance for aquatic ecotoxicity.

The Marine eutrophication category totals 2.38 μ Pt, representing 0.7% of the total. The main contributor is the flowmeter (0.56 μ Pt, 23.6%), followed by the water tank (0.46 μ Pt, 19.3%), sodium hypochlorite (0.46 μ Pt, 19.2%), and the water pump (0.39 μ Pt, 16.4%). Smaller contributions are associated with the pressure indicator (0.14 μ Pt, 5.9%), the butterfly valve (0.12 μ Pt, 5.0%), and the pressure transmitter (0.11 μ Pt, 4.7%). These impacts are linked to emissions occurring in upstream manufacturing and chemical production processes, including energy-related emissions and releases associated with polymer, metal, and chemical supply chains.

The Freshwater eutrophication category amounts to 19.00 μ Pt, corresponding to 5.2% of the total environmental burden. The most significant contributor is the flowmeter (6.10 μ Pt, 32.1%), followed by the water pump (4.10 μ Pt, 21.6%) and sodium hypochlorite (2.74 μ Pt, 14.4%). Additional relevant sources include the water tank (1.57 μ Pt, 8.3%), the pressure indicator (1.52 μ Pt, 8.0%), the pressure transmitter (1.22 μ Pt, 6.4%), and the conductivity meter (1.09 μ Pt, 5.7%). These impacts reflect upstream emissions associated with the production of instrumentation, pumps, and sodium hypochlorite, particularly from processes linked to energy use, metals, and chemical manufacturing.

Water use category amounts to 3.40 μ Pt, corresponding to 0.9% of the total environmental burden. The leading contributor is sodium hypochlorite (2.23 μ Pt, 65.6%), followed by tap water (0.65 μ Pt, 19.2%), the water pump (0.46 μ Pt, 13.6%), and the flowmeter (0.40 μ Pt, 11.8%). At the same time, some components, such as the water tank and butterfly valve, show negative contributions, which slightly reduce the category total. Overall, this result indicates that the water use profile is mainly associated with the production of chemical and technical inputs required for the reclaimed filtration unit rather than with direct water consumption alone.



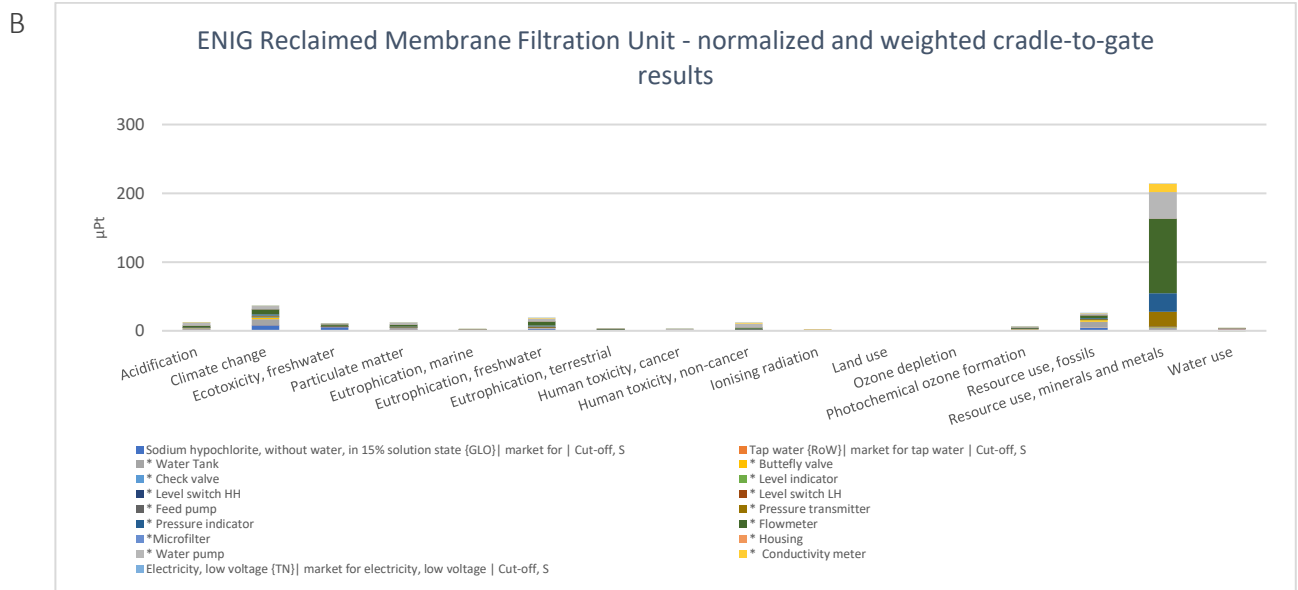


Figure 15: Cradle-to-gate environmental performance of the ENIG reclaimed membrane filtration unit within the UC2 iMERMAID Scenario. (A) Relative contribution of individual components and materials to each midpoint impact category. (B) Normalized and weighted cradle-to-gate results showing the absolute contribution (μPt) of each impact category to the total environmental profile.

3.2.4.3 Cradle-to-grave results: Pilot application

The cradle-to-grave results describe the environmental profile of the iMERMAID scenario at the Opalia site, in which the existing wastewater treatment configuration is complemented by the ENIG and EDEN systems as additional treatment steps. The assessment integrates the operation of the current Opalia treatment system with the life cycle impacts associated with the deployment of both technologies, including their production and transport to the site, electricity use during operation, and end-of-life treatment. More specifically, the cradle-to-grave analysis includes:

- Opalia operation, representing the existing wastewater treatment process at the site
- ENIG and EDEN cradle-to-gate, including system production and transport to the Opalia facility
- ENIG and EDEN operation, restricted to electricity use during operation
- ENIG and EDEN end-of-life treatment

The contribution analyses by life cycle stage, shown in Figure 16, provide the basis for identifying the main drivers of the environmental profile of the iMERMAID scenario at the Opalia site across the impact categories considered.

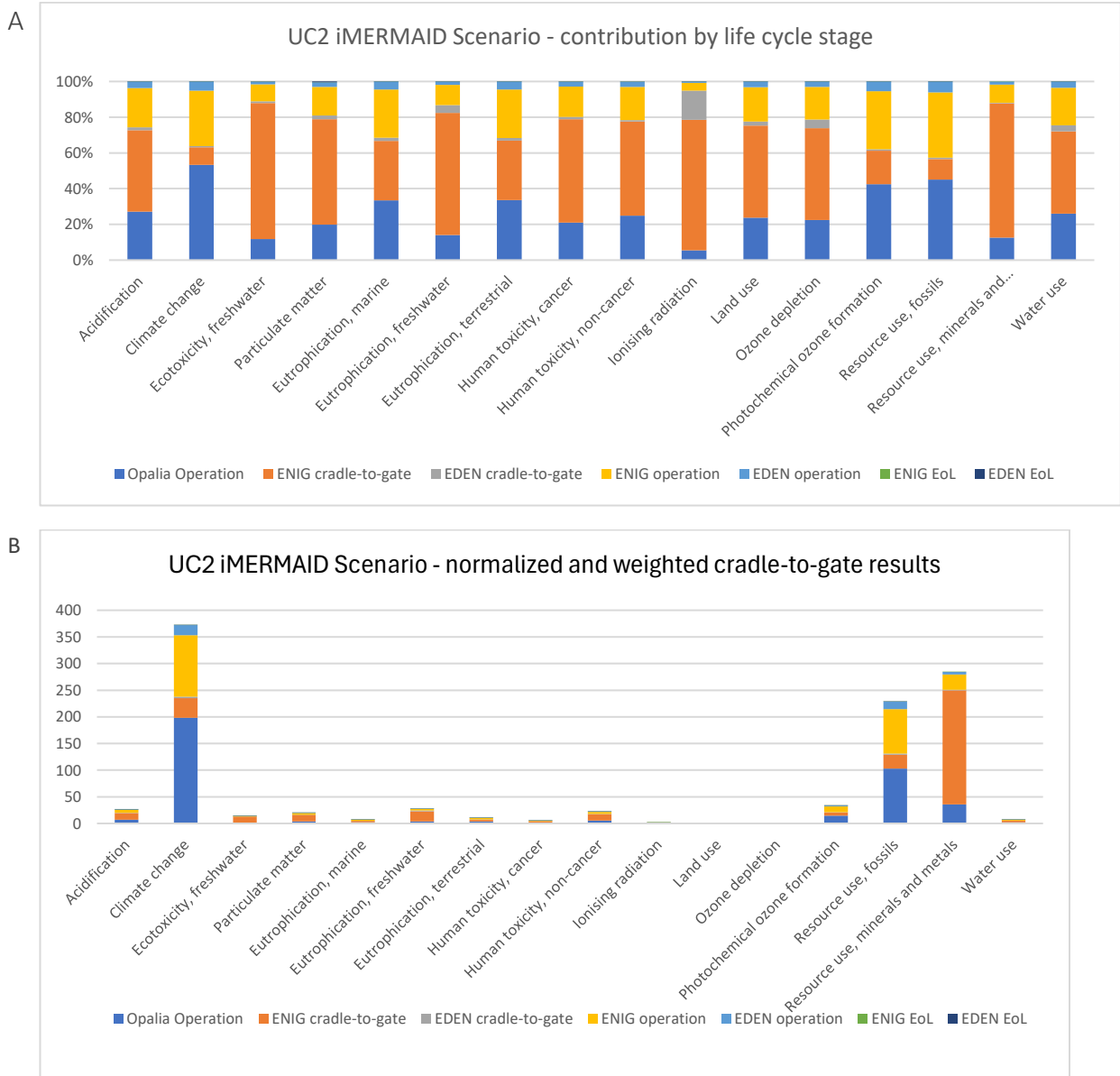


Figure 16: Environmental impact results for the UC2 iMERMAID scenario. (A) Contribution analysis showing the relative share of each life cycle stage to the impact categories considered, expressed as a percentage of total impact per functional unit (1 m³ of treated wastewater). (B) Normalized and weighted results expressed in Pt, highlighting the relative importance of impact categories and life cycle stages

In the cradle-to-grave iMERMAID scenario, the environmental profile is mainly shaped by Opalia operation, ENIG cradle-to-gate, and ENIG operation, which contribute 384 μPt, 364 μPt, and 265 μPt, respectively. Together, these three life cycle stages account for 1013 μPt, corresponding to 95.0% of the total weighted result. By contrast, EDEN operation contributes 44 μPt, or 4.1%. The end-of-life stages of both technologies are negligible, together representing only about 0.02% of the total. This distribution indicates that the environmental burden of the post-implementation scenario is driven primarily by the existing wastewater treatment operation, the production of the ENIG system, and electricity use during operation of the additional treatment steps.

The environmental profile of the UC2 iMERMAID scenario is mainly defined by climate change, resource use, minerals and metals, and resource use, fossils, which together account for 82.9% of the total result. Climate change reaches 372 μ Pt and is largely associated with Opalia operation, which contributes 53.2% of the category total, followed by ENIG operation at 31.2%. A similar pattern is observed for resource use, fossils, where Opalia operation and ENIG operation account for 45.2% and 36.6%, respectively. In both categories, the dominance of these stages is directly linked to electricity consumption, since the operation of Opalia, ENIG, and EDEN is modelled exclusively through electricity use. Given that the Tunisian grid mix is largely based on natural gas, the upstream burdens associated with electricity generation strongly shape the climate change and fossil resource use profile of the integrated treatment system.

In contrast, resource use, minerals and metals is dominated by ENIG cradle-to-gate, which contributes 214 μ Pt and represents about 75% of the category total. This is mainly associated with the electronic components and steel parts required for the production of the ENIG system, indicating that equipment manufacturing is a central driver of this category.

From a project perspective, it is also relevant to consider the categories more directly associated with water systems, particularly freshwater ecotoxicity, water use, and freshwater eutrophication. Although these categories contribute only a limited share to the total environmental profile, they remain particularly relevant in the context of wastewater treatment and the objectives of the iMERMAID project. Freshwater ecotoxicity accounts for 1.4% of the total result and is largely driven by ENIG cradle-to-gate, which contributes 76.0% of this impact category. This is mainly related to the use of sodium hypochlorite and electronic components, whose upstream production is associated with emissions that are relevant for aquatic ecotoxicity. Water use represents 0.7% of the total result and is again mainly influenced by ENIG cradle-to-gate, responsible for 46.1% of the category. The main drivers here are sodium hypochlorite, electricity use, and water consumed during the production of the ENIG system and its inputs. Freshwater eutrophication contributes 2.6% of the total result and is also dominated by ENIG cradle-to-gate, which accounts for 68.3% of this category. In this case, the main contributions are linked to electronic components, the water pump, electricity use, and sodium hypochlorite,

This indicates that, for these water-related categories, the main contribution does not arise from the operational stages, which are restricted to electricity use, but from the upstream burdens associated with the production of the technologies.

3.2.5 Comparative analysis of the LCA results of the baseline and iMERMAID scenarios

The comparison between the baseline and iMERMAID scenarios, as presented in Table 7, shows that the introduction of the ENIG and EDEN treatment steps increases the overall environmental burden of the system at the level of normalized and weighted LCA results. The total impact rises from 383.72 μ Pt in the baseline scenario to 1066 μ Pt in the iMERMAID scenario, corresponding to an increase of 682.28 μ Pt, or about 178%. This result reflects the fact that the innovative configuration does not replace the existing Opalia treatment system, but complements it with additional treatment stages, whose implementation requires extra equipment and additional electricity consumption during operation.

Table 7: Comparative normalized and weighted LCA results for the baseline and iMERMAID scenarios, with ENIG and EDEN cradle-to-gate contributions shown for interpretation support

Damage category	Baseline scenario	iMERMAID scenario	Baseline vs. iMERMAID scenarios	ENIG cradle to gate contribution	EDEN cradle to gate contribution	Unit
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<i>Acidification</i>	7.24	26.61	267.5%	12.10	0.43	μPt
<i>Climate change</i>	198.22	372.25	87.8%	36.97	2.40	μPt
<i>Ecotoxicity, freshwater</i>	1.72	14.56	746.5%	11.08	0.13	μPt
<i>Particulate matter</i>	4.03	20.35	405.0%	12.03	0.42	μPt
<i>Eutrophication, marine</i>	2.40	7.16	198.3%	2.38	0.12	μPt
<i>Eutrophication, freshwater</i>	3.93	27.85	608.7%	19.02	1.21	μPt
<i>Eutrophication, terrestrial</i>	3.66	10.89	197.5%	3.63	0.15	μPt
<i>Human toxicity, cancer</i>	1.21	5.73	373.6%	3.31	0.07	μPt
<i>Human toxicity, non-cancer</i>	5.61	22.59	302.7%	11.92	0.18	μPt
<i>Ionising radiation</i>	0.11	1.93	1654.5%	1.41	0.31	μPt
<i>Land use</i>	0.28	1.18	321.4%	0.61	0.03	μPt
<i>Ozone depletion</i>	0.18	0.78	333.3%	0.40	0.04	μPt
<i>Photochemical ozone formation</i>	14.38	33.78	134.9%	6.30	0.29	μPt
<i>Resource use, fossils</i>	103.10	228.39	121.5%	26.05	1.96	μPt
<i>Resource use, minerals and metals</i>	35.74	284.37	695.7%	213.77	1.15	μPt
<i>Water use</i>	1.92	7.38	284.4%	3.40	0.24	μPt
Total	383.72	1066	177.8%	364.38	9.12	μPt

The increase is mainly shaped by the same impact categories that dominate the iMERMAID scenario overall, namely climate change, resource use, minerals and metals, and resource use, fossils. Climate change increases from 198.22 μPt to 372.25 μPt , corresponding to an increase of 87.8%, while resource use, fossils rises from 103.10 μPt to 228.39 μPt , an increase of 121.5%. These two categories are strongly influenced by the higher electricity demand of the integrated treatment train. In the iMERMAID scenario, the operation of Opalia, ENIG, and EDEN is modelled exclusively through electricity use, and the Tunisian grid mix remains largely dependent on natural gas. As a result, the expansion of the treatment system translates directly into higher burdens in climate change and fossil resource use.

The most pronounced shift is observed in resource use, minerals and metals, which increases from 35.74 μPt in the baseline to 284.37 μPt in the iMERMAID scenario, corresponding to an increase of 248.63 μPt , or about 696%. In the baseline scenario, because the physical infrastructure of the facility was not included, consistent with the approach commonly found in the state-of-the-art literature, this category is driven mainly by upstream electricity supply. After the introduction of the ENIG and EDEN technologies, the contribution pattern changes substantially. The additional treatment units require material-intensive equipment, particularly electronic components and steel parts, and their operation also leads to a marked increase in electricity demand. Consequently, the category shifts from being mainly electricity-driven to being influenced by the material requirements of the technologies themselves, especially the ENIG cradle-to-gate stage. This comparison highlights that the introduction of the additional treatment train modifies both the scale and the structure of the environmental profile.

Other midpoint categories also increase in the iMERMAID scenario, including particulate matter, human toxicity, eutrophication, and acidification. In most cases, this reflects the combined effect of two mechanisms: first, the increase in electricity-related burdens associated with the operational stages, and second, the upstream burdens associated with the manufacture of ENIG and EDEN. The relative importance of these two mechanisms varies by category. Categories such as climate change, resource use,

fossils, and photochemical ozone formation are mainly shaped by operational electricity demand, whereas categories such as freshwater eutrophication, freshwater ecotoxicity, and resource use, minerals and metals are more strongly influenced by the production of the additional treatment technologies, especially ENIG.

Beyond the dominant contributors to the total result, the water-related impact categories are particularly relevant for interpretation in light of the remediation purpose of the iMERMAID scenario. Freshwater ecotoxicity increases from 1.72 μ Pt to 14.56 μ Pt, freshwater eutrophication from 3.93 μ Pt to 27.85 μ Pt, and water use from 1.92 μ Pt to 7.38 μ Pt. These changes indicate that the implementation of the additional treatment train introduces new upstream burdens associated with chemical inputs, electronic components, pumps, instrumentation, and electricity use. In particular, ENIG cradle-to-gate plays a major role in these categories due to sodium hypochlorite use, instrumentation-related materials, and pump-related equipment. At the same time, these results must be interpreted in the specific context of iMERMAID, where the purpose of the new configuration is not merely to reduce the LCA burden of wastewater treatment, but to provide an additional remediation function through the reduction of substances of concern in the treated effluent.

For this reason, the comparative LCA results should not be interpreted in isolation. The iMERMAID scenario introduces additional environmental burdens because it adds treatment complexity, materials, and electricity demand to the existing system. However, its environmental relevance lies in the expected improvement in water quality delivered by the additional treatment steps. The comparative assessment should therefore be read together with the handprint analysis, which captures the beneficial effect of contaminant removal and provides the complementary perspective needed to assess the overall environmental value of the technology.

3.2.6 Water quality footprint and handprint

In use case 2, the innovative treatment train is intended to reduce the concentration of pharmaceutical substances of concern in the final wastewater stream discharged from the Opalia facility. In this context, the handprint assessment was developed to quantify the beneficial environmental effect associated with the reduction of the freshwater ecotoxicity potential of the treated effluent. In line with the project approach for environmental remediation technologies, the handprint is defined here as the positive environmental effect achieved through the reduction of the impact intensity of the discharged stream enabled by the innovative treatment system.

Although other water-related impact categories, such as freshwater eutrophication and marine eutrophication, are relevant in the broader environmental assessment, the handprint in this case focuses specifically on freshwater ecotoxicity. This is because there is no direct link between the selected pharmaceutical substances of concern and eutrophication-related impact pathways, which are mainly associated with nitrogen- and phosphorus-containing compounds. In addition, neither EF 3.1 nor USEtox provides characterization factors for these substances in freshwater or marine eutrophication categories. For this reason, one handprint was calculated for each substance of concern only in relation to freshwater ecotoxicity.

It should be noted that the post-implementation LCA does not account for emissions of diclofenac, ketoprofen, and ibuprofen to water. As a result, the freshwater ecotoxicity outcome from the LCA reflects only the burdens associated with operation of the treatment system itself, which in the use phase are

limited to electricity consumption and its upstream supply chain. The freshwater ecotoxicity potential associated with the selected substances of concern is therefore not represented in the LCA results. The handprint assessment was developed to address this gap by quantifying the reduction in ecotoxicity potential achieved through treatment. This separation is methodologically important, as it avoids double counting and ensures that the remediation benefit associated with substance removal is evaluated independently from the operational burdens captured in the LCA.

Since concentration data for the untreated influent were not available, the handprint assessment uses the Opalia WWTP effluent as the reference stream. This is considered an appropriate approximation for the present analysis, given that the current treatment system is based primarily on biological treatment and is not expected to achieve substantial removal of the selected pharmaceutical substances of concern due to their recalcitrant behaviour to conventional treatments as biological reactors.

An important aspect of the UC2 configuration is that the substances of concern are not assumed to be treated simultaneously in a single mixed wastewater stream. Rather, the treatment system is considered to operate on substance-specific effluent conditions, reflecting the fact that the related pharmaceutical products are not produced at the same time. Accordingly, the handprint is presented separately for each substance of concern. Across these calculations, the operational inventory of the treatment train remains unchanged, since the same treatment configuration, inputs, and operating conditions are assumed for the ENIG and EDEN systems. What changes from one case to another is the concentration of the target substance in the influent, the removal efficiency achieved during treatment, and consequently the resulting reduction in freshwater ecotoxicity potential.

The handprint calculation combines two elements. The first is the potential freshwater ecotoxicity intensity of the discharged stream, determined separately for the Opalia WWTP effluent, the effluent after ENIG treatment, and the effluent after EDEN treatment. This was calculated by multiplying the concentration of each substance of concern, expressed in kg/m^3 , by its freshwater ecotoxicity characterization factor, expressed in CTUe/kg , resulting in a potential freshwater ecotoxicity intensity in CTUe per m^3 . The second element is the freshwater ecotoxicity burden associated with operation of the treatment system itself. For this purpose, the same use-phase inventory applied in the post-implementation LCA was used to quantify the freshwater ecotoxicity associated with operation of the treatment train. On this basis, the handprint expresses the reduction in the freshwater ecotoxicity potential of the final discharged stream achieved by the innovative treatment system, interpreted together with the freshwater ecotoxicity burden generated during operation.

3.2.6.1 Handprint assessment for Diclofenac

For diclofenac, the concentration measured in the Opalia WWTP effluent is 627.71 mg/L, equivalent to $0.63 \text{ kg}/\text{m}^3$. Using the freshwater ecotoxicity characterization factor of 6000 CTUe/kg , this corresponds to a potential freshwater ecotoxicity intensity of 3766.26 CTUe per m^3 of discharged effluent. After treatment in the ENIG system, the diclofenac concentration decreases to 84.91 mg/L, or $0.08 \text{ kg}/\text{m}^3$, resulting in a freshwater ecotoxicity intensity of 509.46 CTUe/m^3 . Following the EDEN treatment step, the concentration is further reduced to 68.92 mg/L, or $0.07 \text{ kg}/\text{m}^3$, resulting in a final freshwater ecotoxicity intensity of 413.52 CTUe/m^3 .

This progression indicates a substantial reduction in the potential freshwater ecotoxicity associated with diclofenac along the treatment train. Relative to the Opalia WWTP effluent, ENIG alone reduces the freshwater ecotoxicity intensity by 3256.80 CTUe/m³, corresponding to an 86.5% decrease. The subsequent EDEN treatment provides an additional reduction of 95.94 CTUe/m³ relative to the ENIG effluent, equivalent to 18.8%. Considering the full treatment sequence, the freshwater ecotoxicity intensity associated with diclofenac decreases by 3352.74 CTUe/m³, corresponding to an overall reduction of about 89.0% relative to the reference stream.

The operational freshwater ecotoxicity burden associated with the full treatment train, considering the WWTP, ENIG, and EDEN operational phases, amounts to 43.02 CTUe/m³. This includes 5.09 CTUe/m³ associated with WWTP operation, 36.84 CTUe/m³ associated with ENIG operation, and 1.09 CTUe/m³ associated with EDEN operation. When this operational burden is considered together with the remaining diclofenac-related freshwater ecotoxicity potential in the final effluent, equal to 413.52 CTUe/m³, the total residual freshwater ecotoxicity potential after implementation is 456.54 CTUe/m³. In comparison, the reference condition amounts to 3771.35 CTUe/m³, including 3766.26 CTUe/m³ from the diclofenac-related freshwater ecotoxicity potential in the Opalia WWTP effluent and 5.09 CTUe/m³ from WWTP operation. Therefore, the full treatment configuration leads to a net reduction of 3314.81 CTUe/m³, corresponding to an overall reduction of 87.9%. This indicates that, even when the operational freshwater ecotoxicity burdens of the WWTP, ENIG, and EDEN stages are included, the innovative treatment system still provides a substantial net environmental benefit for diclofenac by reducing the freshwater ecotoxicity potential of the final discharged effluent.

Table 8: Diclofenac concentration and corresponding potential freshwater ecotoxicity intensity across the treatment stages considered in the handprint assessment, including the Opalia WWTP effluent and the effluent after ENIG and EDEN treatment, expressed per m³ of discharged effluent.

Treatment stage	Concentration (mg/L)	Concentration (kg/m ³)	CF freshwater ecotoxicity (CTUe/kg)	Potential freshwater ecotoxicity intensity (CTUe/m ³)
<i>Opalia WWTP effluent</i>	627.71	0.62771	6000	3766.26
<i>After ENIG treatment</i>	84.91	0.08491		509.46
<i>After EDEN treatment</i>	68.92	0.06892		413.52

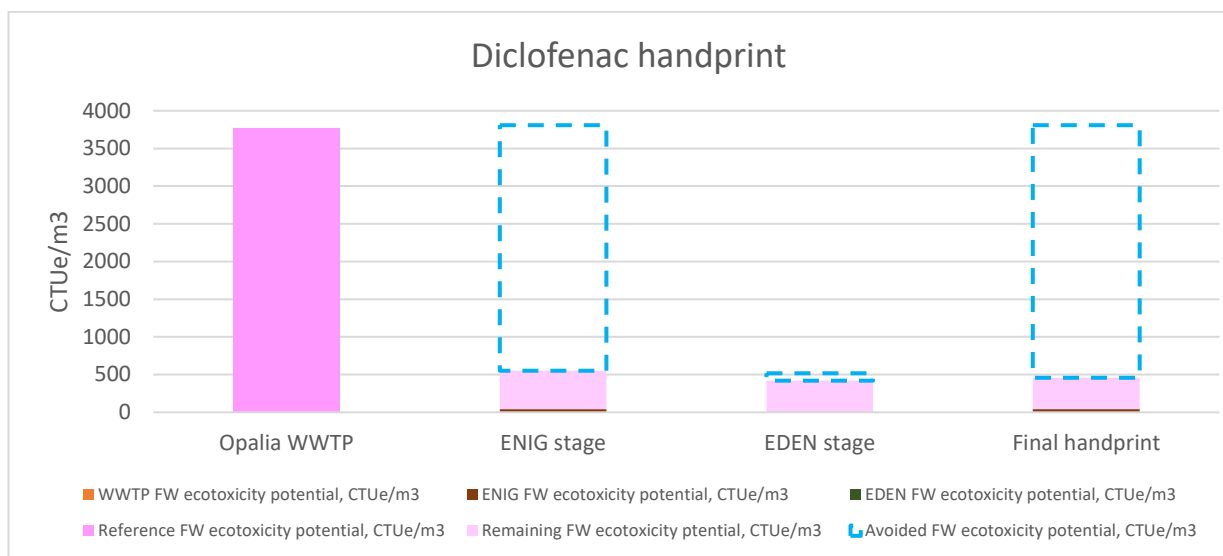


Figure 17: Handprint representation for diclofenac, showing the reference ecotoxicity potential at the Opalia WWTP effluent, the use-phase ecotoxicity burden associated with electricity consumption in the treatment train, the remaining potential after ENIG and EDEN treatment, and the avoided potential achieved at each stage. Freshwater (FW) ecotoxicity potentials are expressed in CTUe/m³.

3.2.6.2 Handprint for Ketoprofen

Since a freshwater ecotoxicity characterization factor for ketoprofen was not available in EF 3.1 or in the USEtox dataset used in this study, it was derived in accordance with the USEtox framework for freshwater ecotoxicity. The characterization factor was obtained by combining fate, exposure, and effect terms, with the fate and exposure factors taken from USEtox and the effect factor derived from aquatic toxicity data (Japanese Ministry of the Environment, 2023; Owsianiak et al., 2023). In the absence of chronic ecotoxicity data, acute toxicity endpoints for representative freshwater taxa were converted into chronic-equivalent values using the default acute-to-chronic extrapolation approach applied in USEtox-related guidance for organic substances. These chronic-equivalent values were used to calculate the HC50, from which the effect factor and the final freshwater ecotoxicity characterization factor were derived. This ensured that ketoprofen could be assessed within the same methodological logic applied to the other substances, while maintaining transparency regarding the assumptions introduced.

Based on the characterization factor derived according to the USEtox framework, the potential freshwater ecotoxicity intensity of ketoprofen was quantified at each treatment stage in order to assess the reduction achieved along the treatment train. For ketoprofen, the Opalia WWTP effluent contains 223.70 mg/L, corresponding to 0.22 kg/m³. Applying the freshwater ecotoxicity characterization factor of 2190 CTUe/kg results in a potential freshwater ecotoxicity intensity of 489.90 CTUe/m³ for the reference stream. After the ENIG treatment step, the ketoprofen concentration is reduced to 66.57 mg/L, equivalent to 0.07 kg/m³, and the corresponding ecotoxicity intensity decreases to 145.79 CTUe/m³. Following treatment in EDEN, the concentration falls further to 34.52 mg/L, or 0.03 kg/m³, yielding a final freshwater ecotoxicity intensity of 75.60 CTUe/m³.

These results show a marked decline in ketoprofen-related freshwater ecotoxicity across the treatment train. The ENIG system lowers the ecotoxicity intensity by 344.11 CTUe/m³ compared with the Opalia WWTP effluent, which corresponds to a decrease of 70.2%. The subsequent EDEN step provides a further

reduction of 70.19 CTUe/m³ relative to the ENIG effluent, equivalent to 48.1%. Taken together, the two treatment stages reduce the ketoprofen-related freshwater ecotoxicity intensity by 414.30 CTUe/m³, corresponding to an overall decrease of about 84.6% relative to the reference stream.

For ketoprofen, inclusion of the operational freshwater ecotoxicity burdens from the WWTP, ENIG, and EDEN stages changes the final balance but does not alter the overall interpretation of the result. The combined operational burden of the full treatment train is 43.02 CTUe/m³, composed of 5.09 CTUe/m³ from WWTP operation, 36.84 CTUe/m³ from ENIG operation, and 1.09 CTUe/m³ from EDEN operation. Added to the remaining ketoprofen-related freshwater ecotoxicity potential in the treated effluent, 75.60 CTUe/m³, this results in a final residual freshwater ecotoxicity potential of 118.62 CTUe/m³. The corresponding reference condition is 494.99 CTUe/m³, combining the ketoprofen-related freshwater ecotoxicity potential in the Opalia WWTP effluent, 489.90 CTUe/m³, with the WWTP operational burden of 5.09 CTUe/m³. On this basis, the full treatment configuration achieves a net reduction of 376.37 CTUe/m³, equivalent to an overall decrease of 76.0%. Therefore, although the operational burdens reduce the net benefit compared with the substance-only avoided ecotoxicity potential, the ENIG and EDEN configuration still provides a clear environmental benefit for ketoprofen by lowering the freshwater ecotoxicity potential of the final discharged effluent.

Table 9: Ketoprofen concentration and corresponding potential freshwater ecotoxicity intensity across the treatment stages considered in the handprint assessment, including the Opalia WWTP effluent and the effluent after ENIG and EDEN treatment, expressed per m³ of discharged effluent.

Treatment stage	Concentration (mg/L)	Concentration (kg/m ³)	CF freshwater ecotoxicity (CTUe/kg)	Potential freshwater ecotoxicity intensity (CTUe/m ³)
<i>Opalia WWTP effluent</i>	223.7	0.2237	2190	489.9
<i>After ENIG treatment</i>	66.57	0.06657		145.79
<i>After EDEN treatment</i>	34.52	0.03452		75.6

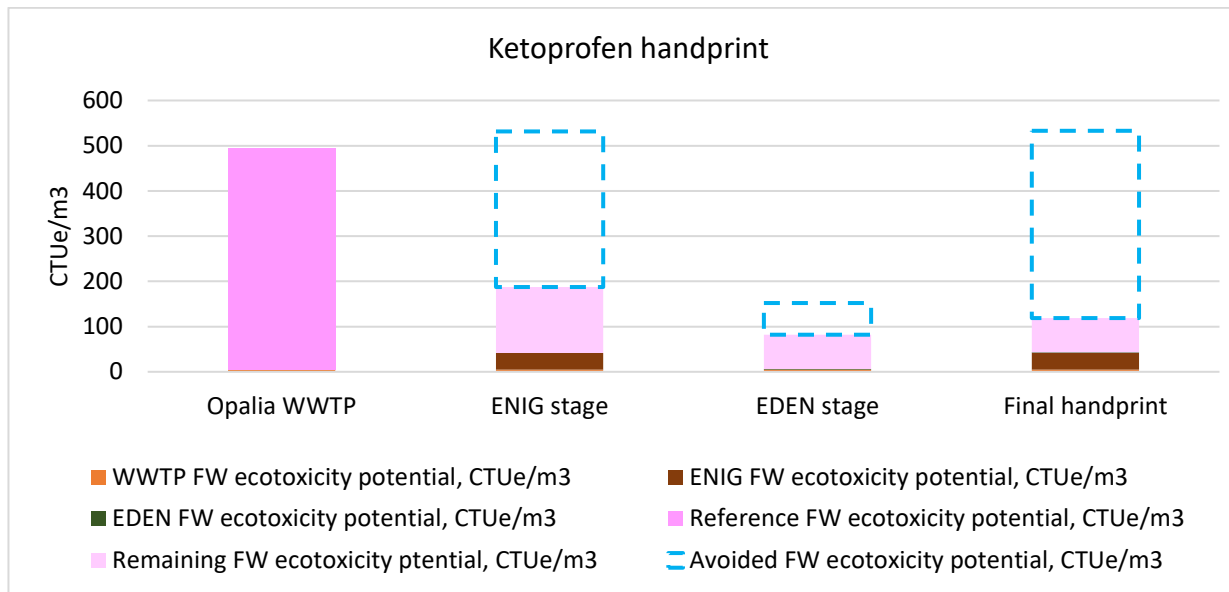


Figure 18: Handprint representation for ketoprofen, showing the reference ecotoxicity potential at the Opalia WWTP effluent, the use-phase ecotoxicity burden associated with electricity consumption in the treatment train, the remaining potential after ENIG and EDEN treatment, and the avoided potential achieved at each stage. Freshwater (FW) ecotoxicity potentials are expressed in CTUe/m³.

3.2.6.3 Handprint for Ibuprofen

For ibuprofen, the concentration measured in the Opalia WWTP effluent is 2337.65 mg/L, corresponding to 2.34 kg/m³. Using the freshwater ecotoxicity characterization factor of 786 CTUe/kg, this results in a potential freshwater ecotoxicity intensity of 1837.99 CTUe/m³ for the reference stream. After treatment in the ENIG system, the ibuprofen concentration decreases to 213.00 mg/L, equivalent to 0.21 kg/m³, reducing the corresponding freshwater ecotoxicity intensity to 167.42 CTUe/m³. Following the EDEN treatment step, the concentration is further reduced to 26.71 mg/L, or 0.03 kg/m³, resulting in a final freshwater ecotoxicity intensity of 20.99 CTUe/m³.

The results indicate a pronounced reduction in ibuprofen-related freshwater ecotoxicity along the treatment train. Compared with the Opalia WWTP effluent, ENIG reduces the ecotoxicity intensity by 1670.57 CTUe/m³, corresponding to a decrease of 90.9%. The subsequent EDEN step further reduces the ecotoxicity intensity by 146.43 CTUe/m³ relative to the ENIG effluent, equivalent to 87.5%. Considering the full treatment sequence, the freshwater ecotoxicity intensity associated with ibuprofen decreases by 1817.00 CTUe/m³, corresponding to an overall reduction of about 98.9% relative to the reference stream.

When the operational freshwater ecotoxicity burdens of the WWTP, ENIG, and EDEN stages are incorporated into the handprint balance, the overall result remains strongly favourable. The combined operational burden of the full treatment train amounts to 43.02 CTUe/m³, comprising 5.09 CTUe/m³ from WWTP operation, 36.84 CTUe/m³ from ENIG operation, and 1.09 CTUe/m³ from EDEN operation. Together with the remaining ibuprofen-related freshwater ecotoxicity potential in the final effluent, 20.99 CTUe/m³, this gives a final residual freshwater ecotoxicity potential of 64.01 CTUe/m³ after implementation. By comparison, the reference condition amounts to 1843.08 CTUe/m³, combining 1837.99 CTUe/m³ from ibuprofen in the Opalia WWTP effluent and 5.09 CTUe/m³ from WWTP operation. The resulting net reduction is therefore 1779.07 CTUe/m³, equivalent to an overall decrease of 96.5%. This confirms that,

even after accounting for the additional operational burdens introduced by the ENIG and EDEN stages, the treatment configuration delivers a robust net environmental benefit for ibuprofen, with the residual freshwater ecotoxicity potential after implementation remaining substantially lower than the reference condition.

Table 10: Ibuprofen concentration and corresponding potential freshwater ecotoxicity intensity across the treatment stages considered in the handprint assessment, including the Opalia WWTP effluent and the effluent after ENIG and EDEN treatment, expressed per m3 of discharged effluent.

Treatment stage	Concentration (mg/L)	Concentration (kg/m3)	CF freshwater ecotoxicity (CTUe/kg)	Potential freshwater ecotoxicity intensity (CTUe/m3)
Opalia WWTP effluent	2337.65	2.33765		1837.99
After ENIG treatment	213	0.213	786	167.42
After EDEN treatment	26.71	0.02671		20.99

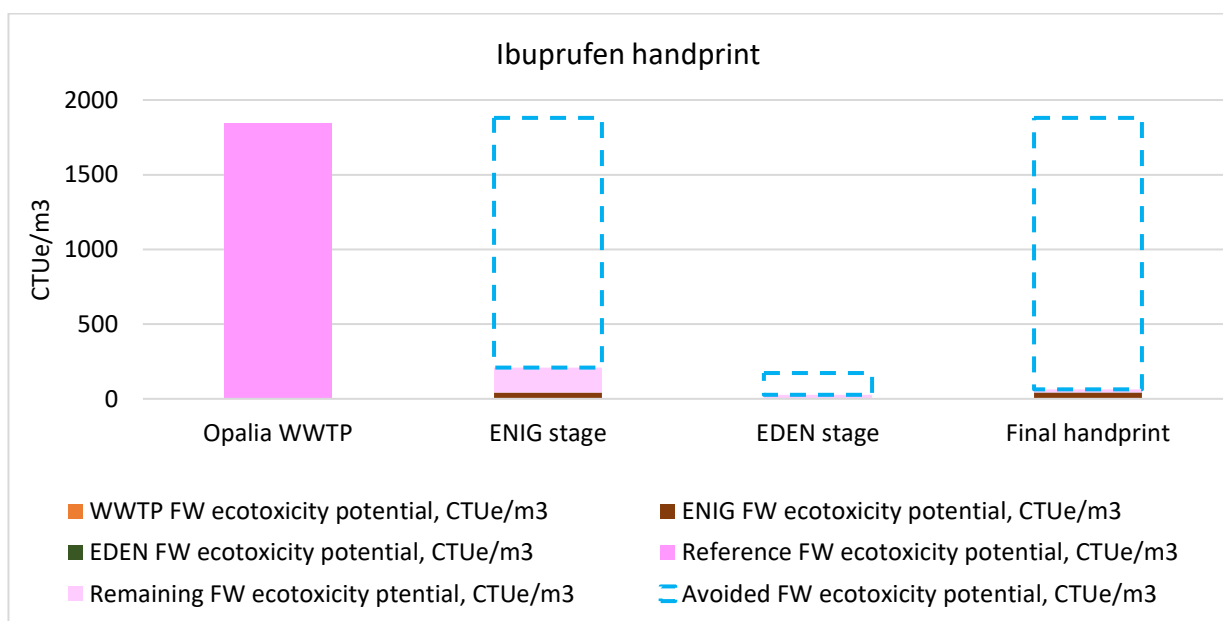


Figure 19: Handprint representation for ibuprofen, showing the reference ecotoxicity potential at the Opalia WWTP effluent, the use-phase ecotoxicity burden associated with electricity consumption in the treatment train, the remaining potential after ENIG and EDEN treatment, and the avoided potential achieved at each stage. Freshwater (FW) ecotoxicity potentials are expressed in CTUe/m3.

3.3 Use Case 3: Application of 4D Scavenger technology at SMAT

3.3.1 Demonstrated technology and system context

UC3 focuses on the removal of heavy metals from wastewater generated by industrial activities. It involves the integration of the innovative 4D Scavenger technology into the wastewater treatment plant operated by Società Metropolitana Acque Torino S.p.A. (SMAT) in Brandizzo (Torino, IT), Italy, which serves about 9,000 inhabitants.

The facility receives effluent from the sewage system, which includes both domestic and industrial sources such as metal treatment, coating facilities and a car accessories factory. In case high concentration of heavy metals reaches the wastewater treatment plant, it may cause problems with treatment and subsequent release into water bodies. Real-time monitoring and high removal efficiency could help to address this problem. Furthermore, it is important to identify treatment technologies capable of removing even low concentrations of pollutants, with a view to the possible reuse of wastewater. In this context, lower concentrations could be defined depending on the intended use of the wastewater.

This issue is addressed within the iMERMAID project through the application of the 4D Scavenger technology developed by Weeefiner. The 4D Scavenger is designed to selectively extract heavy metals from water, thereby significantly reducing pollution levels. It employs 3D-printed, porous filters to recover or remove valuable or toxic metals dissolved in industrial and municipal wastewater. The technology is customized to meet the specific requirements of the application, including adjustments to the material, size, structure, and process. A notable feature of the 4D Scavengers is their ability to enhance the chemical reaction kinetics of existing materials, such as ion exchange resins.

The intervention targets the removal of the following heavy metals from wastewater:

- Aluminium (Al)
- Copper (Cu)
- Zinc (Zn)

3.3.2 Scenario definition and inventory modelling

The system boundary for the life cycle assessment and water footprint analysis of UC3 was established, and the relevant processes, inputs, and outputs were delineated in collaboration with the plant operator SMAT and the technology provider Weeefiner.

For foreground processes such as electricity consumption, wastewater flows and the mass of materials used, primary activity data was collected. When secondary data was required, the selection adhered to the criterion of representativeness. Datasets from Ecoinvent (version 3.11), the Oekobau.dat database, and EPDs of technologically representative products were utilised accordingly. In case the impact assessment methods used for EPDs differed from the EF 3.1 method employed here, only the corresponding impact categories are used, which might lead to an overall underestimation of impacts. As electricity is concerned, the Finnish electricity consumption mix was used to model the Scavenger production phase, while wind energy was used in the use phase, as demonstrated by certificates of origin. For further background data (e.g., chemicals employed in the use phase or transportation of components to the Scavenger production facility), Ecoinvent datasets were used. The used data sources are documented in detail in Table 42 and Table 43.

UC3 Baseline Scenario: The scenario consists in the operation of the wastewater treatment plant in use in Brandizzo, where biological treatment is carried out, preceded by an initial pretreatment to remove solids and oils, and followed by a disinfection treatment to reduce the microbial load. Excess sludge is stored in

the thickener and is periodically removed and transported by tanker truck to the central treatment plant in Castiglione Torinese, where it is discharged at the inlet of the water line and undergoes the same treatment process as the incoming water. The treatment process starts with a first oxidation stage, where sludge is separated from wastewater. The separated sludge is then treated in the sludge line where undergoes in an anaerobic digestion process, where biogas is produced. The sludge then undergoes a dehydration process using centrifuges: some of the centrifuged sludge is used for agricultural recovery, while another part is further dried and reused in cement factories. A part of the dehydrated and centrifuged sludge is mixed to obtain a mixture that is incinerated. Hence the sludge that is produced in Brandizzo can be used in:

- Agricultural recovery.
- Cement factories.
- Incineration processes.

For the baseline calculation, the consolidated data collected by SMAT, along the year 2024, was used and scaled to account for the functional unit. Relevant activity variables and elementary flow data include:

- The yearly water flow and recirculation rate, which allows to scale the remaining inputs, indicated for the whole year 2024, to the functional unit.
- Electricity consumption: activity data based on operational parameters collected by SMAT. Wind energy generation was assessed based on secondary data on onshore wind turbines (>3 megawatt (MW), output: high voltage electricity) and electricity voltage transformation processes to medium and low voltage.
- Auxiliary materials: mass of reagent used by type (aluminium sulphate, peracetic acid), transport distance and mode.
- Sludge treatment: The modelled treatment processes are anaerobic digestion, drying and incineration. It should be noted that minor processes taking place at the Castiglione sludge treatment plant (sedimentation and dehydration through centrifuges) are not accounted for in the model due to lack of data.
- Estimated GHG emissions to air (CO₂, N₂O, CH₄) originating from biological treatment, nitrification and denitrification processes, released into surface body.

UC3 iMERMAID Scenario: Despite the effective biological treatment carried out at SMAT, which strongly reduces the presence of phosphorous and nitrogen in wastewater, in case of high concentration in the effluent heavy metals cannot be completely reduced during the treatment.

To address this issue within the iMERMAID project, the 4DScavenger remediation system developed by Weeefiner is installed as a tertiary treatment after the final disinfection. The goal of this incremental setup is to improve the removal of heavy metals. The assumptions, activity data and inventory used to evaluate the subsequent process steps are summarized in the following. A flow diagram displaying the inputs and outputs of the system is presented in Figure 20.

- Manufacturing of the 4DScavenger: The device was modelled using data on the components (mass and material composition) retrieved from Weeefiner. The modelling took place at material level using Ecoinvent datasets or at the component level using available EPDs of comparable components. All components listed by Weeefiner were included in the inventory. The same applies for the supporting components listed below, which are needed for the installation of the Scavenger at the plant. In the following, the components and the assumptions made in the choice of the datasets used and other parameters are:

- Reactor piping, material: polyvinyl chloride (PVC). The material was approximated through a generic dataset for PVC production via suspension polymerization, this being the most widespread PVC production technique.
- Recycled Polyamide 12 (PA12): the material is used to produce the case of the device and is brought to the wished shape via 3D printing. Being the dataset for recycled PA12 not available on Ecoinvent, the dataset for virgin PA12 was used.
- Ion exchanger: the data source chosen represents the production of ion exchanger for water treatment in Switzerland, for which the highest geographical representativeness is expected.
- Reactor bolts and nuts: based on the data for stainless steel crews from the Oekobaudat database (Oekobaudat, 2023).
- Gasket: impact assessment results from EPD of comparable product used (GF Piping Systems, 2022).
- Electricity for 3D printer: Finnish electricity consumption mix.
- Further assumptions: secondary packaging is left unconsidered. Where mass data was not available, Scavenger components are modelled based on mass data estimated by Weeefiner.
- Manufacturing of supporting components:
 - Piping, material: PVC-U. The material was approximated through a generic dataset for PVC production via suspension polymerization, this being the most widespread PVC production technique
 - Support frame: chromium steel assumed as material, Transport of raw material to frame manufacturing assumed to be 130 km according to PEF guidelines.
 - Valves (manual and automatic): EPD for butterfly valves used as a reference (GF Piping Systems, 2022)
 - Magnetic pump: estimate based on material composition (carbon fibre reinforced plastic, silicon carbide and synthetic rubber).
 - Instrumentation: estimated based on EPD of generic product (ABB, 2022).
 - Automation components: based on EPD of specific product used (Siemens, 2024).
- Transport of materials and components to production location: transport mode and distance were estimated by Weeefiner based on the country of origin.
- Installation:
 - Cardboard used as packaging: corrugated board box.
 - EURO pallets: Ecoinvent dataset EUR-flat pallet used as a proxy.
- Transport from production site to installation: the transport distance from the Weeefiner production site to the SMAT facility in Brandizzo and the transport modes used (container ship and lorry) are taken into account. This transportation process is specific to the application and cannot be generalized for other uses of the Scavenger technology.
- Packaging waste: the packaging materials are assumed to be treated in Italy as waste paperboard and municipal solid waste, respectively.
- Use phase: Having the pilot presented several challenges that affected the remediation performance of the Scavenger, the use phase parameters were simulated by Weeefiner based on another application of the technology carried out in Finland, adapted to the iMERMAID UC3 pilot through quantitative modelling. The following activities and processes are included in the model:
 - Electricity consumption: activity data based on operational parameters estimated by Weeefiner. Wind energy supply processes modelled as for the baseline scenario: wind energy generation was assessed based on secondary data for onshore wind turbines (>3

- megawatt (MW), output: high voltage electricity) and electricity voltage transformation processes to medium and low voltage.
 - Eluent: modelled using dataset for sulfuric acid. Deionised water was added to the model to reach the target dilution rate.
 - Regenerant: sodium hydroxide. Chlor-alkali electrolysis used in the model as a proxy. Deionised water was added to the model to reach the target dilution rate.
 - Water for rinsing: from the underground, without treatment
 - Metals waste (for removed metals): treated as metal waste, approximated using the Ecoinvent process “treatment of waste copper, municipal incineration” as conservative estimate.
 - Chemicals waste (for chemicals used as rinsing and regenerant): assumed to be landfilled according to estimates by the project partner.
 - Transport: Chemicals and waste are assumed to be transported by lorry (EURO 4) to the plant. The transport distance is estimated being 20 km (chemicals) and 50 km (waste).
- End-of-life of the Scavenger: the end-of-life fate of the Scavenger is assumed to be municipal solid waste, while the supporting components are assumed to be treated partly as solid waste and partly as electric and electronics waste. In all cases, the waste treatment is assumed to take place in Italy.
- End-of-life of the supporting components: depending on the prevalent material of the components, these were assumed to be treated either as municipal solid waste or as waste electric and electronic equipment.
- Contaminant concentration for aluminium, copper and zinc: the concentration before treatment was measured in Brandizzo during the pilot period, while the concentration after treatment was estimated as explained above.
- The Scavenger lifetime is assumed to be 2 years, except for the piping, in which the expected lifetime can be up to 20 years. The lifetime of the supporting components is assumed to be 20 years. The Scavenger is assumed to treat 8341 m³ water per year (16682 m³ for a 2-year lifetime).

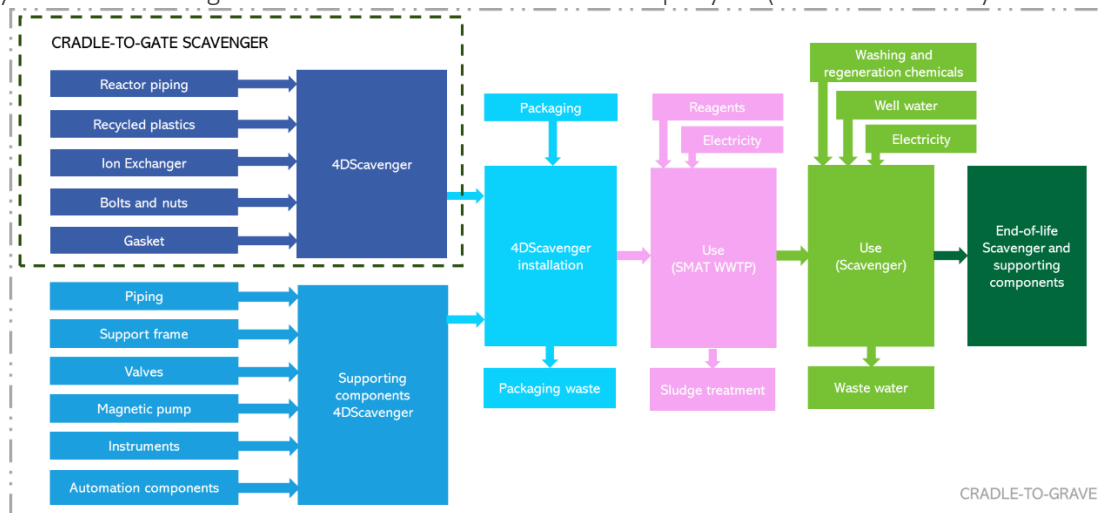


Figure 20: System boundaries for UC3, including the production of the 4DScavenger and the supporting components necessary for its deployment, transportation and installation of the Scavenger, operation of the SMAT plant and the Scavenger technology, and end-of-life. The processes involved are simplified and merged in the picture in order to provide a clearer overview of the system.

3.3.3 Baseline Scenario results

In the following, the environmental impacts originated by the SMAT wastewater treatment (the processes in purple in Figure 20), without the utilization of the Scavenger, are displayed per m³ of treated water.

Figure 21 shows the contribution of different life cycle stages and processes to individual environmental impacts.

First of all, the considerable contribution of direct emissions in the climate change impact category (73%) should be noted. In other impact categories, paracetic acid, electricity consumption and sludge treatment dominate the field, with aluminium sulphate contributing by more than 10% only to acidification and particulate matter formation.

Paracetic acid shows a high contribution to SMAT's freshwater ecotoxicity impact (63%) (due to hydrogen sulfide emissions), the use of material resources (44%), due to the involvement of metals (mainly tellurium, gold and copper) in the production infrastructure assumed in the background dataset, particulate matter formation (53%) and water use (48%).

Electricity consumption has a particularly high contribution to carcinogenic human toxicity (79%) and ionizing radiation (40%), which might be related to the non-renewable energy sources used to power electricity transmission networks.

Finally, sludge treatment processes affect most of all marine eutrophication (48%) and land use (36%), both in relation to the water input to the drying process, possibly used for cooling.

The impacts related to transport processes (transport of chemicals to SMAT and transport of sludge to treatment) are negligible and have been aggregated to the process or material they are related to.

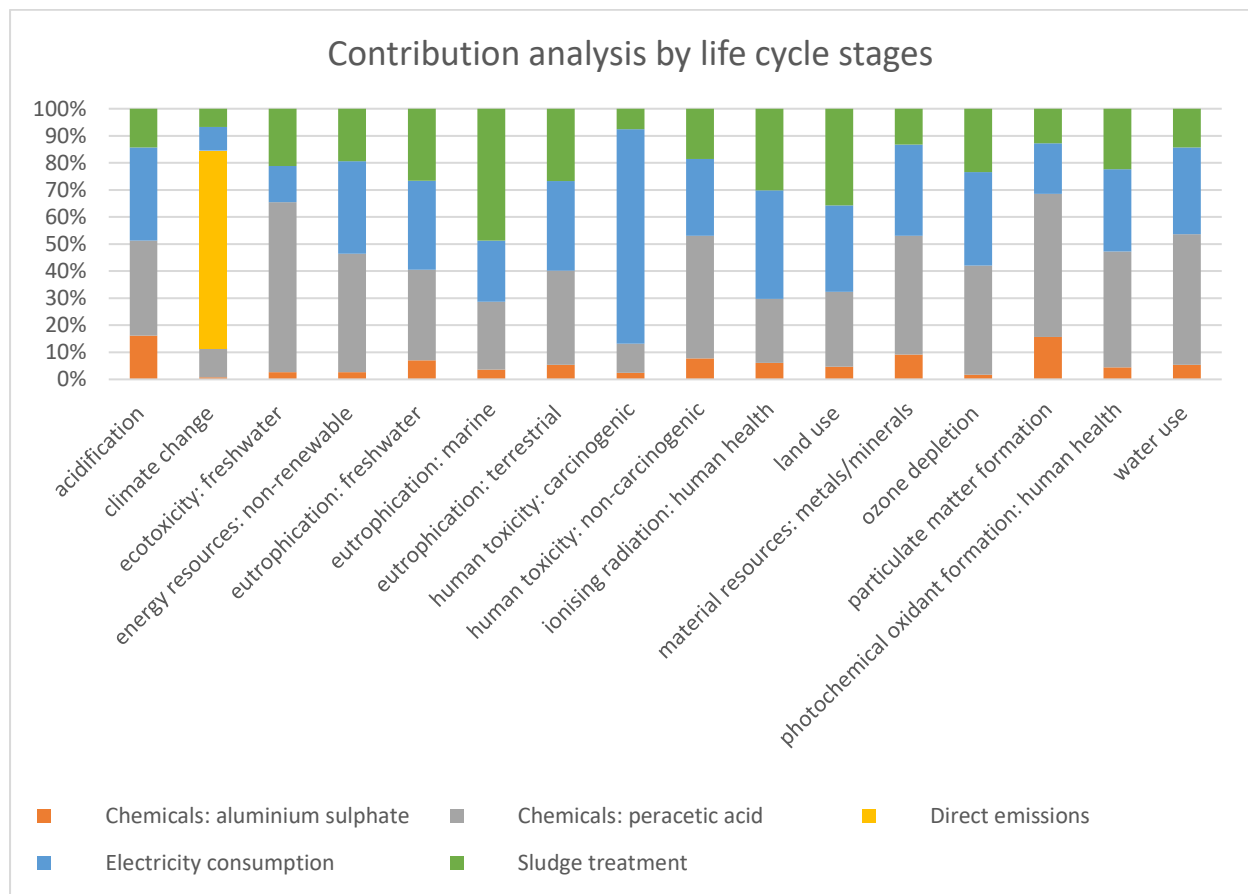


Figure 21: Contribution of inputs and outputs to the environmental impacts generated by the SMAT's WWTP in Brandizzo.

If normalized and weighted results according to the Environmental Footprint method are taken into account (see Figure 22), which allow to set different impacts in relation to each other and account for the

societal relevance of the individual impact and the uncertainties related to the impact assessment methods, the aggregated environmental impact amounts to 33.95 μ Pt.

The most significant impact is attributable to climate change (65%), followed by non-renewable energy resources (13%). While climate change impacts are mainly related to direct emissions taking place at the plant, non-renewable resources are related to background processes such as chemicals production and electricity transmission, which are modelled in secondary data sets via electricity mixes that foresee fossil resources. Across all processes, after normalization and weighting direct emission are responsible for 47% of all impacts, followed by the production of peracetic acid (22%) and electricity (17%). Sludge treatment accounts for 11% of the system's environmental impacts and aluminium sulphate for 3%.

Except for the direct GHG emissions, which are measured at the company's premises, the results are obtained using secondary data with a variable degree of representativeness. The data on wind energy production and electricity production have a high regional representativeness (datasets for Italy), while datasets on peracetic acid and aluminium sulphate production are representative for the European region.

Furthermore, data on sludge treatment have a limited regional representativeness (Switzerland for the anaerobic digestion and drying process, global average for the incineration process). It should be noted that the completeness of the sludge treatment modelling is limited, since no technologically representative data was available to assess the processes of sedimentation and dehydration through centrifuges.

It should be mentioned that, in line with the cut-off method selected for these studies, no credits are assigned for the substitution of the production of biogas, cement and fertilizers.

The complete results are reported in

	Input/output	Lifetime [years]	Selected material/process dataset	Comments material dataset selection	Transportation distance [km]	Select datasets
Support frame	Input	20	steel production, electric, chromium steel 18/8, RER; metal working, average for steel product manufacturing, RER	modelled according to main material composition	40	Ecoinvent ton, di
Pump	Input	20	carbon fibre reinforced plastic, injection moulded, GLO; silicon carbide production, ROW; synthetic rubber production, ROW	modelled according to main material composition	19000	Ecoinvent freight ton, c Ecoinvent freight ship, h
Pipes	Input	20	polyvinyl chloride production, suspension polymerisation, RER; extrusion, plastic pipes, RER	modelled according to main material composition	1000	Ecoinvent freight ton, c Ecoinvent freight ship, h
Valves	Input	20		Data used: generic product	2000	Ecoinvent freight ton, c

			<i>see EPD for butterfly valves (GF Piping Systems, 2022)</i>			<i>Ecoinvent freight ship, h</i>
<i>Measurement instruments</i>	Input	20	<i>see EPD of generic instrument (ABB, 2022)</i>	<i>Data used: generic product</i>	1000	<i>Ecoinvent freight ton, di</i>
<i>Automation components</i>	Input	20	<i>see EPD (Siemens, 2024)</i>	<i>Data used: specific product</i>	50	<i>Ecoinvent freight ton, di</i>
Datasets used installation and transportation	<i>Input/output</i>	<i>Lifetime [years]</i>	<i>Selected material/process dataset</i>	<i>Comments material dataset selection</i>	<i>Transportation distance [km]</i>	<i>Selected datasets</i>
<i>Cardboard box</i>	Input		corrugated board box production, RER		50	<i>Ecoinvent freight metric EURO</i>
<i>Pallet</i>	Input		EUR-flat pallet production, RER		50	<i>Ecoinvent freight metric EURO</i>
<i>Waste cardboard box</i>	Output		market for waste paperboard, IT		50	<i>Ecoinvent freight metric EURO</i>
<i>Waste Pallet</i>	Output		market for municipal solid waste, IT		50	<i>Ecoinvent freight metric EURO</i>
<i>Scavenger transportation to installation</i>	Transport only				3000	<i>Ecoinvent freight metric EURO transp contain fuel of</i>
Datasets used Scavenger use phase	<i>Input/output</i>	<i>Lifetime [years]</i>	<i>Selected material/process dataset</i>	<i>Comments material dataset selection</i>	<i>Transportation distance [km]</i>	<i>Selected datasets</i>
<i>Electricity</i>	Input		<i>electricity production, wind, >3MW turbine, onshore, IT; electricity voltage transformation from high to medium voltage, IT; electricity voltage transformation from medium to low voltage</i>			
<i>Regenerant</i>	Input		<i>chlor-alkali electrolysis, average production, RER; market for water, deionised, Europe</i>	<i>95% dilution rate</i>	20	<i>Ecoinvent freight metric EURO</i>
<i>Eluent</i>	Input		<i>sulfuric acid production, RER; market for water, deionised, Europe</i>	<i>50% dilution rate</i>	20	<i>Ecoinvent freight</i>

						metric EURO
<i>Water</i>	<i>Input</i>		<i>tap water production, underground water without treatment</i>			
<i>Metals waste</i>	<i>Output</i>		<i>treatment of waste copper, municipal incineration, Europe</i>		50	Ecoin freigh metric EURO
<i>Chemicals waste</i>	<i>Output</i>		<i>treatment of municipal solid waste, sanitary landfill, IT</i>		50	Ecoin freigh metric EURO
Datasets used for end-of-life Scavenger and supporting components	<i>Input/output</i>	<i>Lifetime [years]</i>	<i>Selected material/process dataset</i>	<i>Comments material dataset selection</i>	<i>Transportation distance [km]</i>	<i>Select datas</i>
<i>Supporting components: treatment of electronic waste</i>	<i>Output</i>		<i>treatment of waste electric and electronic equipment, shredding, GLO</i>		50	Ecoin freigh metric EURO
<i>Supporting components: treatment of other waste</i>	<i>Output</i>		<i>market for municipal solid waste, IT</i>		50	Ecoin freigh metric EURO
<i>Scavenger: waste treatment</i>	<i>Output</i>		<i>market for municipal solid waste, IT</i>		50	Ecoin freigh metric EURO



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Table 44, Table 45 and

Table 46.

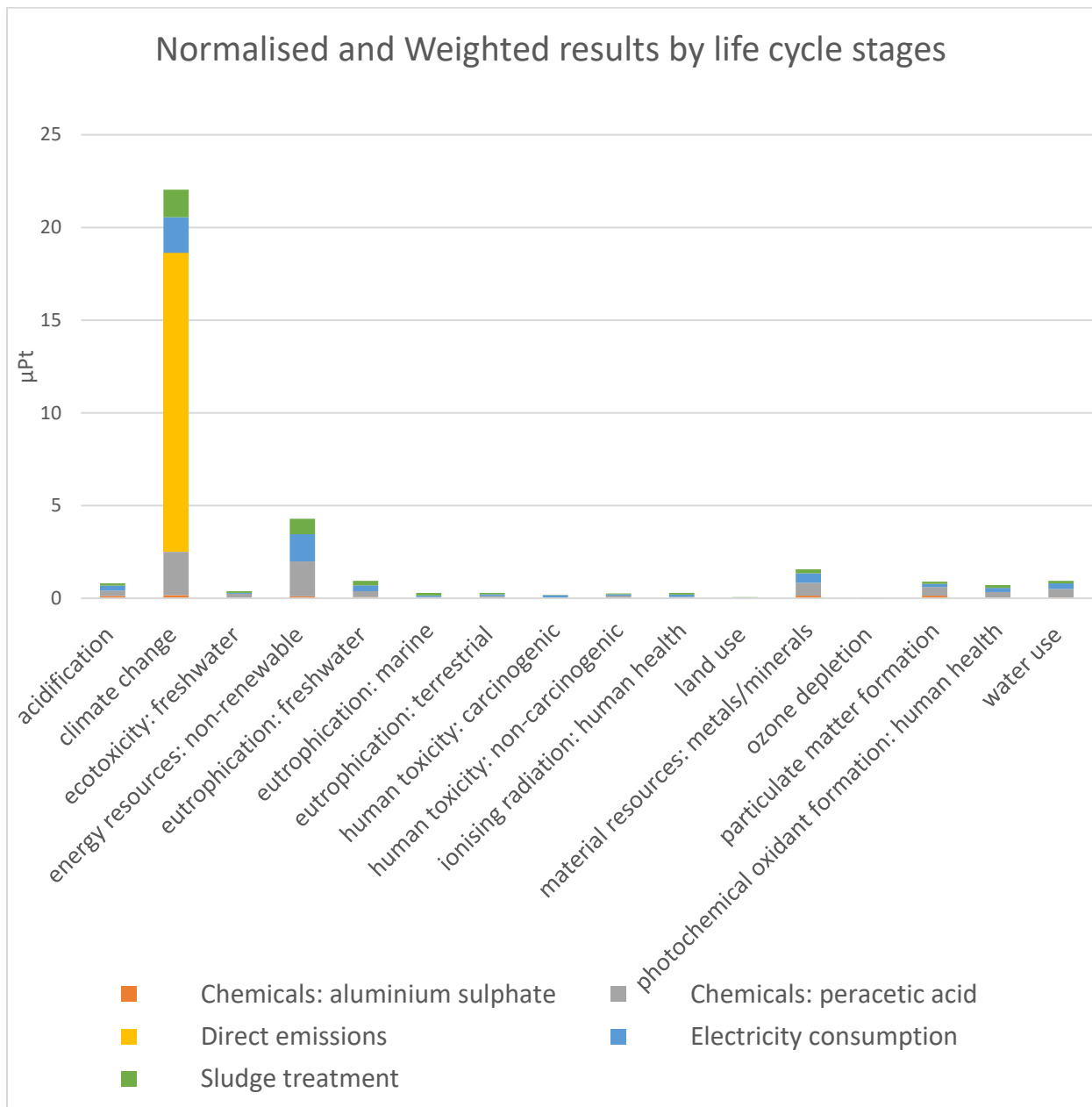


Figure 22: Environmental impacts of the SMAT's WWTP in Brandizzo per m³ of water treated. Normalised and weighted results according to the Environmental Footprint 3.1 method.

3.3.4 iMERMAID Scenario results

In the following section, the results for the iMERMAID scenario are presented. First, the cradle-to-gate results for the Scavenger are presented, in order to identify hotspots related to the materials and processes involved in the production. Further on, the cradle-to-grave results for the iMERMAID application will be shown and the related results displayed and analysed.

3.3.4.1 Cradle-to-gate impact: 4DScavenger

Figure 23 shows the contribution of different components to each of the environmental impacts included in the EF 3.1 method. While production waste, the transport of components to the production site, bolts and nuts, PA12 and the gasket have low to irrelevant impacts, electricity consumption, the ion exchanger and the reactor piping dominate the picture, with the latter having an above-average contribution to freshwater eutrophication (mainly due to nitrogen oxide emissions in the production of polyvinyl), land use and water use. The ion exchanger is a driver of human toxicity and ozone depletion (due to metal emissions and emissions of bromotrifluoromethane and bromomethane, respectively), while electricity consumption affects the use of mineral resources, human toxicity (non-carcinogenic) and ionizing radiation, due to the prevalence of nuclear energy in the Finnish electricity mix.

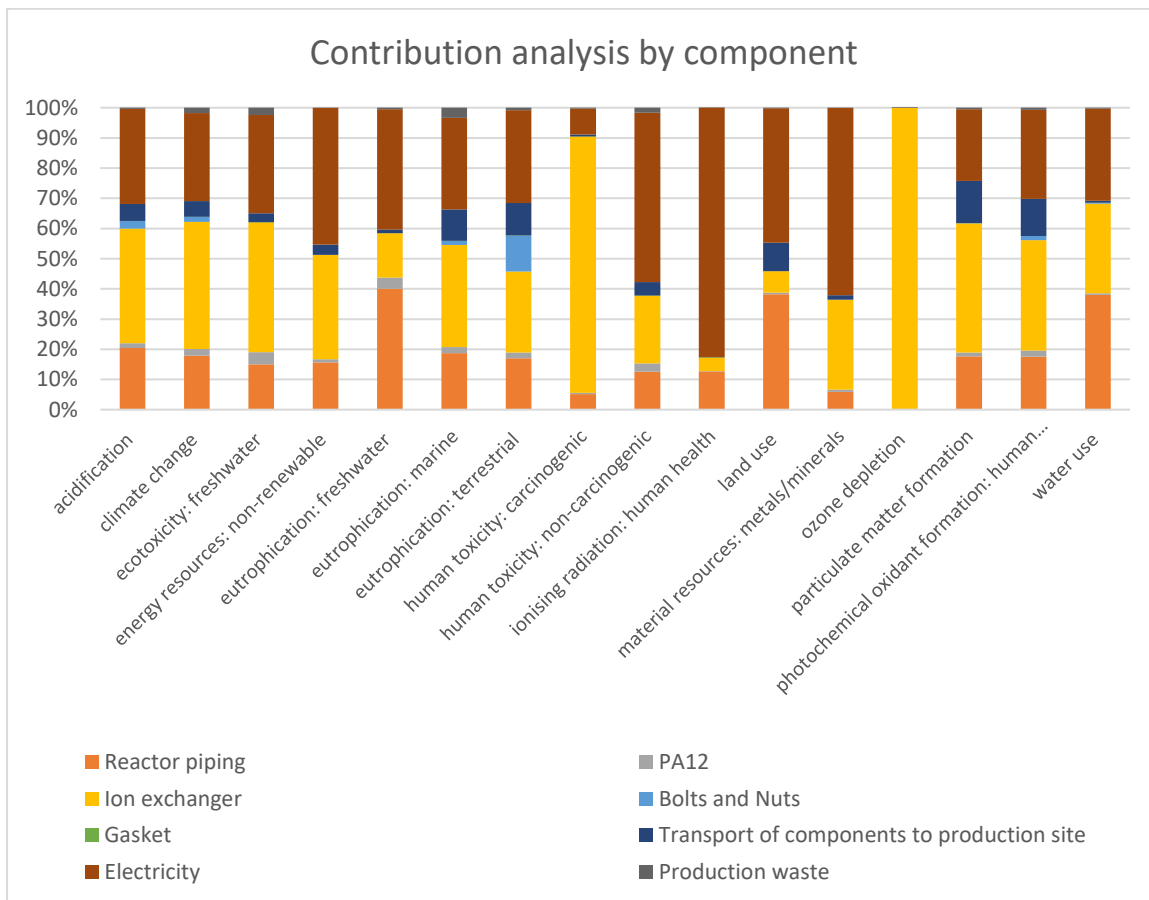


Figure 23: Contribution of the different components, electricity and production waste to the cradle-to-gate impacts of the 4DScavenger according to the EF 3.1 impact assessment method.

The analysis of the normalized and weighted results allows for setting the different impacts brought about by the product system in comparison to each other.

The total impact score for the Scavenger (cradle-to-gate), given the assumed 2-years lifetime as well as the estimated amount of treated water during the Scavenger lifetime (1668200 m³), the total impact per functional unit is 0.21 µPt.

The results show non-renewable energy resources as most relevant impact category (63% across all components), followed by land use (22%). A minor role plays climate change, water use and ionizing radiation, while all other impact categories appear negligible.

Considering the total contribution of single components and processes, electricity plays the main role (43%), followed by the ion exchanger (30%) and the reactor piping (21%). The complete results are displayed in Table 47, Table 48 and Table 49.

3.3.4.2 Cradle-to-grave results – Pilot application

The cradle-to-gate results take into account the pilot system holistically. Besides the use phase of the SMAT plant and the cradle-to-gate assessment of the Scavenger, the cradle-to-gate analysis accounts for:

- Supporting components, which include instruments such as pumps, pipes and measurement tools;
- Transport and installation: including the transport of the Scavenger and the related packaging material from the production site to the installation site, the production and end-of-life of packaging;
- The use of the Scavenger, including the production and end-of-life (landfill) of the regenerant and eluent and the water used to guarantee the functioning of the Scavenger, and the electricity consumption;
- The end-of-life of the Scavenger and related supporting materials, according to material-based estimates.

Figure 25 shows the contribution of these life cycle stages to the different impact categories.

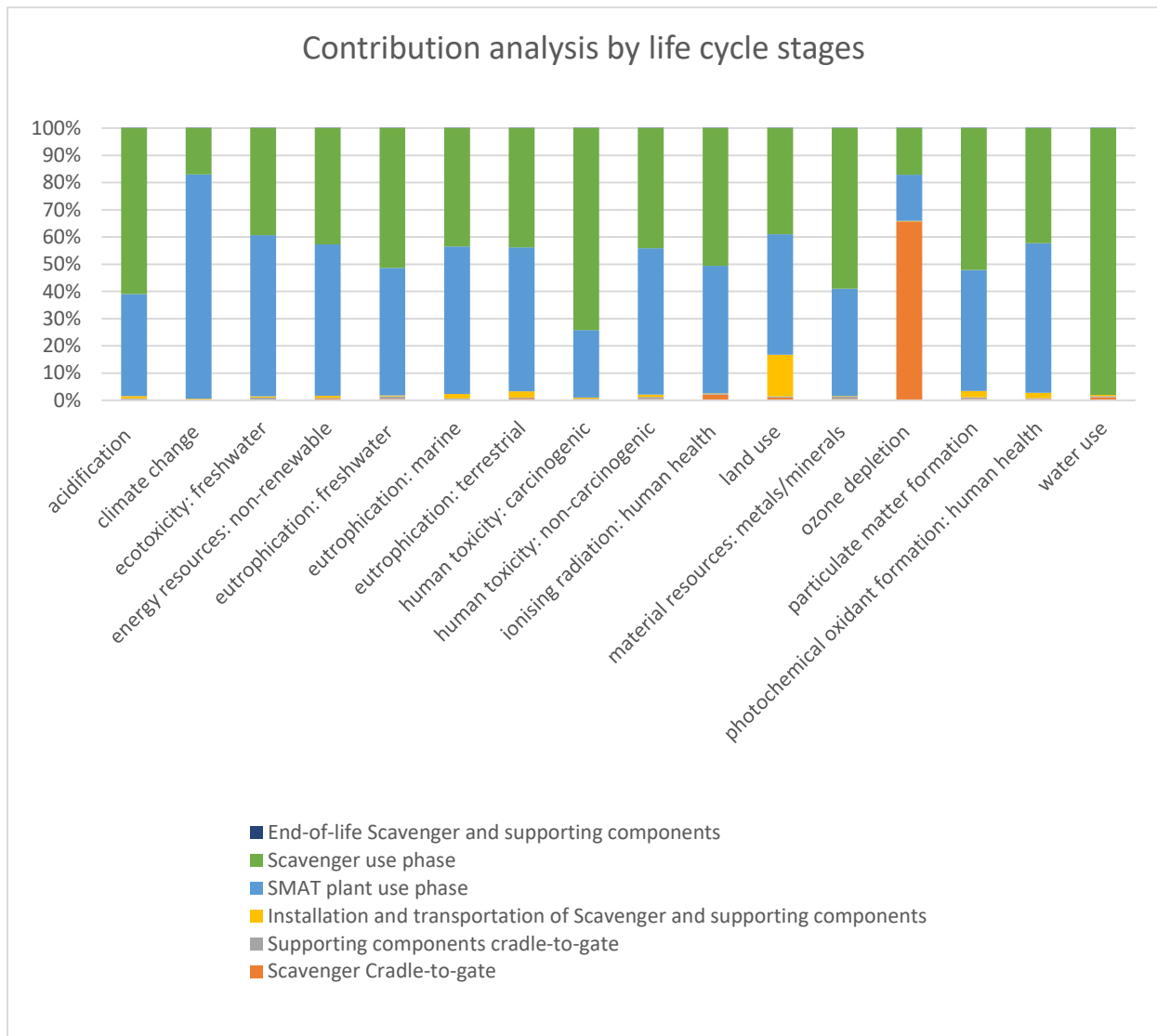


Figure 24: Contribution of the different life cycle stages to the cradle-to-grave impacts of the application of the 4DScavenger used at the SMAT facility. The assessment is carried out according to the EF 3.1 impact assessment method.

In the cradle-to-grave iMERMAID scenario, the Scavenger cradle-to-gate contributes only limitedly to most of the impact categories accounted for in the study, except for ozone depletion due to the use of the ion exchanger, as displayed in Figure 23. The main contributors to other impact categories are the SMAT plant use phase, which includes the same processes and activity data as the baseline scenario analysed in section 3.3 (see also Figure 21 and Figure 22), and the Scavenger use phase. The SMAT plant use phase is accountable for more than 50% in the categories climate change (82%), freshwater ecotoxicity, use of non-renewable resources, photochemical oxidant formation, marine eutrophication and water use. The Scavenger use phase on the other hand dominated the picture in the categories acidification, freshwater eutrophication, human toxicity (cancerogenic), ionizing radiation and particulate matter formation.

The main impacts are due to the use of electricity. Though being produced with renewable sources (wind), the electricity purchased by SMAT is transformed and transmitted in an electricity network dominated by fossil fuels. This shows also in the LCA model. Wind electricity production has as an output high voltage electricity. Since the SMAT plant uses low voltage electricity, the wind power is assumed to undergo two

transformation processes (from high to medium, and from medium to low voltage). The fact that such transformation processes are energy intensive, and they are modelled in the database using an electricity consumption mix that includes about 50% of domestic (Italian) mainly fossil-based electricity production (besides 30% of renewable energy and 20% of electricity imports), leads to a high environmental impact of electricity consumption driven by both the SMAT plant use phase and the Scavenger use phase.

If the normalized and weighted results are accounted for (see Figure 25), the prevalence of impacts on climate change and non-renewable energy resources appears clear. It should be acknowledged that this is strongly related to the methodological choices of the EF method developers, which attributed a high weighting factor to climate change and strongly discounted the high uncertainty that is intrinsic to certain impact categories, e.g. ecotoxicity.

The life cycle phase contributing the most to the normalized and weighted results is the SMAT plant use phase (66%), followed by the Scavenger use phase (33%). Other life cycle phases (Scavenger and supporting components cradle-to-gate and end-of-life impact as well as installation and transportation) play an insignificant role in the total impact. While the contributors to the Scavenger use phase impacts are analysed in section 3.3.3 and encompass, besides electricity consumption, direct emissions and the production of the peracetic acid used in the plant, the contributors to the Scavenger use phase need to be analysed in more detail.

Within the Scavenger use phase, the main impacts can be attributed to the use of electricity (58% after normalisation and weighting), followed by the production of the regenerant and eluent used for rinsing the Scavenger (27% and 13%, respectively). The treatment of chemicals waste, which is carried out at the pilot location via landfill in accordance with legislative provisions, contributes to 2% of total impacts, due to its 27% share in marine eutrophication impacts of the Scavenger use phase.

Overall, it should be acknowledged that the datasets used to model the processes with the highest impacts have a variable level of representativeness. While the voltage transformation (from high to medium and from medium to low voltage), responsible for 96% of electricity-related climate impacts, are assessed using country-specific grid data, the sodium hydroxide and sulfuric acid used as regenerant and eluent, respectively were modelled via more generic data sets (chlor-alkali electrolysis, average production, and average sulfuric acid production), with low regional representativeness (Europe), thus not allowing for the inclusion of country-specific electricity mix, relevant for the environmental profile of such energy intensive basic chemicals.

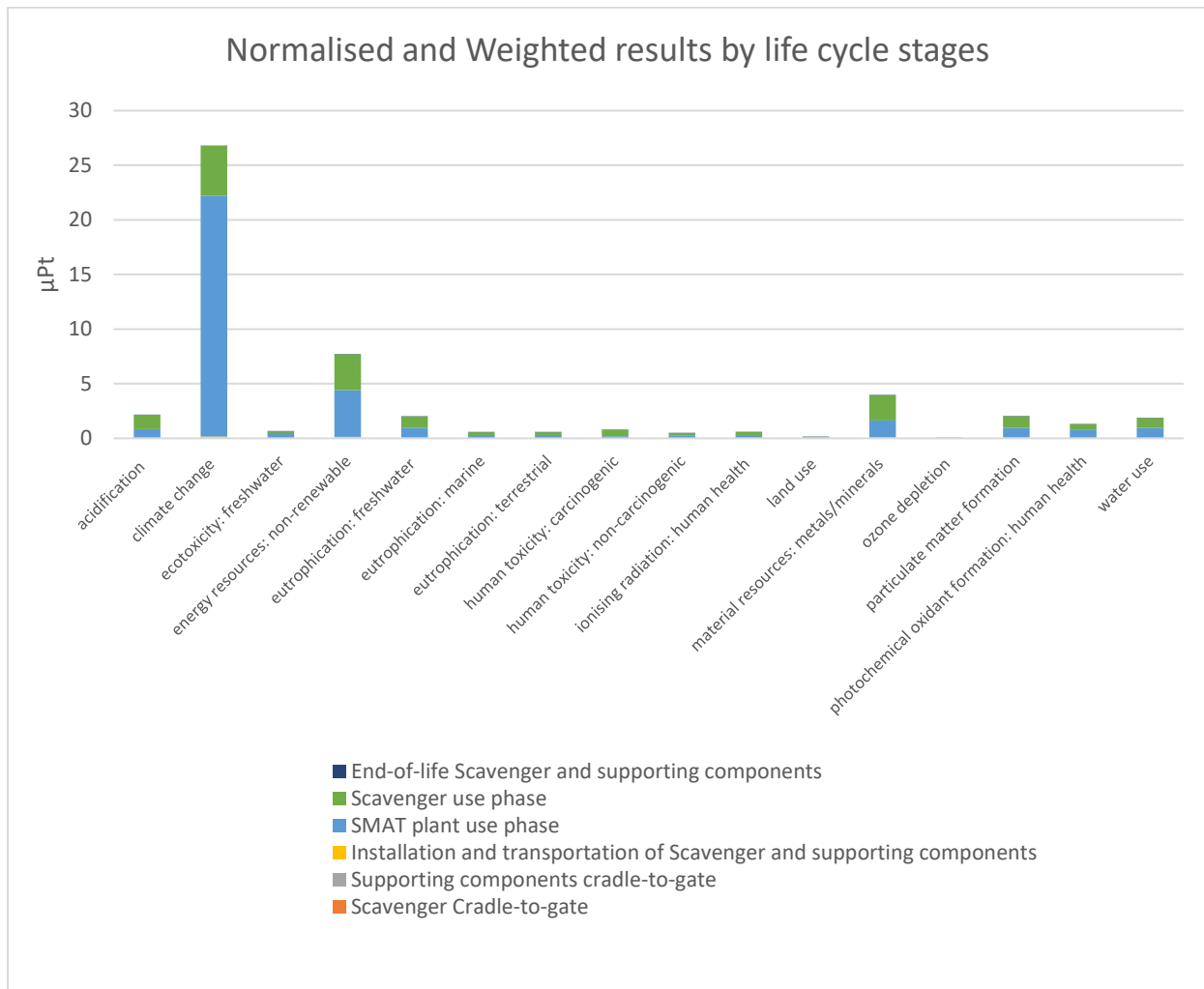


Figure 25: Normalized and weighted results of the Scavenger application cradle-to-grave, including the Scavenger and the supporting components (cradle-to-gate and end-of-life), transportation to site and installation, use of the SMAT plant and use of the Scavenger. The assessment is carried out according to the EF 3.1 impact assessment method.

3.3.5 Comparative analysis of the LCA results of the baseline and iMERMAID scenarios

Comparing the baseline scenario to the iMERMAID scenario demonstrates that the implementation of the Scavenger technology at the SMAT plant increases the system’s overall environmental impact. The overall increase amounts to 52% (from 17.56 µPt, from 33.95 µPt in the baseline to 51.51 µPt in the iMERMAID scenario), based on normalised and weighted results. Thereof, 56% be reconducted to the Scavenger’s energy use, while about 40% is related to the chemicals used for regeneration and rinsing.

This increase is due to the incremental character of the Weefiner technology, which is added to the SMAT treatment process. Equipment, supporting components and energy demand occurring in the iMERMAID scenario do not substitute any of the treatment steps performed at SMAT, which results in an overall increase of production activities and resources consumption linked to the technology implementation. The LCA results (normalised and weighted, per FU) for both scenarios and the relative difference are displayed

in Table 11. The table is complemented by the detailed impacts from electricity consumption at the SMAT plant and the Scavenger's operational phase, providing context for interpretation.

Table 11: Comparison of the baseline scenario (operation of the SMAT wastewater treatment plant in Brandizzo) and the iMERMAID scenario. For a better understanding of contributing processes, the impact originated by electricity consumption in both SMAT operations and the Scavenger use phase are displayed.

Impact category	Baseline scenario	iMERMAID scenario	iMERMAID scenario vs. baseline scenario	Electricity consumption – SMAT operation	Electricity consumption – Scavenger use phase	Unit
Acidification	0.80	2.14	+167 %	0.467151598	1.300928501	μPt
Climate change	22.04	26.76	+21 %	3.256693918	4.550449036	μPt
Ecotoxicity: freshwater	0.38	0.64	+69 %	0.085511493	0.250204057	μPt
Energy resources: non-renewable	4.28	7.69	+80 %	2.481757362	3.281704939	μPt
Eutrophication: freshwater	0.94	2.01	+113 %	0.525897801	1.031233659	μPt
Eutrophication: marine	0.30	0.55	+85 %	0.113143794	0.237918486	μPt
Eutrophication: terrestrial	0.29	0.55	+89 %	0.164221889	0.242218891	μPt
Human toxicity: carcinogenic	0.19	0.77	+302 %	0.257285477	0.571361414	μPt
Human toxicity: non-carcinogenic	0.26	0.49	+86 %	0.126005728	0.214106829	μPt
Ionising radiation: human health	0.28	0.61	+113 %	0.193269294	0.307473877	μPt
Land use	0.06	0.13	+126 %	0.031566293	0.051457515	μPt
Material resources: metals/minerals	1.57	3.97	+154 %	0.893692436	2.338956037	μPt
Ozone depletion	0.01	0.03	+493 %	0.003334097	0.005797906	μPt
Particulate matter formation	0.90	2.02	+125 %	0.284436408	1.051210746	μPt
Photochemical oxidant formation: human health	0.72	1.31	+82 %	0.369679309	0.552764157	μPt
Water use	0.94	1.86	+98 %	0.50783782	0.901553115	μPt
Total	33.95	51.51	+52 %	9.76148472	16.88933917	μPt

The main contributors to the absolute increase in the iMERMAID scenario are climate change, energy resources (non-renewable) and resource use (minerals and metals). Climate change rises by 21%, from 22.04 μPt to 26.76 μPt. A higher relative rise can be observed for non-renewable energy resources (+80%) and minerals and metals (+154%). These changes originate from the electricity demand of the Scavenger use phase (needed for operating the pump and electronic instruments). Though using wind power, the fact that the grid is based to a high degree on fossil fuels leads to a strong absolute increase of environmental impacts related to electricity production.

Besides the minerals and metals category, significant relative shifts (> +100%) can be observed for acidification, freshwater ecotoxicity, human toxicity, land use, ozone depletion and particulate matter formation. While the rise in land use and ozone depletion is mainly due to increased electricity consumption in the iMERMAID scenario, other impact categories are driven by the production of chemicals used for regenerating and rinsing the Scavenger. The production of sulfuric acid strongly contributes to the increase of acidification and particulate matter formation, due to sulphur dioxide emissions to air. On the other hand, the regenerant production is a driver for freshwater ecotoxicity and human toxicity, due to chloride and dioxins emissions to water, respectively. A considerable increase could be denoted also for

water use, related to electricity consumption (56%) and to the sulfuric acid production needed for the eluent (32%).

Water-related impacts are particularly relevant for interpretation, given the remediation objectives of the iMERMAID scenario. In UC3, the removal of Aluminium (Al), Zinc (Zn) and Copper (Cu) is envisaged. According to the classification of the EF 3.1 method, these metals lead to freshwater ecotoxicity, which is attributed in the baseline scenario a moderate impact (0.38 μ Pt) and witnesses a 69% increase in the iMERMAID scenario. Still, in the iMERMAID scenario, freshwater ecotoxicity accounts for only 1.2% of total environmental impacts, partly due to the uncertainties related to the toxicity-related impact pathways, which are “discounted” in the normalization factor applied in the calculation (see section 2.1.3).

3.3.6 Water quality footprint and handprint

In this section, the environmental benefits brought about by the implementation of the Scavenger are set in relationship to the life cycle impacts of the iMERMAID scenario. The environmental impact considered in the water footprint and handprint is freshwater ecotoxicity, since aluminium (Al), zinc (Zn) and copper (Cu), identified in UC3 as relevant contaminants of concern, lead to freshwater ecotoxicity.

The following three key metrics are considered:

1. The remediation performance of the technology, i.e., the difference between the environmental impacts of the emissions occurring without and with the application of the Scavenger
2. The water ecotoxicity footprint by life cycle stage, calculated as one of the 16 impact categories of the LCA using the EF 3.1 method.
3. The ecotoxicity handprint, which is calculated by subtracting the ecotoxicity footprint from the remediation potential.

While the remediation performance only accounts for the technical capacities of the implemented technology, the handprint enables accounting for trade-offs between cleaning up local water pollution and the environmental effects of each stage in the life cycle, which may occur in various regions around the world, allowing them to be considered together.

The remediation performance calculation is based on the pollutant concentration at the Scavenger inlet (after the SMAT treatment) and outlet (after the Scavenger treatment). The values for the inlet concentration are based on the results of three sampling campaigns occurred between 2024 and 2025. The outlet concentration values were calculated by Weeefiner, utilizing previous successful implementations of the Scavenger.

Table 12 displays the emissions inventory used to calculate the remediation performance. It includes the concentration of the contaminants of concern aluminium, zinc and copper at the Scavenger inlet and outlet, the total removal at inventory level, and the remediation performance expressed as (prevented) ecotoxicity impact in CTUe/m³.

On the inventory level, the pollutants concentration reduction was estimated at 95% for all three pollutants under consideration. In total, the removed metal mass was composed to 82% by aluminium, 16% by zinc and 2% by copper.

After characterisation, the total remediation performance amounts to 1.78 CTUe/m³. Given the divergencies in the severity of the ecotoxicity impact brought about by the three contaminants of concern, reflected in the different orders of magnitude of the characterisation factors for aluminium and zinc on the one hand (4350 and 1660 CTUe/kg) and copper on the other hand (4.65 CTUe/kg), the remediation performance was dominated even more prominently by aluminium removal, responsible for 93%, followed

by zinc (7%). Due to the far lower characterization factor, the contribution of copper at the level of characterised results is even smaller than at inventory level (0.02%).

Table 12: Data for the calculation of the Scavenger remediation performance: Inventory data, characterisation factors and freshwater ecotoxicity impact results.

CoC	Treatment stage	Concentration (mg/L)	Removal (kg/m ³)	CF freshwater ecotoxicity (CTUe/kg)	Remediation performance (CTUe/m ³)
	Al	Scavenger inlet	0.4	0.00038	4350
Scavenger outlet		0.02			
Zn	Scavenger inlet	0.08	0.000076	1660	0.126
	Scavenger outlet	0.004			
Cu	Scavenger inlet	0.01	0.0000095	4.65	0.000442
	Scavenger outlet	0.0005			
Total	Scavenger inlet	0.49	0.0004655		1.78
	Scavenger outlet	0.0245			

All in all, the remediation potential shows that the Scavenger, according to the manufacturer's estimates, has the capacity to mitigate the ecotoxicity impact caused by the contaminants of concern aluminium, zinc and copper (iError! No se encuentra el origen de la referencia. A). At the same time, the ecotoxicity footprint of the of the SMAT plant operation and of the Scavenger (production, supporting components, transportation and installation, use and end-of-life) reveal the strong effects related to electricity and chemicals consumption (iError! No se encuentra el origen de la referencia. B). Differently than the remediated contaminants, which contribute to alleviating the environmental pressure locally, the freshwater ecotoxicity impacts occurring through electricity and chemicals consumption potentially show effects in other regions, e.g. in proximity of fossil-based power plants or chemicals production facilities. However, the remediation potential of the Scavenger (iMERMAID scenario) leads to an overall reduction of the ecotoxicity footprint by 37% (iError! No se encuentra el origen de la referencia. C).

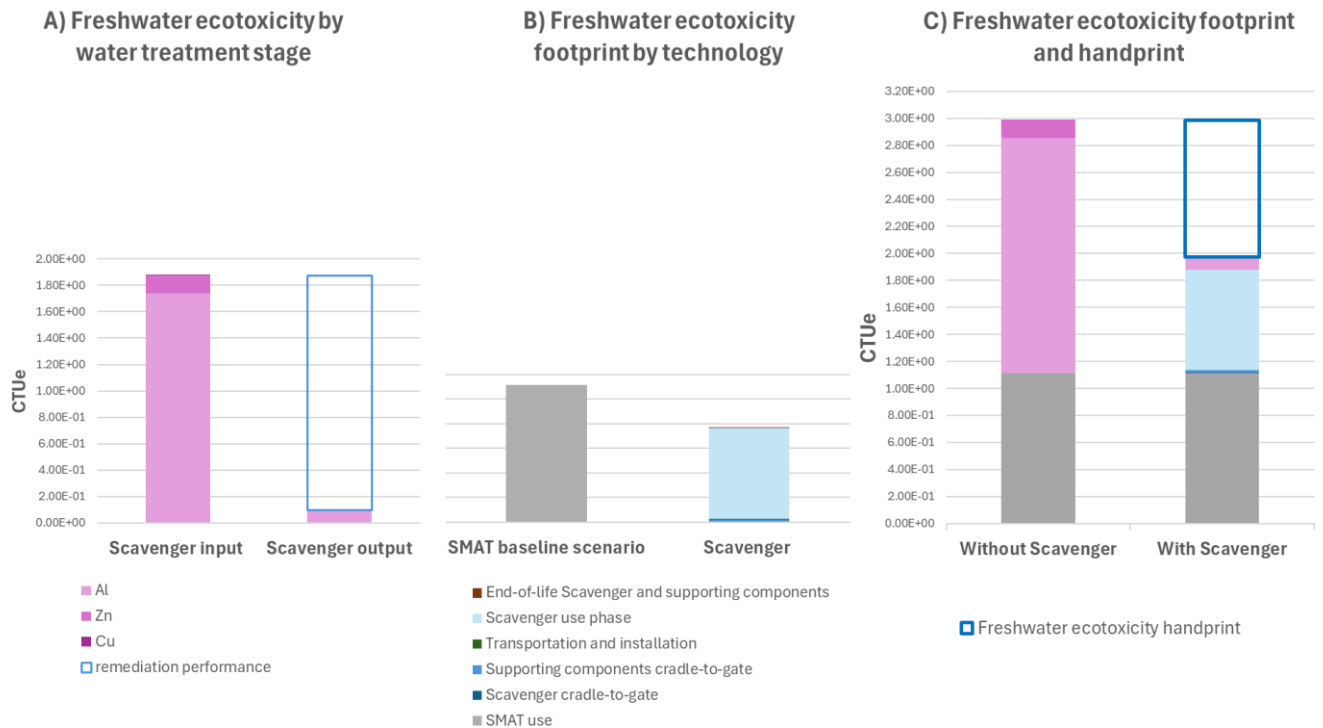


Figure 26: A) Freshwater ecotoxicity impact caused by the effluent's contaminants concentration, without and with the Scavenger; B) Freshwater ecotoxicity footprint by technology; C) Freshwater ecotoxicity footprint including those caused by the quality of the treated water.

All in all, the implementation of the Scavenger at the SMAT wastewater treatment plant leads to a reduction of overall freshwater ecotoxicity impacts within the system under analysis, which witnesses an overall shift in the location of water contaminants from the SMAT effluent (baseline scenario) to the energy and chemicals supply chain related to the operation of the Scavenger.

For a complete understanding, it is necessary to analyse the handprint considering the overall LCA results. These indicate that freshwater ecotoxicity represents only a very limited portion of the overall environmental impacts within both the baseline and iMERMAID scenarios (accounting for about 1% of the total environmental profile following normalization and weighting). For this reason, despite the contribution of the Scavenger to freshwater ecotoxicity remediation, when considering the Scavenger implementation at a specific site, the remaining environmental impacts such as climate change and the user of mineral resources need to be accounted for as well to make pondered technology application decisions.

3.4 Use Case 5: Application of Microfluidic System at ESDAK

3.4.1 Demonstrated technology and system context

UC5 addresses the challenge of treating landfill leachate that contains a range of organic and inorganic contaminants faced by ESDAK, the Unifide Waste Management Association of Crete, which is responsible among others for the treatment of landfill leachates.

Within the iMERMAID project, the microfluidic water treatment system developed by EDEN, which utilises advanced oxidation processes to remove pollutants from leachate and is described in 3.2, is applied at the Pera Galini municipal solid waste sanitary landfill facility, which has a capacity of 100-110m³/day. In the baseline scenario (without application of the microfluidic system), two treatment lines are applied. In the first one, a physicochemical and a biological treatment are carried out, followed by a tertiary treatment

via reverse osmosis (RO1). In the second treatment line, active since 2026, part of the leachate flow is directed towards a new treatment line, which consists of a reverse osmosis treatment only (RO2). During the pilot phase, the microfluidic system substitutes the RO1 system. The flow diagram provided by ESDAK (Figure 28) displays the different steps of the landfill leachate treatment system.

This setup allows investigating the efficacy of the microfluidic system in the removal of the following target compounds:

- Bisphenol A: a chemical compound used in plastics manufacturing
- Bentazone: a chemical belonging to the thiazidine group used in herbicides
- Propamocarb: a fungicide used in agriculture
- Perfluorooctanoic acid (PFOA): belongs to the group of per- and polyfluoroalkyl substances (PFASs), which includes persistent organic pollutants
- Metals: Zn(II), Cd(II), Pb(II), Cu(II)

Bisphenol A, Bentazone, Propamocarb and PFOA were measured during the pilot and are taken into account when calculating the handprint. Metals were measured as the pilot was not active. Therefore, the remediation performance through the multifluidic system cannot be accounted for in the technology's handprint.

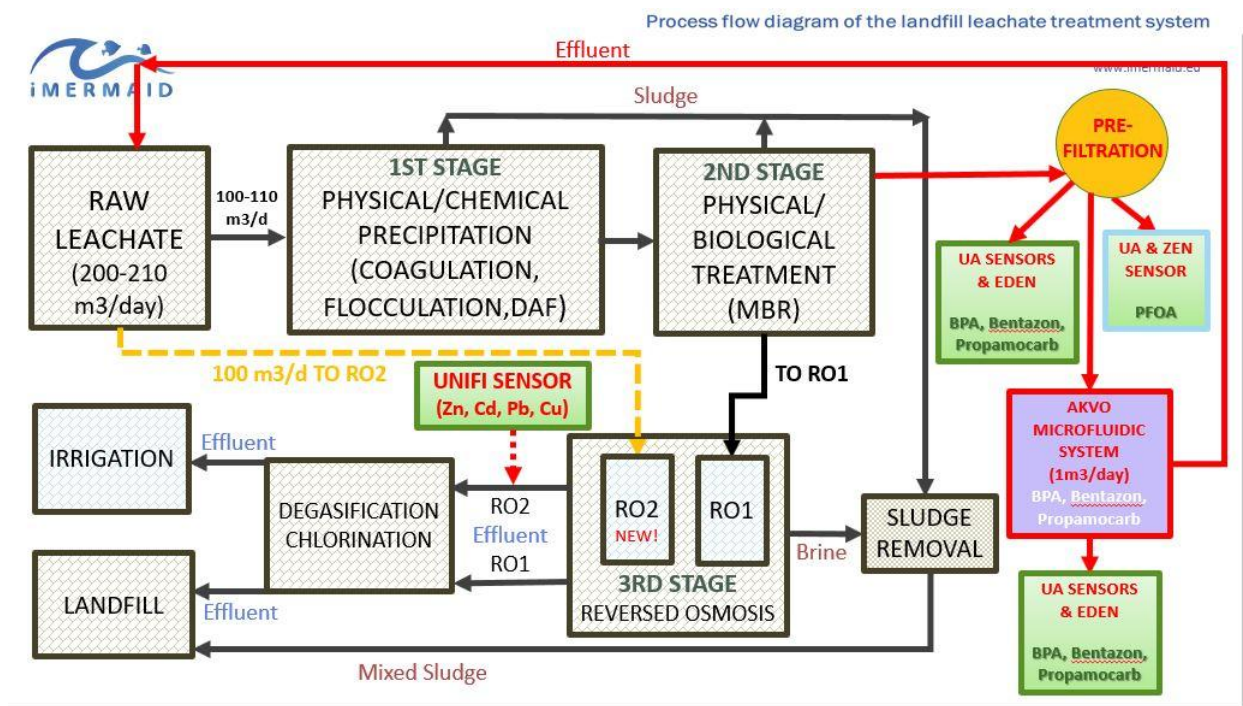


Figure 27: Flow diagram of the leachate treatment system. The black arrows display the process taking place in the baseline scenario, including the tertiary treatment via reverse osmosis, while the red arrows show the experimental setup during the pilot phase of the microfluidic system.

3.4.2 Scenario definition and inventory modelling

The description of the data and modelling assumptions used for microfluidic system are described in section 3.2.4.1.

UC5 baseline scenario: With regard to the Pera Galini facility, data needed to assess the baseline scenario was available at ESDAK and collected within the project. The collected data regard activity and purchase data (mainly reagents and chemicals used for the treatment, including estimated transport distance and mode), electricity consumption, and the total amount of treated water during the month in which the pilot took place (1981.75 m³ for the reference period March 2026), which allowed to scale the results to the functional unit of 1m³ of treated water. No data on direct emissions at the plant and leachate landfilling were available. The system boundary and processes included in the baseline scenario are displayed in Figure 28 and secondary datasets and assumptions are detailed in Table 53.

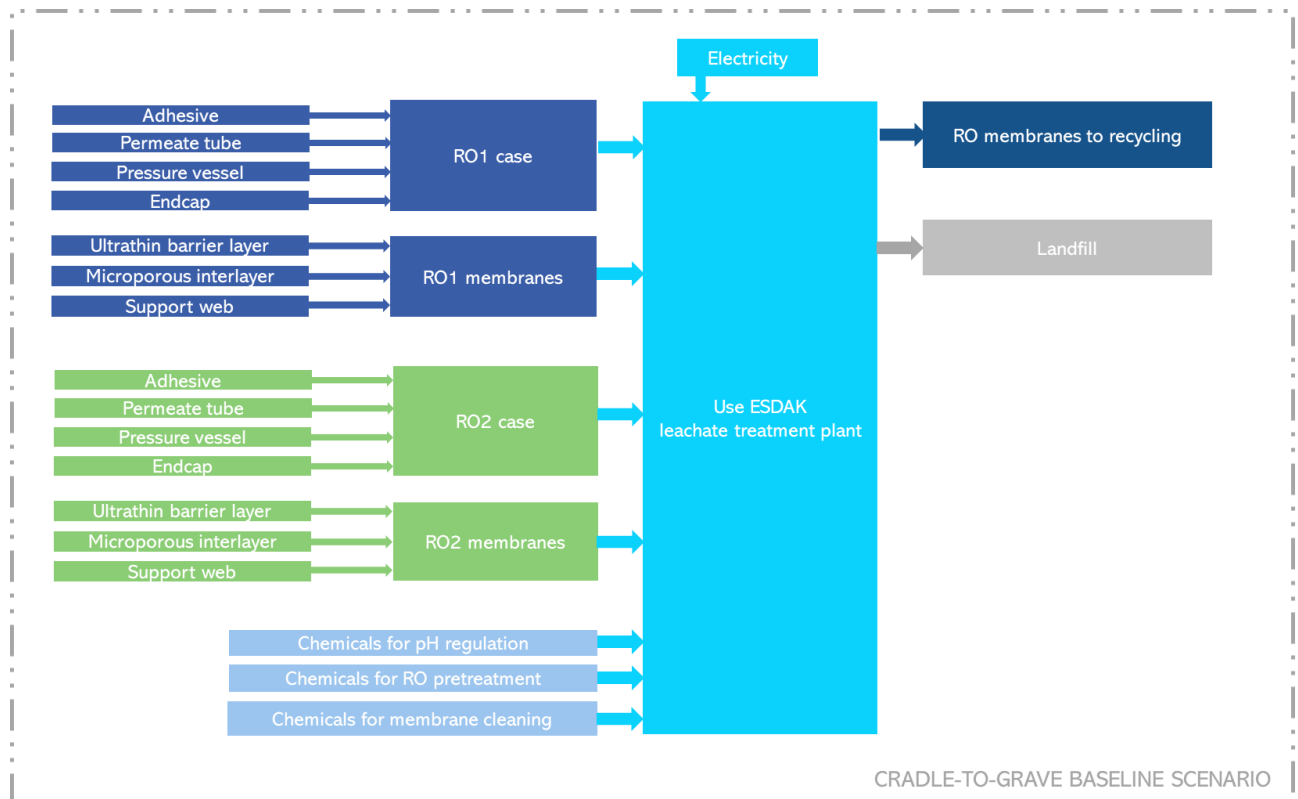


Figure 28 System boundaries and processes included in UC5 baseline scenario

While the foreground system is modelled according to the primary data provided by ESDAK, secondary data from the Ecoinvent 3.11 database were used for background processes. In the following, the selection of secondary data is illustrated for all input and output types.

- Electricity consumption: medium voltage electricity from grid, consumption mix for Greece
- NaOH for pH calibration: European average dataset for chlor-alkali electrolysis used
- Sulphuric acid (H₂SO₄) for RO pretreatment: European average dataset for sulphuric acid production
- Polyelectrolyte for RO pretreatment: Global average dataset for market for poly(lactic acid), granulate (polyacrylamide is the dominant chemical basis of commercial polyelectrolytes)
- Polyaluminium Chloride (PAC): market for polyaluminium chloride, global.

- Antiscalant for RO membrane cleaning: assumptions on the product composition were met according to the technical datasheet of an antiscalant product employed in wastewater treatment provided by the producer Kemira².
- Sodium hypochlorite for chlorination: European average, market for sodium hypochlorite
- RO membranes: since no database or literature data displaying the inventory or impact assessment for RO membranes was available, these were modelled based on the mass and material composition available in technical literature and on estimates regarding the share of each material on the total mass.
 - The mass of one RO membrane is assumed to amount to 13.5 kg (Hydranautica, 2022)
 - The components of the RO membrane were estimated according to the information entailed in (DuPont, 2025b; Lenntech, 2025), if not differently indicated:
 - Ultrathin barrier layer (polyamide), estimated mass share: 5%
 - Microporous Interlayer (polysulfone), estimated mass share: 15%
 - Support web (polyester), estimated mass share: 15%
 - Adhesive, estimated mass share: 2%
 - Permeate tube (polypropylene, material estimated), estimated mass share: 30%
 - Pressure vessel (fiber reinforces plastics, according to (CodeLine, n.d.)), estimated mass share 30%
 - Endcap (injection molded ABC plastics, according to (DuPont, 2025a)), estimated mass share 3%
 - The membrane is modelled according to the materials listed above with Ecoinvent 3.11 data for Europe
 - The use of 42 new membranes per year is assumed, according to 2024 data.
- Transport to plant: According to ESDAK's indications, the chemicals employed at the facility are shipped from Greece (160 km by lorry and 325 km by ship). The transport of RO components to assembly is estimated according to the PEF default values, assuming that the materials suppliers are located within Europe: 130 km by truck (>32 t, EURO 4); 240 km by train (average freight train); and 270 km by ship (European Commission, 2021).
- RO membranes (to recycling): The recycling process is not accounted for, since it is considered part of the following life cycle of the membranes. This is in line with the cut-off allocation method applied throughout the study (see section 2.1.1).
- End-of-life of the leachate: According to the operator of the Pera Galini landfill, the brine and sludge resulting from the leachate treatment are recirculated into the active cell of the landfill, which receives a substantial volume of waste, daily. Although environmental monitoring is carried out for leachate and groundwater, the results of these analyses provide no clear indication as to whether the brine and sludge have any impact on the site. This is primarily due to the relatively small quantities of these materials in comparison to the volume of leachate generated by the waste mass. Due to this lack of information, the landfill-related environmental impacts will be excluded from this study. It should be acknowledged that this exclusion might lead to a slight underestimation of the overall impacts.

UC5 iMERMAID scenario foresees the substitution of the RO membranes and the related chemicals by the microfluidic system illustrated in UC 2, section 3.2.4.1. The system boundary and included processes are

² Retrieved upon request under <https://www.kemira.com/products/antiscalants-and-dispersants/>

illustrated in Figure 29. The microfluidic system and the membrane filtration unit, including the electricity consumption and End-of-Life, are modelled as in UC2.

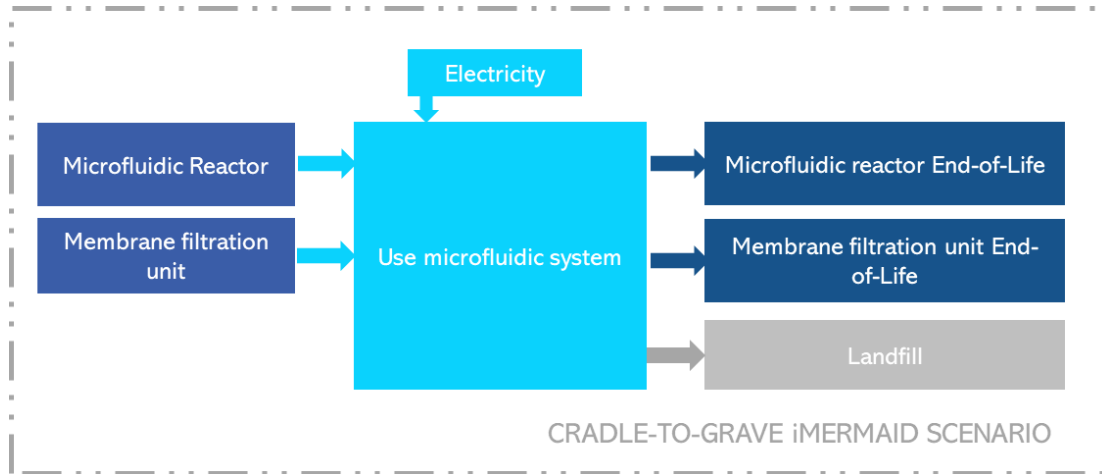


Figure 29: System boundaries and processes included in UC5 iMERMAID scenario

In addition to the baseline and the iMERMAID scenario, for UC5 also an **alternative improved scenario** will be assessed. This consists in the sole use of RO2, with the leachate skipping the physical-chemical and the physical-biological treatment (first and second stage, respectively), following the yellow dotted pathway illustrated in

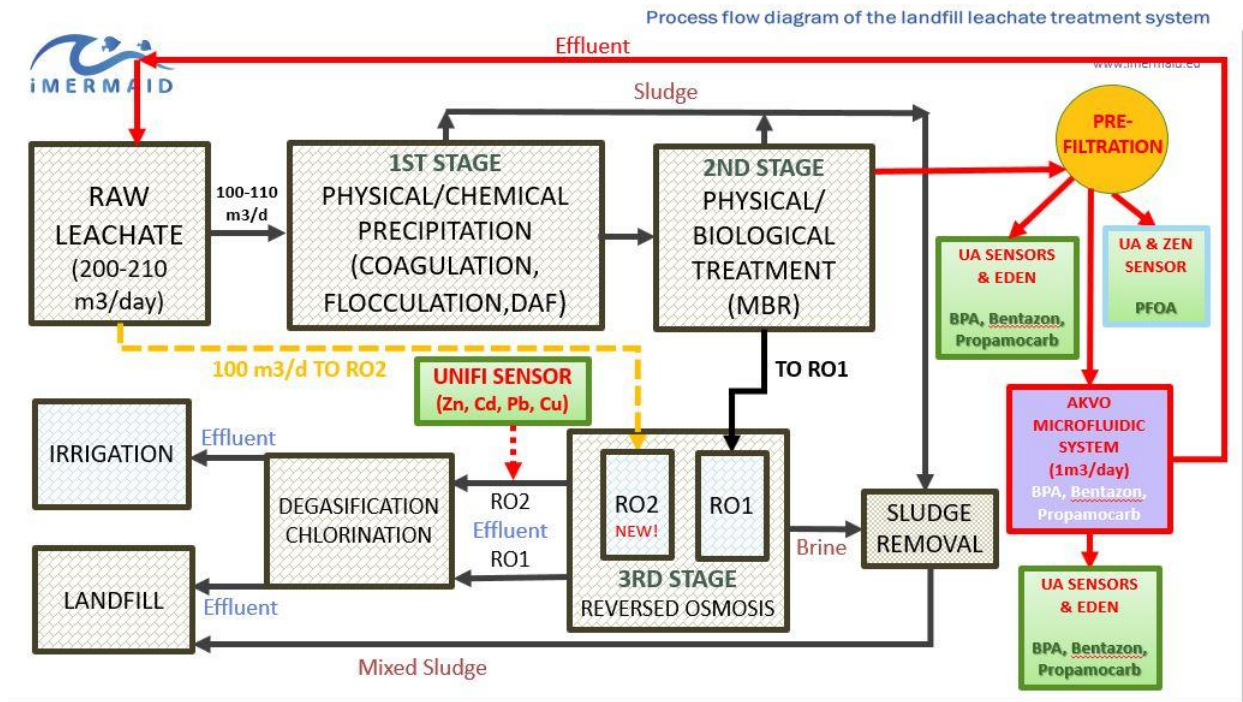


Figure 27: Flow diagram of the leachate treatment system. The black arrows display the process taking place in the baseline scenario, including the tertiary treatment via reverse osmosis, while the red arrows show the experimental setup during the pilot phase of the microfluidic system.

. The inputs and outputs involved in the operation of the alternative improved scenario are displayed in Figure 30.

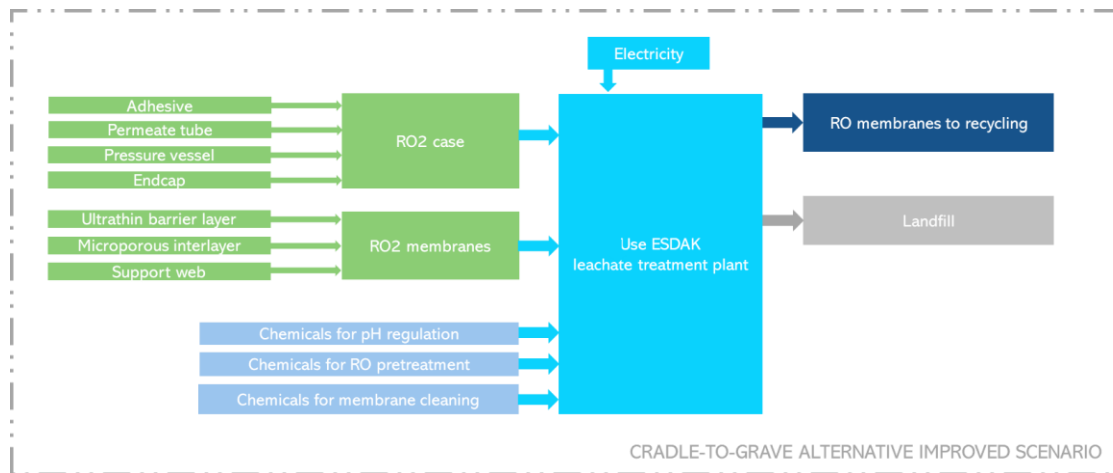


Figure 30: System boundaries and processes included in UC5 alternative improved scenario

3.4.3 Baseline Scenario results

The baseline scenario includes the two treatment pathways taking place in 2026 at the ESDAK plant. The first pathway is composed by the first and second stage treatment complemented by reverse osmosis (RO1, see black arrow in Figure 28); the second one relying solely on reverse osmosis (RO2, see yellow arrows in Figure 28).

The contribution of different life cycle stages and processes is displayed in Figure 31. Following impact contributors are detailed in the analysis: the cradle-to-gate and end-of-life (EoL) impacts of the reverse osmosis cases and membranes (for both RO1 and RO2); chemicals used during the use phase, by function (for RO and pH calibration and chlorination), electricity consumption by process step (1st and 2nd stage, RO1, RO2) and transport (of RO cases and filters to the waste plant and of the same to waste treatment).

The contribution profile is strongly dominated by the use phase (electricity consumption and chemicals for RO utilized during the plant operation), while the production of RO membranes and membrane cases, their EoL play a minor role. Above all, electricity use strongly affects freshwater eutrophication (95%), ozone depletion (93%), climate change and the use of non-renewable energy resources (87%), human toxicity non-cancer (80%), while chemicals for RO drive water use (72%), particulate matter formation (66%), use of metals/minerals (63%), acidification (58%), ecotoxicity (49%) and land use (47%). Among the chemicals used, the highest impact share is attributable to sulfuric acid production and polyaluminium chloride.

The high contribution of electricity is due to the high share of gas in the Greek electricity consumption mix as available in the Ecoinvent dataset utilized in the model.

The production of RO cases and membranes contributes for less than 2% in all EF impact categories. Even less relevant impacts can be attributed to the end-of-life of RO cases and membranes and to the Chemicals used for pH calibration and chlorination. Transport processes quite irrelevant for several impact categories, have a relevant contribution to terrestrial and marine eutrophication (23% and 17%, respectively), photochemical oxidant formation (15%) and land use (10%).

Detailed characterised results can be found in Table 54.

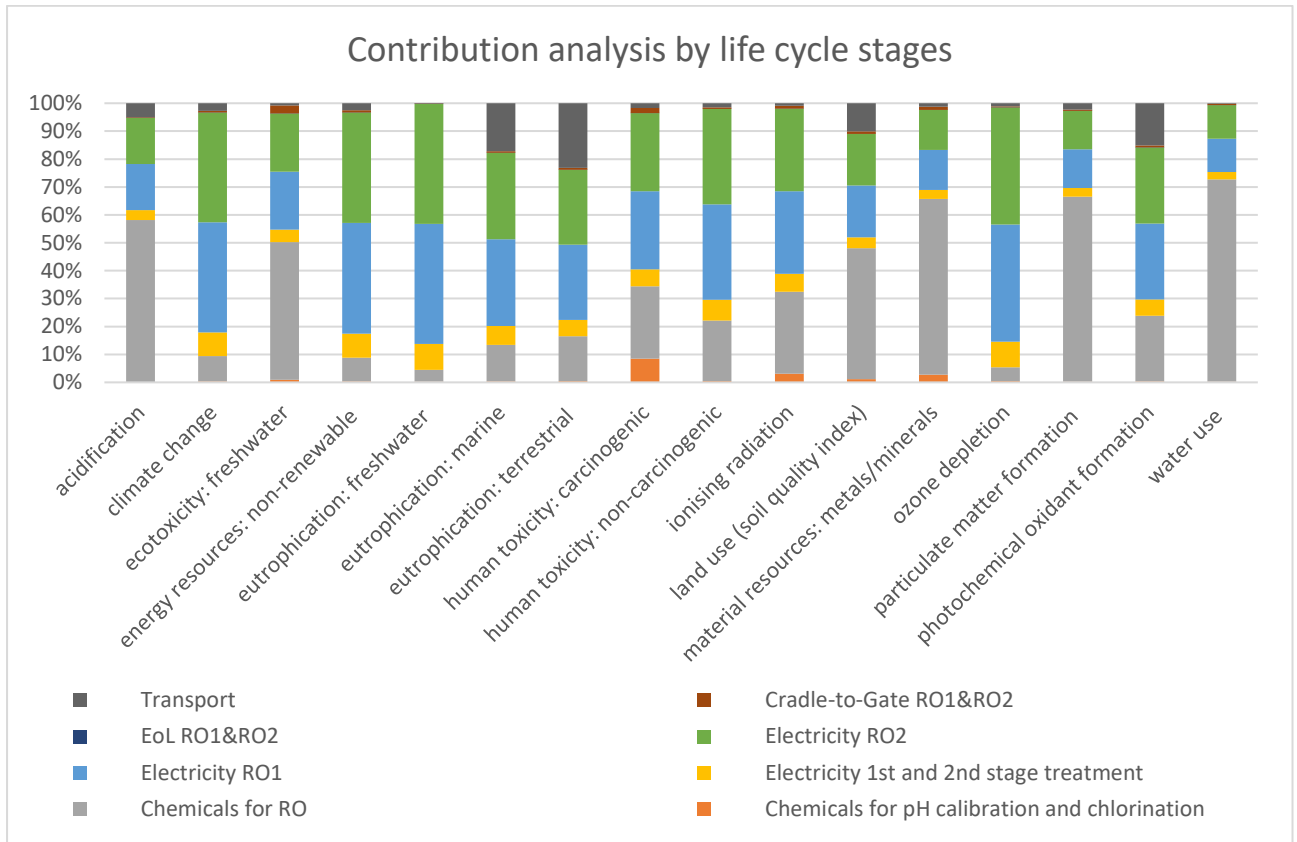


Figure 31: Characterized results for the life cycle environmental impacts of the ESDAK plant per m3 of water treated.

The normalized and weighted results, which juxtapose the severity of different impact categories, highlight the relative relevance of environmental impacts. In the UC5 baseline scenario, the main impact is climate change (27%), followed by non-renewable energy resources (18%), eutrophication (17%), acidification (12%) and particulate matter formation (9%). From a process perspective, electricity contributes to 70% of the total environmental footprint, followed by the Chemicals used for RO. The environmental footprint per m3 of treated water amounts to 1116 µPt.

In absolute figures, the environmental footprint for the treatment of Detailed results after normalization and weighting can be found in Table 55 and Table 56.

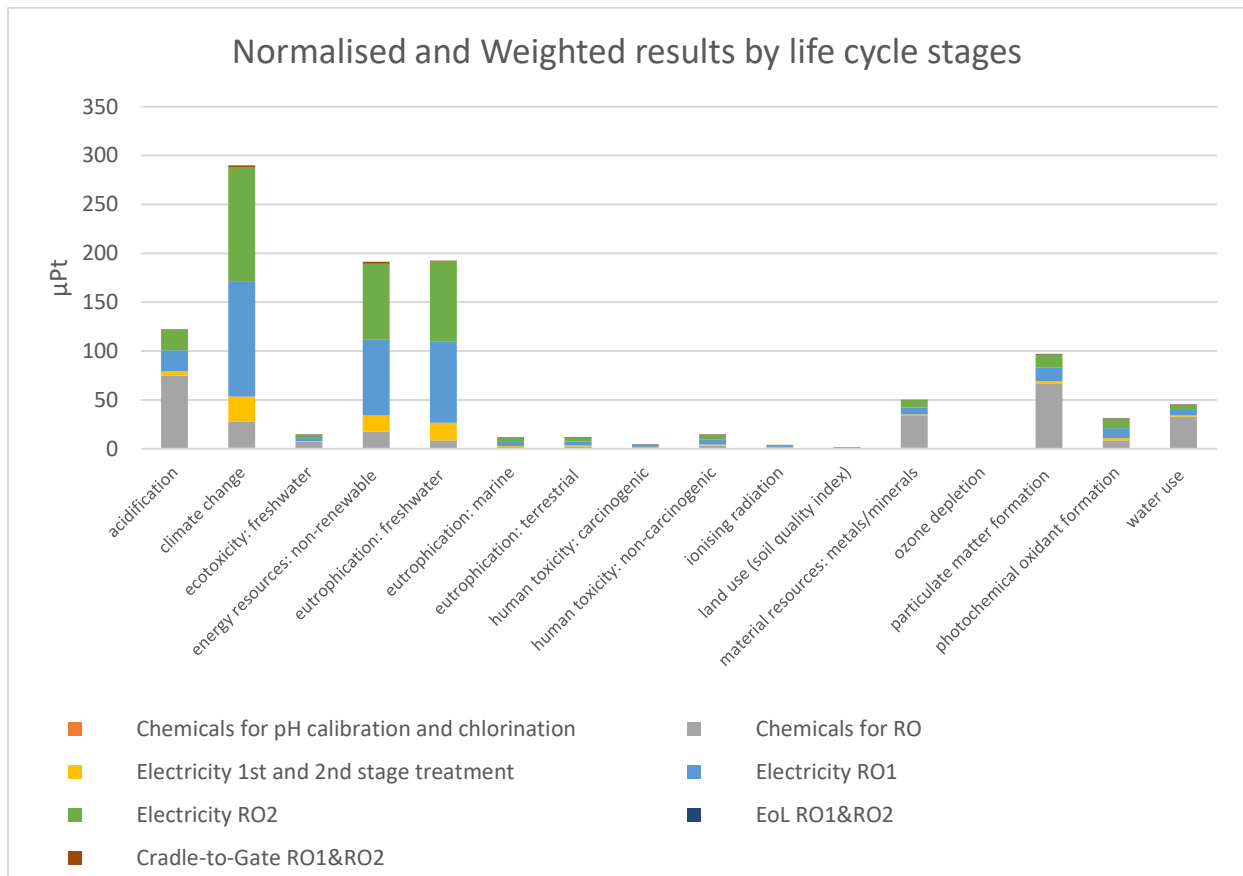


Figure 32: Normalized and weighted results for the life cycle environmental impacts of the ESDAK plant per m3 of water treated.

3.4.4 iMERMAID Scenario results

3.4.4.1 Cradle-to-gate impact – Microfluidic Reactor and Membrane filtration unit

The technology applied in UC5 is the microfluidic system developed by EDEN. A detailed description and cradle-to-gate LCA results are available in section 3.2.4.1. and 3.2.4.2.

3.4.4.2 Cradle-to-grave results – Pilot application

The iMERMAID scenario includes the first and second stage treatment, followed by the pilot-specific treatment through the pre-filtration system and the microfluidic system. While for the first and second stage treatment only the electricity consumption is accounted for, for the specific technology employed, the multifluidic system, besides energy consumption, also the cradle-to-gate and end-of-life impacts are accounted for. The pre-filtration system is modelled using a material-based approach and electricity consumption estimates.

Figure 33 shows how different life cycle stages contribute to the different impact categories. It can be noted that electricity is responsible for more than 90% of the impacts in 11 out of 16 impact categories. The multifluidic system cradle-to-gate plays a non-negligible role in the categories ionising radiation (37%), ozone depletion (26%) and use of material resources (25%). The pre-filtration membrane, the end-of-life of the multifluidic system and transport processes play no role in the results.

Within the iMERMAID scenario, 46% of the electricity consumption occurs for the first and second stage treatment, followed by the multifluidic system (27%) and the pre-treatment (26%)

Detailed characterised results can be found in Table 57.

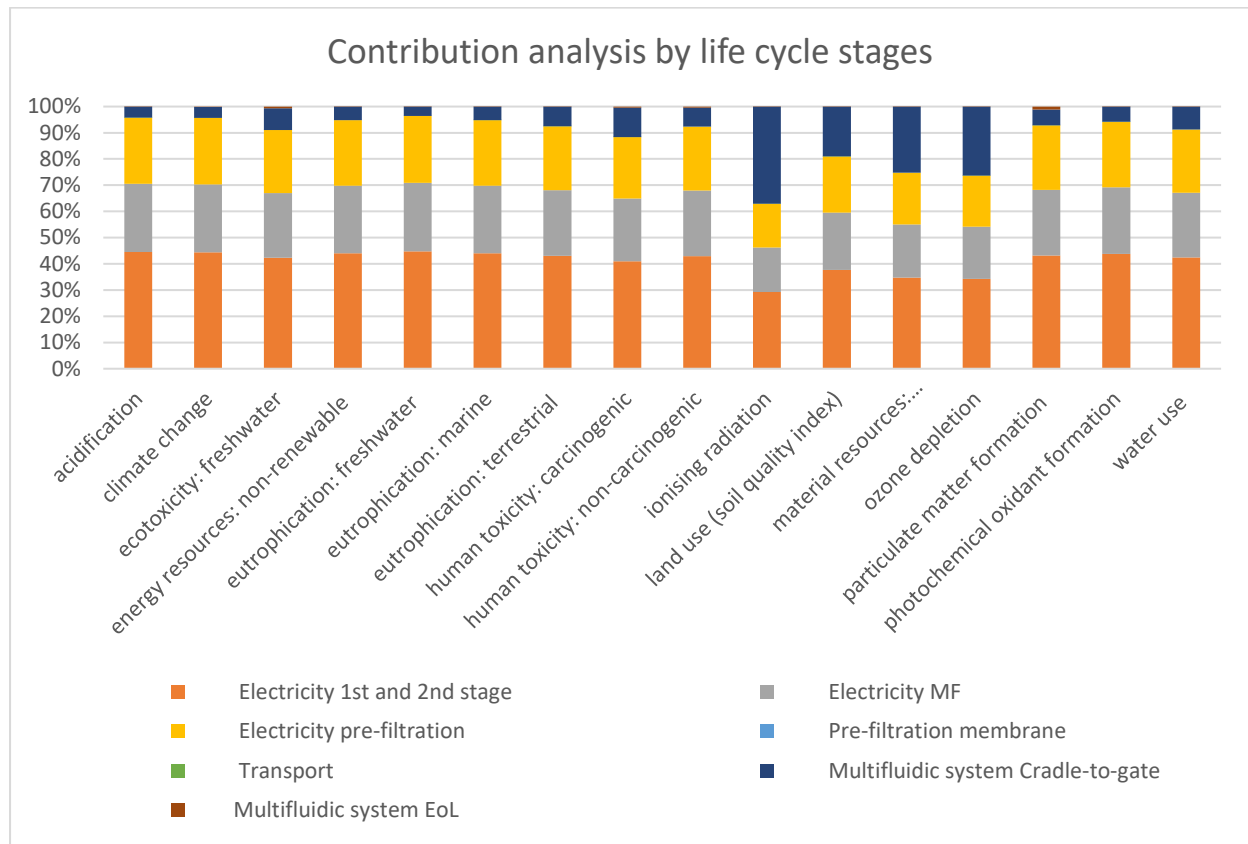


Figure 33: Characterized results for the life cycle environmental impacts of the iMERMAID scenario per m³ of water treated

Concerning the total environmental footprint, the normalised and weighted results show a total impact of 175 μ Pt per m³ of water treated. The dominating impact is climate change (33%), followed by freshwater eutrophication and non-renewable energy resources (23% and 22%, respectively). Electricity consumption is responsible for 90% of all normalized and weighted impacts. Figure 34, Table 58 and Table 59 illustrate.

the

results.

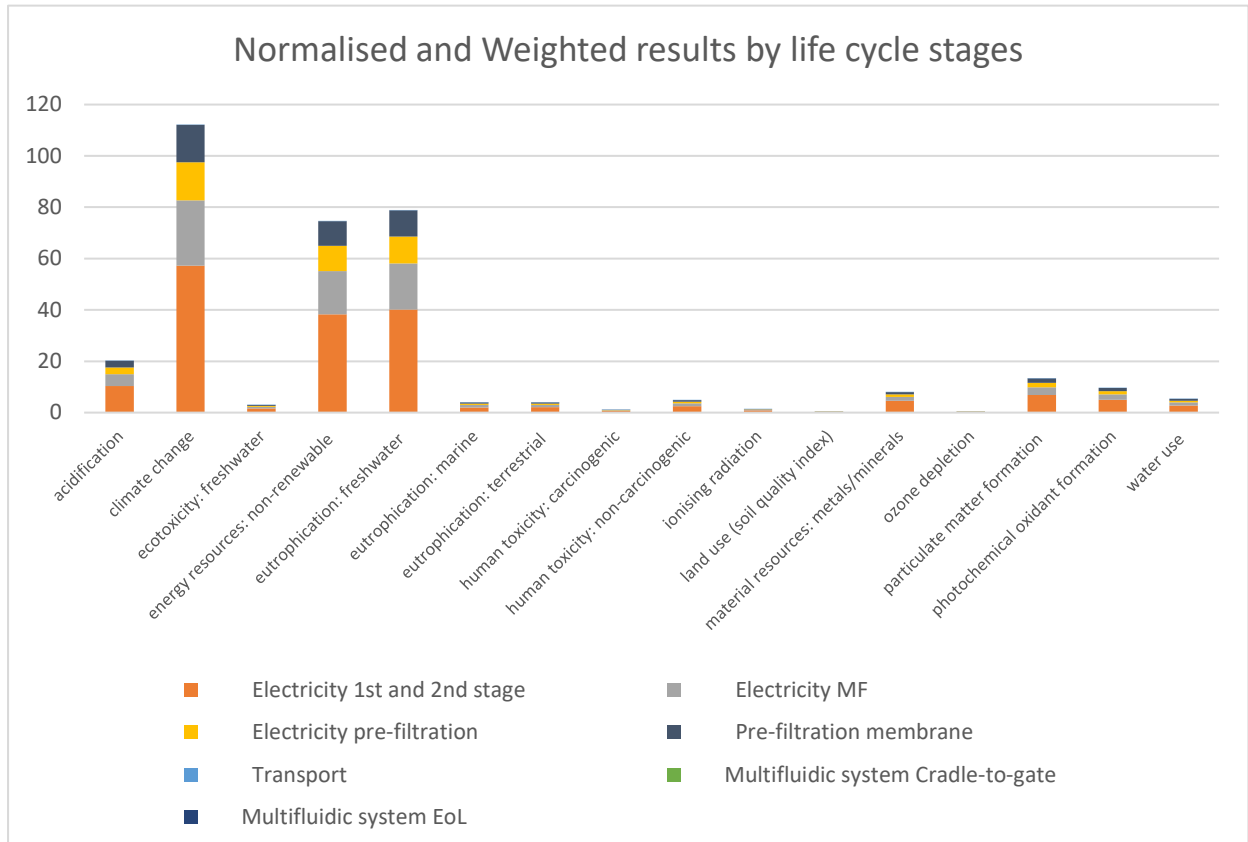


Figure 34: Normalized and weighted results for the life cycle environmental impacts of the iMERMAID scenario per m3 of water treated

3.4.4.3 Cradle-to-grave results – Alternative improvement scenario

An alternative improvement scenario was analysed for UC5, following ESDAK’s wish to analyse the impacts of an alternative to the baseline scenario that is already in place as one of the two parallel pathways presented and analysed in the baseline scenario. It consists of the sole use of Reverse Osmosis (RO2),

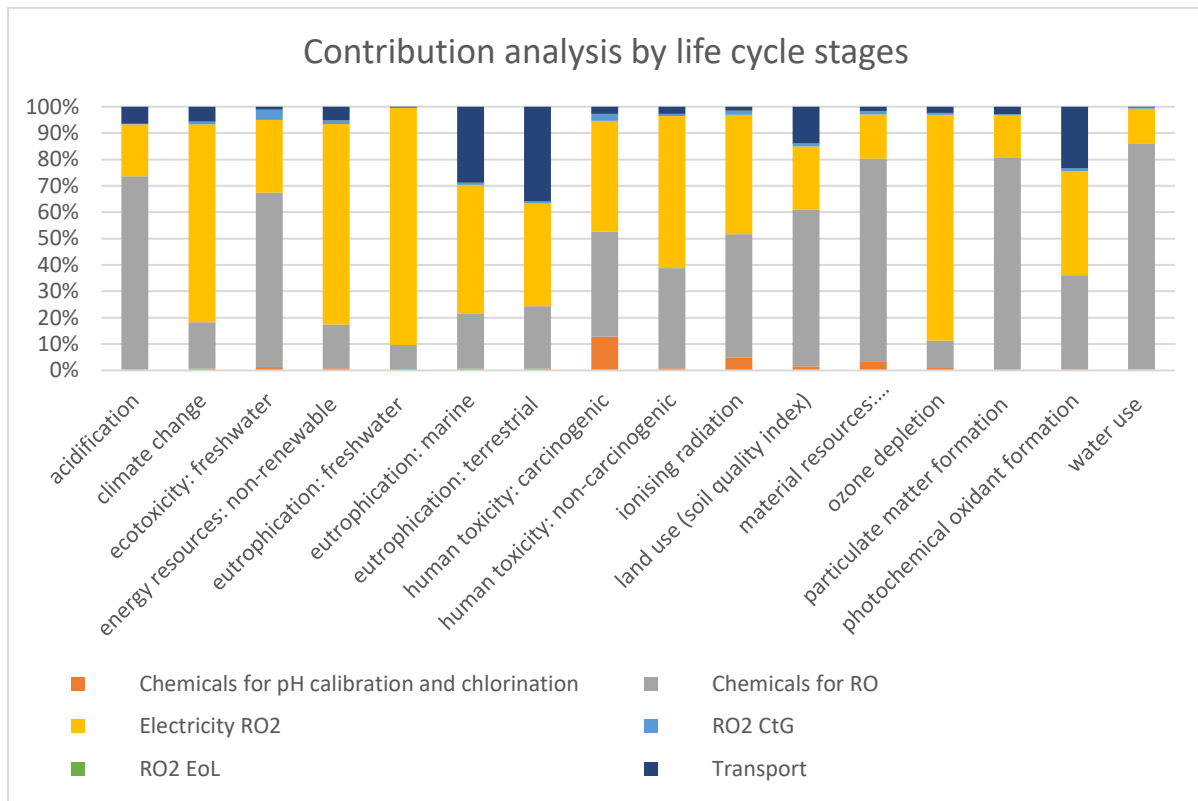


Figure 35: Characterised results for the life cycle environmental impacts of the Alternative improvement scenario per m³ of water treated

The total environmental footprint is 701 $\mu\text{Pt}/\text{m}^3$, mainly driven by climate change (22%), acidification (15%), non-renewable energy resources (14%), freshwater eutrophication (13%) and particulate matter formation (12%). As emerged in the contribution analysis above, electricity and chemicals are the main drivers of the total impact (51% and 42%, respectively), followed by transport processes (5%). Chemicals for pH calibration and chlorination, RO2 cradle-to-gate and RO2 end-of-life have no significant total impact (below 1%).

The results are displayed in Figure 36 and detailed in Table 61 and Table 62.

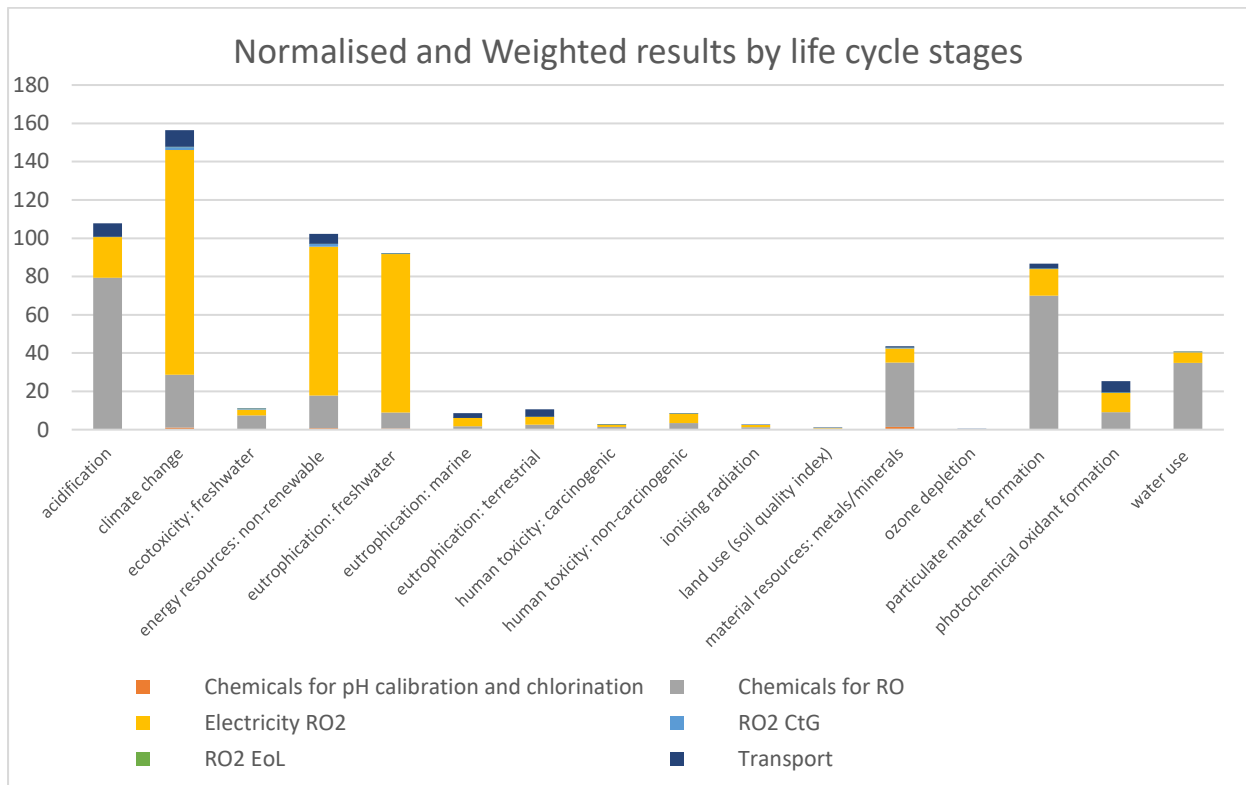


Figure 36: Normalized and weighted results for the life cycle environmental impacts of the Alternative improvement scenario per m3 of water treated

3.4.5 Comparative analysis of the LCA results of baseline, iMERMAID and alternative improved scenario

The results indicate that the iMERMAID scenario consistently achieves the lowest impacts among the three scenarios, followed by the Alternative improvement scenario (see **¡Error! No se encuentra el origen de la referencia.**).

Table 13: Comparison of the baseline scenario (operation of the ESDAK leachate treatment plant), the iMERMAID scenario and the Alternative improvement scenario.

Impact category	Baseline scenario	iMERMAID scenario	Alternative improvement scenario	iMERMAID scenario vs. baseline scenario	Alternative improvement scenario vs. iMERMAID scenario	iMERMAID scenario vs. alternative improvement scenario	unit
Acidification	128.5	10.3	107.8	-92 %	-16 %	-90 %	μPt
Climate change	298.1	57.3	156.4	-81 %	-48 %	-63 %	μPt
Ecotoxicity: freshwater	14.7	1.6	11.1	-89 %	-25 %	-86 %	μPt
Energy resources: non-renewable	196.2	38.3	102.3	-80 %	-48 %	-63 %	μPt
Eutrophication: freshwater	192.9	40.1	92.2	-79 %	-52 %	-56 %	μPt
Eutrophication: marine	13.5	2.1	8.6	-85 %	-37 %	-76 %	μPt
Eutrophication: terrestrial	15.4	2.1	10.6	-86 %	-31 %	-80 %	μPt
Human toxicity: carcinogenic	4.2	0.6	2.8	-85 %	-33 %	-78 %	μPt

Human toxicity: non-carcinogenic	14.6	2.5	8.7	-83 %	-41 %	-71 %	μPt
Ionising radiation: human health	3.9	0.8	2.5	-78 %	-35 %	-66 %	μPt
Land use	1.3	0.1	1.0	-89 %	-23 %	-86 %	μPt
Material resources: metals/minerals	51.0	4.6	43.6	-91 %	-14 %	-90 %	μPt
Ozone depletion	0.6	0.1	0.3	-73 %	-51 %	-46 %	μPt
Particulate matter formation	99.4	6.9	86.6	-93 %	-13 %	-92 %	μPt
Photochemical oxidant formation: human health	36.9	5.0	25.4	-87 %	-31 %	-80 %	μPt
Water use	45.4	2.8	40.7	-94 %	-10 %	-93 %	μPt
Total	1116.4	175.2	700.6	-84 %	-37 %	-75 %	μPt

Across all midpoint categories, the iMERMAID scenario reduces impacts relative to the baseline by 73% to 94%. The highest relative reductions are observed for water use (-94%), particulate matter formation (-93%), acidification (-92%), and material resources: metals/minerals (-91%), while ozone depletion shows the smallest, though still substantial, reduction (-73%). The alternative improvement scenario also performs better than the baseline, but its reductions are more limited, ranging from 10% to 52% depending on the impact category. When directly compared with the alternative improvement scenario, the iMERMAID scenario still shows markedly lower impacts in every category, with additional reductions between 46% and 93%.

Given the contaminants of concern analysed in UC5 and their impact on freshwater ecotoxicity, the related performance in the different scenario, i.e. the specific ecotoxicity footprint, is particularly relevant for contextualizing the benefits of the iMERMAID scenario. Freshwater ecotoxicity decreases from 14.7 μPt in the baseline to 1.56 μPt in the iMERMAID scenario, corresponding to an 89% reduction. To a lesser extent, a remediation effect with respect to freshwater ecotoxicity can be seen also in the Alternative improvement scenario (-25%). These findings indicate that the iMERMAID scenario not only lowers the total environmental footprint but also provides strong improvements in the category that is most closely linked to the remediation objectives.

3.4.6 Water quality footprint and handprint

This section analysis and contextualises the environmental benefits associated with implementation of the microfluidic system by juxtaposing them to the water quality footprint of the iMERMAID scenario. The water footprint and handprint assessment focus on freshwater ecotoxicity, as Bisphenol A, Bentazone, Propamocarb and PFOA, identified in UC5 as the principal contaminants of concern and measured during the pilot, are relevant contributors to this impact category. The Alternative improvement scenario was not accounted for in this analysis, but

The following three key metrics are considered:

- 1 The remediation performance of the technology, i.e., the difference between the environmental impacts of the contaminants detected in the treated leachate without and with the application of the multifluidic system.
- 2 The water ecotoxicity footprint by life cycle stage, calculated as one of the 16 impact categories of the LCA using the EF 3.1 method.
- 3 The ecotoxicity handprint, which is calculated by subtracting the ecotoxicity footprint from the remediation potential.

The remediation performance reflects only the technical effectiveness of the technology. In contrast, the handprint also accounts for the trade-offs between local water pollution reduction and specific environmental impacts occurring elsewhere in the life cycle (the water quality footprint with focus on freshwater ecotoxicity), allowing both effects to be assessed together.

The remediation performance calculation is based on the pollutant concentration at the inlet of the microfluidic system (after the pre-treatment) and at its outlet (after the treatment via microfluidic system). The values for the inlet and outlet concentrations for Bisphenol A, Bentazone and Propamocarb were measured on 11th March 2026. The date was selected following EDEN’s suggestion, since no artefacts (e.g., higher outlet than inlet CoC concentration) could be detected in the laboratory results. PFOA was not accounted for because none of the dates, in which measurements took place, values for both the inlet and the outlet concentration were available.

Table 14 shows the emissions inventory used to calculate the remediation performance. It displays the concentration of the contaminants of concern bisphenol A, bentazone and propamocarb at the microfluidic system inlet and outlet, the total removal at inventory level, and the remediation performance expressed as (prevented) ecotoxicity impact in CTUe/m³.

On the inventory level, the pollutants concentration reduction was 25% for Bisphenol A, 24% for Bentazone and 22% for Propamocarb. In total, the removed metal mass was composed to 99% by Bisphenol A.

After characterisation, the total remediation performance amounts to 5.19 CTUe/m³. Given the divergencies in the severity of the ecotoxicity impact brought about by the three contaminants of concern, reflected in the different orders of magnitude of the characterisation factors for Bisphenol A (5169 CTUe/kg), Bentazone (1470.3 CTUe/kg) and Propamocarb (424.62 CTUe/kg), Bisphenol A dominated also the figures on the remediation performance (Figure 37A).

Table 14: Data for the calculation of the Microfluidic system remediation performance: Inventory data, characterisation factors and freshwater ecotoxicity impact results

CoC	Treatment stage	Concentration (µg/L)	Removal (kg/m ³)	CF freshwater ecotoxicity (CTUe/kg)	Remediation performance (CTUe/m ³)
Bisphenol A	Microfluidic inlet system	6601	0.001005	5160	5.19
	Microfluidic outlet system	5052			
Bentazone	Microfluidic inlet system	4.7	0.0000016	1470.3	0.00235
	Microfluidic outlet system	3			
Propamocarb	Microfluidic inlet system	16	0.0000056	424.62	0.00238
	Microfluidic outlet system	10.4			
Total	Microfluidic inlet system	6621.7	0.0010122		5.19
	Microfluidic outlet system	5065.4			

Juxtaposing the remediation performance by water treatment stage to the water footprint by technology reveals that the freshwater ecotoxicity impact occurring for the current ESDAK treatment is about twice

as high as the ecotoxicity impact caused by Bisphenol A, Bentazone and Propamocarb in water (see Figure 37).

The implementation of the microfluidic system at the ESDAK leachate treatment plant brings about a reduction of the total freshwater ecotoxicity impact linked to the system. First, the treatment itself leads to a total inlet-to-outlet reduction (remediation performance) of 25% (Figure 37A). Second, the cradle-to-gate freshwater ecotoxicity footprint of the treatments decreases by 89% (Figure 37B). Third, the remediation impacts of the multifluidic system outweigh the additional footprint due to the multifluidic system production, transportation, end-of-life and electricity consumption, thus leading to a handprint of 15%. For this use case, the *footprint without multifluidic system* taken into account for the handprint calculation refers to the first and second treatment stage, which represents the inlet of the microfluidic system, and is the only reference system for which contaminants concentration data has been collected in parallel to the outlet data. For the future, an additional analysis could be carried out measuring on the same day the contaminants concentration also for the baseline scenario, i.e. placing detector before and after RO1 and RO2. Given the variable contaminants concentration of the leachate, the contemporary measurements at all 4 measurements points (before and after the multifluidic system, before and after the RO1) are highly recommendable.

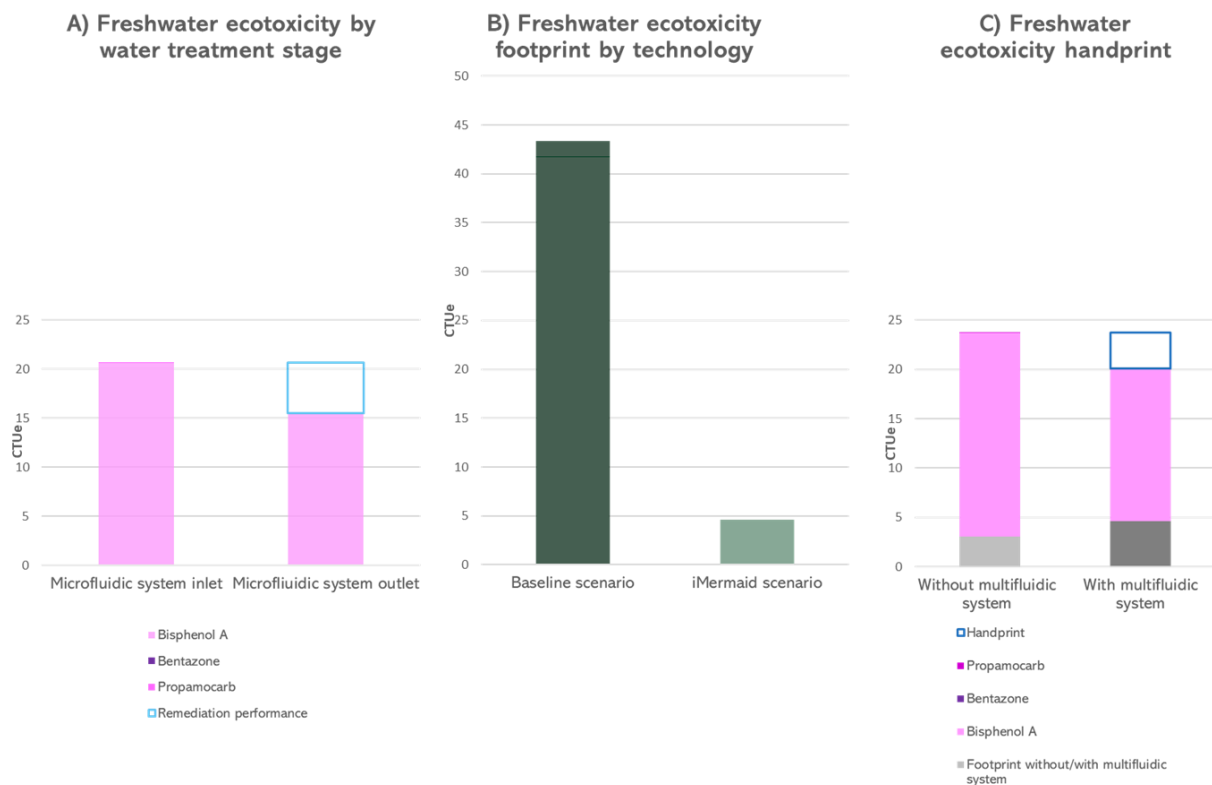


Figure 37: A) Freshwater ecotoxicity impact caused by the contaminants in the leachate, at inlet and outlet; B) Freshwater ecotoxicity footprint by technology used; C) Freshwater ecotoxicity handprint.

4.0 Discussion and conclusions

4.1 *Identification of Environmental Hotspots*

The baseline scenarios across the iMERMAID Use Cases reveal that the primary environmental hotspots are consistently linked to operational electricity consumption and, where measured, to direct emissions. In conventional wastewater/leachate treatment plants (WWTPs), electricity demand not only dominates in most cases the climate change and resource depletion impact categories, but also indirectly drives water use, freshwater ecotoxicity, and eutrophication impacts through upstream emissions in the energy supply chain. For example, in UC1 and UC2, more than 85% of the total weighted environmental impacts are attributable to electricity use for biological treatment processes, with sludge management representing a secondary but notable contributor—especially for categories such as acidification, land use, and human toxicity. In UC5, a 70% share is attributable to electricity, followed by the chemicals used for RO pretreatment and membrane cleaning (25%).

In the iMERMAID scenarios, the integration of advanced treatment technologies, such as Pulsed Discharge Plasma (PDP), bioinspired microfluidic reactors, recycled RO membrane pre-filtration, and 4D Scavenger, introduce additional, but limited environmental burdens. Life Cycle Assessment (LCA) results indicate that the cradle-to-gate impacts of these technologies are primarily associated with the production of high-purity materials (e.g., electronics-grade silicon, LEDs, and polymers), component manufacturing, and transport. For example, the ENIG pre-filtration unit's water use impact is dominated by the regeneration of reclaimed RO membranes, while the 4D Scavenger's environmental footprint is driven by the ion exchanger, reactor piping, and electricity for 3D printing.

Though interesting under the perspective of sustainable manufacturing and purchase management, the cradle-to-gate impacts of the technologies is, from an environmental viewpoint, mainly negligible if compared to the use phase. This shows the highest relative impact in all cases. Use phase electricity represents 99% of environmental impacts in UC1 and UC3, 35% in UC2, and 90% in UC 5.

Considering the different scenarios in comparison, the iMERMAID scenario presents an increase of environmental footprint by 38% (UC1), 178% (UC2), and 52% (UC3), because in these cases the advanced treatment technology was utilised in addition to the existing plant. The only case of partial process substitution is UC5, in which reverse osmosis is substituted by the multifluidic system, thus leading to a reduction of electricity consumption during use. This results in a total environmental footprint reduction of 84%.

Downstream benefits such as reduced chemical emissions and improved effluent quality were showed based on the environmental impact related to the contaminants of concern identified for each case studies and measured during the pilots. On this basis, the water ecotoxicity footprint and handprint were calculated for each use case.

All Use Cases showed a notable reduction of contaminants concentration: 100% in UC1, 95% for UC3, 25% for UC5 and between 75% and 96% for UC2 (88% for diclofenac, 75% for ketoprofen, and 96% for ibuprofen).

The Freshwater ecotoxicity handprint amounts to 0.44 CTUe/m₃ (UC1), 639.17 CTUe/m₃ (UC2), 1.01 CTUe/m₃ (UC3) and 3.64 CTUe/m₃ (UC5). The differences in order of magnitude between the use cases are related to the high initial contaminant concentration detected in UC2. Still, the normalised and weighted LCA results of the iMERMAID scenarios highlight that Freshwater ecotoxicity has, in all Use Cases, a share of 1% to 2% of the total environmental impacts. This shows that the use of wastewater treatment technologies on the one end remediates water pollution, on the other hand is responsible for

environmental trade-off such as climate change or the use of fossil resources, strongly linked to the energy systems in place in the countries where the pilots took place.

All in all, the piloted technologies either were successful in contaminants remediation during the pilot (UC1 and UC2), have been successful in other pilots, whose results were taken as a basis for the simulation of the iMERMAID scenario (UC3) or were successful on some of the days in which the measurements took place (UC5). For more details, the related deliverable can be consulted (*D4.3 - Report on the demonstration activities in San Esteban de Litera (Huesca, Spain), Limassol (Cyprus), Turin (Italy), Crete (Greece), Kalaat Al Andalouss (Tunisia)*).

It should be noted that the handprint depends among others on the initial contaminant concentration. If this is low, despite a high percentual remediation performance, the benefits of the technology do not outweigh the footprint as strongly as in cases with a higher inlet concentration.

4.2 Data and Methodological Limitations

The assessment is based in state-of-the-art LCA practice, following the scoping and modelling principles that had proved viable in published case studies (e.g., the volumetric functional unit, see section 2.4), and using robust primary data from technology developers and plant operators.

The whole life cycle of the wastewater treatment technologies is accounted for, including the end-of-life phase where possible, seldom assessed in available studies. The results justify the existing cut-offs (see section 2.4), since the impact is negligible if compared to other life cycle stages. A further novelty is represented by the impact assessment method used. Different than in the studies analyzed in the State of the Art (section 2.4.), which see a prevalent application of the ReCiPe impact assessment method to wastewater treatment technologies, EF 3.1 was applied here. This is a first step to bridge the existing gap between academic practice and policy requirements, to ensure consistency with EU Commission Recommendation 2021/2279 on the use of the Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and organisations, and comparability with related initiatives.

Despite these advances, several limitations should be acknowledged. First, the system boundaries exclude the construction and dismantling of existing WWTP infrastructure, focusing instead on operational phases and the life cycle of the new technologies. Second, background datasets (e.g., Ecoinvent, EPDs) may not fully reflect local geographic or technological conditions, introducing uncertainty in inventory modelling. Third, pilot-scale data is used for the innovative technologies, which may not capture scale-up effects or long-term operational performance. Fourth, the evaluation of for the environmental impacts caused by emerging contaminants, might be constrained by the availability of characterization factors and the representativeness of default emission factors. Finally, the use of normalization and weighting in the EF method involves value choices that, while policy-aligned, may influence the prioritization of impact categories. These limitations are transparently documented to support appropriate interpretation and highlight areas for future dataset development and methodological refinement.

Most importantly, regarding the application of the handprint method in the different case studies it should be noted that the part of the system considered and the comparison possibilities depend on the position of pollutant detectors in the different use cases. This fact, together with the differences in targeted CoCs, inlet concentrations and technologies, make any comparison between the different use cases or to the effectiveness of other technologies impossible at this stage.

4.3 Evaluation of implementation and technology implementation and trade-offs

Besides the life cycle assessment and water footprint and handprint results, the success of the wastewater treatment technology implementation actions in the dedicated use cases were evaluated via a questionnaire over the course of dedicated implementation discussions. The discussion was carried out with the relevant representatives of UC1 (Aqlara and IRIS), UC2 (EDEN, ENIG and Opalia) and UC3 (Weeefiner and SMAT). The interviews took place in April and May 2026.

Before the discussion, the results presented in D1.4 (LCA, water footprint and water handprint) and those presented in D3.5 (life cycle costing) were shared with the partners and formed, along with the participants' technical expertise and experience in the project and beyond, the foundation for the implementation assessments. No discussion was carried out with UC5 partners given the timing of the pilot and the consequent late data and result availability. The results of the evaluation discussions contribute to the assessment of **KPI 1.4: At least 3 no-regret, low-regret and win-win adaptation actions implementations discussion.**

The thematic areas of the discussions were the validation of LCA and LCC results, the perceived implementation value, the confidence in future performance, the adoption conditions, the perceived trade-offs, the strategic and regulatory expectations, replicability and scalability, and the overall regret level. The participants were invited to rate, over the course of the discussions, each sub-topic between -2 and +2, whereby:

- -2: high-regret
- -1: low-regret
- 0: no-regret
- +1: benefits in specific areas
- +2: win-win/benefits in several areas

The 17 assessment statements utilized in the interviews and their specification are displayed in Table 1.

Table 15: Assessment statements utilized in interviews to assess the implementation benefits, regrets and trade-offs

Topic	Assessment statement
Validation of LCA and LCC results	The LCA and LCC results are sufficiently clear to support a discussion on implementation potential, expected benefits, and possible trade-offs.
Perceived implementation value	The technology has practical value beyond the experimental demonstration.
Perceived implementation value	The added treatment step addresses a relevant problem for Socamex or similar wastewater contexts.
Perceived implementation value	If similar performance were achieved at operational scale, the solution would be worth implementing.
Confidence in future performance	The technology is expected to perform reliably under real operating conditions.
Confidence in future performance	The technology is mature enough to be considered for practical implementation.

Adoption conditions	The solution has a clear adoption driver, such as regulation, environmental strategy, client pressure, technical reliability, or cost-related value.
Adoption conditions	The solution can be operated in a way that fits the production pattern, for example continuously, campaign-based, or targeted during specific production periods.
Adoption conditions	The implementation can be considered a low-regret option under realistic use-case conditions.
Perceived trade-offs	The additional costs are acceptable considering the expected benefits.
Perceived trade-offs	The additional environmental impacts is acceptable considering the expected benefits.
Perceived trade-offs	The maintenance requirements are acceptable considering the expected benefits.
Perceived trade-offs	The overall trade-offs are manageable and do not undermine the implementation potential.
Strategic and regulatory expectations	Early adoption would represent a strategic advantage rather than an unnecessary risk.
Replicability and scalability	UC1 has potential to serve as a model for other similar wastewater contexts.
Replicability and scalability	Replication in other sites is feasible under realistic technical and operational conditions.
Partner perception of regret level	Overall, the implementation can be classified as high-regret, low-regret, no-regret, benefits in specific areas, or win-win.

Across the three use cases, the interviews indicate an overall positive implementation outlook, with no partner assigning negative scores in any case. UC1 received the strongest and most consistent support, with almost all ratings at +2 and only a few +1 scores, indicating that the technology is broadly perceived as a win-win option with manageable trade-offs and strong replication potential. UC2 was also clearly positive, but more moderate: most scores fell between +1 and +2, with a few 0 ratings related mainly to technology maturity and confidence in practical implementation, suggesting a promising but still somewhat cautious view. UC3 showed the most conservative profile, with a mix of 0, +1 and +2 scores; the technology was seen as valuable in selected contexts rather than universally compelling, especially because its relevance appears strongest for industrial sites or settings with high heavy-metal loads. Overall, the interviews support the interpretation that all three implementation actions can be considered no-regret to win-win options, although the strength and breadth of perceived benefits differ by use case.

According to the evaluation performed by the partners, UC1 appears as the strongest and most consistent case, despite the implementation difficulties encountered over the course of iMERMAID. It was rated as a clear win-win by both partners, with only minor differences in scoring, with the technology provider showing slightly higher confidence in future performance and adoption conditions.

UC2 partners rated the implementation as providing benefits in specific areas rather than as a full win-win. Its main strength is the strategic relevance for pharmaceutical wastewater. At the same time, maturity, real-world performance, and broader replication are rated cautiously positively.

According to partners' rating, UC3 appears as the most context-dependent case. Its defining feature is relevance for industrial sites or wastewater streams with high heavy-metal loads, while its broader applicability to wastewater treatment plants in general was viewed more cautiously.

Several common patterns emerge from the interviews. First, none of the partners perceived the technologies as high-regret or low-regret options. The overall scores ranged between +1 and +2, with individual topics rated in exceptional cases at 0. Second, operational compatibility and replication feasibility were among the strongest dimensions across use cases, indicating that implementation discussions linked to real-world operating conditions, in line with the technologies' TRL improvement. Third, the main source of caution was not whether the technologies solve relevant problems, but rather how broadly and under which conditions they should be implemented. This is especially evident in UC2, where the perception of maturity and confidence varied, and in UC3, where benefits are clearly stronger in specific industrial contexts than in wastewater treatment plants generally.

Based on these results, **KPI 1.4 can be considered reached**. Implementation discussions for at least three actions were carried out, and all three assessed UCs can reasonably be assessed positively, between no-regret and win-win. Moreover, the interviews provided room for discussion after the pilots, on the basis of quantitative environmental and cost assessment results. Still, it needs to be highlighted that the semi-quantitative rates are based on the personal perception of individuals and are not meant to be used as a basis for the comparison of technological solutions.

4.4 Alignment with EU Policy Goals

The Sustainability assessment has the potential to demonstrate how far the iMERMAID project aligns with the objectives of key EU environmental policy frameworks, as detailed in Table 1. By targeting the removal of priority substances—including pharmaceuticals, pesticides, and heavy metals—the project supports the implementation of the EU Zero Pollution Action Plan, the Marine Strategy Framework Directive, the Water Framework Directive, Convention for the protection of the Mediterranean Sea against pollution and the Chemical Strategy for Sustainability and the Urban Wastewater Treatment Directive (2024/3019).

. The results show that the deployment of modular, low-energy treatment systems, real-time monitoring tools, and circular resource solutions directly contributes to the reduction of pollutant loads in Mediterranean waters, the prevention of pollution at source, and the achievement of Good Environmental Status (GES) as mandated by the MSFD. Furthermore, the choice of the Environmental Footprint (EF) 3.1 method for the impact assessment phase ensures compatibility with EU guidance for measuring and communicating environmental performance, while its integration of water handprint concepts addresses gaps in current policy-oriented assessments.

4.5 Conclusions

This report presents a comprehensive sustainability assessment of the advanced wastewater treatment technologies developed and demonstrated within the iMERMAID project, with a focus on their environmental performance across the assessed Use Cases. The results show that the innovative treatment systems can provide clear remediation benefits for contaminants of concern. At the same time,

these benefits must be interpreted together with the additional burdens introduced by technology manufacturing and operation.

Across the assessed cases, the main environmental hotspots are consistently linked to electricity consumption during operation, and in some cases also to chemical use, direct process emissions, and sludge management. In the baseline systems, electricity demand is the dominant contributor to climate change and fossil resource use. In the iMERMAID scenarios, the added treatment steps generally increase the environmental burden because they introduce additional electricity demand and, depending on the technology, material- and component-related impacts. At the same time, the cradle-to-gate impacts of the innovative devices themselves are generally modest compared with the use-phase burdens, although specific components such as electronic parts, high-purity materials, and instrumentation can be relevant for categories such as resource use, freshwater ecotoxicity, and water use.

The interpretation of these results must also consider the data and methodological limitations of the study. The assessment is based on pilot-scale demonstrations, integrated by iMERMAID partners' estimate on e.g. electricity consumption in a large-scale setting. Therefore, the results do not necessarily represent full-scale commercial operation. Background datasets do not always fully reflect local production conditions, and several assumptions were required for operational parameters, end-of-life treatment, and the modelling of novel or custom-made components. In addition, the handprint assessment is constrained by the availability of monitoring data, characterization factors, and substance-specific concentration data. For these reasons, the results should be understood as a robust hotspot-oriented assessment rather than as a definitive prediction of future large-scale environmental benefits. Future work should therefore focus on improving foreground data quality, refining energy and chemical inventories, and reassessing the systems under scaled-up and optimized operating conditions.

Despite these limitations, the assessment provides results that are highly relevant in relation to EU environmental policy goals. The iMERMAID technologies contribute to the objectives of the EU Zero Pollution Action Plan, the Water Framework Directive, the Marine Strategy Framework Directive, the Chemical Strategy for Sustainability, and the broader goal of reducing pollutant emissions from land-based sources to Mediterranean waters. The study shows that advanced treatment technologies can contribute to pollution prevention and improved water quality; while also making visible the trade-offs associated with energy and material use. In this sense, the sustainability assessment supports policy-relevant decision-making by identifying where technological innovation contributes to contaminant removal and where further eco-design improvements are needed to reduce indirect environmental burdens.

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Technical Note I: Note on updated electricity consumption data for the IRIS PDP system in Use Case 1

The environmental assessment of Use Case 1 was developed using the electricity consumption value for the IRIS PDP system that had been previously shared and applied consistently in the modelling of the iMERMAID scenario. The value used in the report was approximately 9 to 10 kWh/m³, in line with the information available during the development of the study and used in the LCA calculations for the PDP operation phase.

At the final stage of report preparation, IRIS communicated an updated electricity demand of approximately 2.4 kWh/m³ for the PDP system. This revised value is about one quarter of the electricity consumption previously used in the assessment. Due to the timing of this clarification, and in the absence of sufficient time for validation and full recalculation, the updated figure could not be incorporated into the LCA, handprint, or comparative scenario results presented in the current version of the report.

This update is environmentally relevant because electricity consumption is a significant contributor to the impact profile of the IRIS-based iMERMAID scenario. Under the value currently used in the report, IRIS electricity consumption accounts for about 27.7% of the total weighted environmental impact of the scenario. If the updated electricity demand were applied as a simple proportional adjustment, the contribution of IRIS electricity consumption would decrease to about 8.7%, and the total weighted impact would decrease from 9.04E+02 μPt to 7.17E+02 μPt. A similar reduction pattern is observed across impact categories, with the IRIS electricity contribution decreasing from about 27 to 28% to about 8 to 9%, depending on the category.

This means that the current report is likely conservative with respect to the burden associated with PDP operation, and that the LCA results for the iMERMAID scenario are expected to overestimate the contribution of IRIS electricity use to the overall environmental profile. At the same time, the updated value does not invalidate the overall interpretation of the assessment. The iMERMAID scenario would still include the manufacture, operation, and end-of-life of an additional treatment technology, and would therefore remain associated with an additional environmental burden relative to the baseline. What changes is primarily the magnitude of the burden attributed to the PDP operation phase, not the general interpretation of the use case.

This point is particularly relevant in light of the handprint assessment. The handprint was developed to quantify the positive environmental effect associated with the removal of substances of concern from the treated effluent, independently of the burdens captured in the LCA. A reduction in the electricity demand of the PDP system would decrease the environmental burden associated with delivering this treatment function, while not affecting the pollutant-removal benefit itself unless treatment performance assumptions were also revised. In this sense, the updated IRIS value would improve the balance between environmental burden and remediation benefit and would support a more favourable interpretation of the PDP system than the one currently reflected in the report.

These updated values should be regarded as indicative only, since no full recalculation of the integrated environmental assessment was carried out. A proper update would require the consistent revision of all affected LCA results, including the use-phase contribution analysis, the handprint assessment, and the comparison between baseline and iMERMAID scenarios. The purpose of this note is therefore to transparently document the discrepancy between the value used in the report and the updated information shared by IRIS after the environmental analyses had already been completed.

Annex I Use Case 1: Secondary datasets used and results

Table 16: Material, process and transport datasets and assumptions used for modelling UC1 baseline scenario.

Datasets used for baseline scenario, Socamex	Input/output	Selected material/process dataset	Transportation distance [km]	Selected transport dataset
Electricity	Input	Ecoinvent: market for electricity, low voltage, ESP		
Sludge treatment	Output	Ecoinvent: treatment of sewage sludge, 75% water, WWT, WW, average, sanitary landfill, RER		
Direct emissions	Output	Calculations for methane (CH ₄) and nitrous oxide (N ₂ O) are based on data provided by Socamex for 2024 and follow the IPCC methodology.		

Table 17: Material, process and transport datasets used for 116modelling UC1 iMERMAID scenario, IRIS cradle-to-gate.

Datasets used for IRIS, cradle-to-gate	Input/output	Selected material/process dataset	Transportation distance [km]
Metals	Input	Aluminium oxide, non-metallurgical	
Metals	Input	Manganese(III) oxide	
Metals	Input	Zirconium oxide	
Metals	Input	Cobalt oxide	
Metals	Input	Copper, cathode	
Metals	Input	Nickel, class 1	
Metals	Input	Silver	
Metals	Input	Tin	
Metals	Input	Zinc	
Electronics / Electrical	Input	Cathode, LiMn ₂ O ₄ , for Li-ion battery	

Electronics / Electrical	Input	Light emitting diode	
Electronics / Electrical	Input	Silicon, electronics grade	
Chemicals	Input	Epoxy resin	
Chemicals	Input	Ethylene glycol	
Composite material	Input	Glass fibre reinforced plastic, polyamide, injection moulded	
Polymer / Plastic	Input	Nylon 6-6	
Polymer / Plastic	Input	Polyethylene terephthalate, granulate, amorphous	
Polymer / Plastic	Input	Polycarbonate	
Polymer / Plastic	Input	Polypropylene, granulate	
Polymer / Plastic	Input	Silicone product	
Polymer / Plastic	Input	Polyoxymethylene	
Polymer / Plastic	Input	Polymethyl methacrylate, beads	
Transportation	Input	Transport, freight, sea, container ship	
Transportation	Input	Transport, freight, lorry, diesel, unspecified, RER	17,500
Electricity	Input	market for electricity, medium voltage; IT	226

Table 18: Characterized results for UC1 baseline scenario according to the Environmental Footprint method, version 3.1.

Characterised results UC1 Baseline scenario	Unit	Total	*UC1_Socamex_Operation_Before	Socamex__Electricity_Consumption	Sewage sludge treatment
Acidification	mol H+ eq	3.17E-02	1.41E-05	3.17E-02	7.63E-06
Climate change	kg CO2 eq	6.59E+00	4.09E-01	6.19E+00	3.78E-04
Climate change - Biogenic	kg CO2 eq	1.10E-02	0.00E+00	1.10E-02	1.08E-07
Climate change - Fossil	kg CO2 eq	6.54E+00	4.09E-01	6.13E+00	3.78E-04



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<i>Climate change - Land use and LU change</i>	kg CO2 eq	4.46E-02	0.00E+00	4.46E-02	6.84E-08
<i>Ecotoxicity, freshwater</i>	CTUe	1.80E+01	4.38E-03	1.79E+01	6.79E-02
<i>Ecotoxicity, freshwater - inorganics</i>	CTUe	1.48E+01	0.00E+00	1.47E+01	6.79E-02
<i>Ecotoxicity, freshwater - organics</i>	CTUe	3.20E+00	4.38E-03	3.20E+00	1.74E-05
<i>Particulate matter</i>	disease inc.	1.32E-07	3.99E-12	1.32E-07	4.98E-11
<i>Eutrophication, marine</i>	kg N eq	6.12E-03	7.39E-06	6.11E-03	8.74E-06
<i>Eutrophication, freshwater</i>	kg P eq	1.23E-03	0.00E+00	1.23E-03	3.49E-06
<i>Eutrophication, terrestrial</i>	mol N eq	6.28E-02	8.09E-05	6.27E-02	3.43E-05
<i>Human toxicity, cancer</i>	CTUh	2.34E-09	0.00E+00	2.34E-09	3.61E-12
<i>Human toxicity, cancer - inorganics</i>	CTUh	1.13E-09	0.00E+00	1.13E-09	3.57E-12
<i>Human toxicity, cancer - organics</i>	CTUh	1.21E-09	0.00E+00	1.21E-09	3.74E-14
<i>Human toxicity, non-cancer</i>	CTUh	4.88E-08	6.44E-10	4.72E-08	9.44E-10
<i>Human toxicity, non-cancer - inorganics</i>	CTUh	4.63E-08	0.00E+00	4.54E-08	9.44E-10
<i>Human toxicity, non-cancer - organics</i>	CTUh	2.42E-09	6.44E-10	1.78E-09	5.13E-14
<i>Ionising radiation</i>	kBq U-235 eq	5.41E+00	0.00E+00	5.41E+00	1.41E-06
<i>Land use</i>	Pt	1.87E+01	0.00E+00	1.87E+01	5.26E-04
<i>Ozone depletion</i>	kg CFC11 eq	1.37E-07	0.00E+00	1.37E-07	9.16E-13
<i>Photochemical ozone formation</i>	kg NMVOC eq	2.22E-02	1.57E-04	2.20E-02	1.10E-06
<i>Resource use, fossils</i>	MJ	1.69E+02	0.00E+00	1.69E+02	7.92E-04
<i>Resource use, minerals and metals</i>	kg Sb eq	1.59E-05	0.00E+00	1.59E-05	6.01E-10
<i>Water use</i>	m3 depriv.	4.03E+00	0.00E+00	4.03E+00	-1.02E-03

Table 19: Normalised results for UC1 baseline scenario according to the Environmental Footprint method, version 3.1

Normalized results UC1 Baseline scenario	Total	*UC1_Socamex_Operation_Before	Socamex__Electricity_Consumption	Sewage sludge treatment	Sewage sludge treatment
Acidification	5.71E-04	2.53E-07	5.71E-04	1.37E-07	1.37E-07
Climate change	8.73E-04	5.41E-05	8.19E-04	5.01E-08	5.01E-08
Ecotoxicity, freshwater	3.17E-04	7.72E-08	3.16E-04	1.20E-06	1.20E-06
Particulate matter	2.22E-04	6.70E-09	2.22E-04	8.37E-08	8.37E-08
Eutrophication, marine	3.13E-04	3.78E-07	3.12E-04	4.47E-07	4.47E-07
Eutrophication, freshwater	7.65E-04	0.00E+00	7.62E-04	2.17E-06	2.17E-06
Eutrophication, terrestrial	3.55E-04	4.58E-07	3.55E-04	1.94E-07	1.94E-07
Human toxicity, cancer	1.36E-04	0.00E+00	1.35E-04	2.09E-07	2.09E-07
Human toxicity, non-cancer	3.79E-04	5.01E-06	3.66E-04	7.34E-06	7.34E-06
Ionising radiation	1.28E-03	0.00E+00	1.28E-03	3.35E-10	3.35E-10
Land use	2.28E-05	0.00E+00	2.28E-05	6.42E-10	6.42E-10
Ozone depletion	2.62E-06	0.00E+00	2.62E-06	1.75E-11	1.75E-11
Photochemical ozone formation	5.43E-04	3.85E-06	5.39E-04	2.70E-08	2.70E-08
Resource use, fossils	2.60E-03	0.00E+00	2.60E-03	1.22E-08	1.22E-08
Resource use, minerals and metals	2.50E-04	0.00E+00	2.50E-04	9.44E-09	9.44E-09
Water use	3.52E-04	0.00E+00	3.52E-04	-8.91E-08	-8.91E-08

Table 20: Weighted results for UC1 baseline scenario according to the Environmental Footprint method, version 3.1

Weighted results UC1 Baseline scenario	Unit	Total	*UC1_Socamex_Operation_Before	Socamex__Electricity_Consumption	Sewage sludge treatment
Total	μPt	6.56E+02	1.17E+01	6.44E+02	2.66E-01
Acidification	μPt	3.54E+01	1.57E-02	3.54E+01	8.52E-03
Climate change	μPt	1.84E+02	1.14E+01	1.72E+02	1.05E-02
Ecotoxicity, freshwater	μPt	6.08E+00	1.48E-03	6.06E+00	2.30E-02
Particulate matter	μPt	1.99E+01	6.00E-04	1.99E+01	7.50E-03
Eutrophication, marine	μPt	9.27E+00	1.12E-02	9.25E+00	1.32E-02
Eutrophication, freshwater	μPt	2.14E+01	0.00E+00	2.13E+01	6.08E-02
Eutrophication, terrestrial	μPt	1.32E+01	1.70E-02	1.32E+01	7.21E-03
Human toxicity, cancer	μPt	2.89E+00	0.00E+00	2.89E+00	4.46E-03
Human toxicity, non-cancer	μPt	6.97E+00	9.21E-02	6.74E+00	1.35E-01
Ionising radiation	μPt	6.42E+01	0.00E+00	6.42E+01	1.68E-05
Land use	μPt	1.81E+00	0.00E+00	1.81E+00	5.10E-05
Ozone depletion	μPt	1.65E-01	0.00E+00	1.65E-01	1.10E-06
Photochemical ozone formation	μPt	2.59E+01	1.84E-01	2.58E+01	1.29E-03
Resource use, fossils	μPt	2.16E+02	0.00E+00	2.16E+02	1.01E-03
Resource use, minerals and metals	μPt	1.89E+01	0.00E+00	1.89E+01	7.13E-04
Water use	μPt	2.99E+01	0.00E+00	2.99E+01	-7.58E-03

Table 21: Characterized results for UC1 iMERMAID scenario, IRIS cradle-to-gate assessment

Characterized results UC1 IRIS cradle-to-gate	Unit	Total	Aluminum oxide	Cathode Li-ion battery	Zirconium oxide	Cobalt oxide	Copper	Epoxy	Ethylene glycol	Glass fibre	LED	Manganese oxide	Nickel	Nylon	Polyethylene	Polycarbonate	Polypropylene	Silicon	Silicone	Silver	Tin	Zinc	Polyoxymethylene	Polymer	Sea freight	Road freight	Electricity
Acidification	mol H+ eq	0.000162	1.74E-06	8.56E-08	1.65E-10	1.05E-07	4.50E-05	9.57E-07	5.70E-08	1.27E-07	2.58E-07	1.30E-08	1.21E-06	7.63E-07	1.04E-07	2.10E-05	1.01E-07	7.14E-05	2.60E-08	2.93E-08	2.87E-06	1.59E-07	1.48E-06	5.68E-06	8.25E-06	1.69E-07	1.57E-07
Climate change	kg CO2 eq	0.026159	0.000217	1.40E-05	2.27E-08	9.05E-06	0.000553	0.000212	1.29E-05	2.98E-05	4.21E-05	3.05E-06	1.06E-05	0.000175	2.40E-05	0.00464	2.47E-05	0.018308	5.05E-06	2.51E-06	0.000232	1.65E-05	0.000339	0.000886	0.000277	8.20E-05	4.39E-05
Climate change - Biogenic	kg CO2 eq	0.000151	1.05E-07	2.28E-08	3.39E-11	5.58E-08	1.55E-06	2.32E-07	2.01E-08	3.41E-08	7.47E-08	4.28E-09	3.13E-08	1.63E-07	3.53E-08	6.21E-06	3.37E-08	0.00014	5.91E-08	6.57E-09	5.63E-07	1.15E-07	5.30E-07	9.49E-07	4.97E-08	2.51E-08	5.18E-07
Climate change - Fossil	kg CO2 eq	0.025971	0.000217	1.39E-05	2.26E-08	8.93E-06	0.00055	0.000211	1.28E-05	2.98E-05	4.20E-05	3.05E-06	1.05E-05	0.000175	2.39E-05	0.00463	2.46E-05	0.018138	4.99E-06	2.50E-06	0.000231	1.63E-05	0.000338	0.000885	0.000277	8.19E-05	4.34E-05
Climate change - Land use and LU change	kg CO2 eq	3.67E-05	1.11E-07	2.96E-08	3.01E-11	6.20E-08	1.08E-06	1.40E-07	1.21E-08	7.80E-09	7.51E-08	4.36E-09	3.14E-08	8.51E-10	1.81E-08	4.16E-06	1.06E-08	3.00E-05	4.90E-09	4.20E-09	3.66E-07	6.59E-08	2.77E-07	1.95E-09	2.14E-07	3.76E-08	6.83E-09
Ecotoxicity, freshwater	CTUe	0.356493	0.00121	7.21E-05	1.17E-07	0.000166	0.051312	0.007491	3.52E-05	4.19E-05	0.00015	8.24E-06	0.000241	0.000188	8.09E-05	0.212947	6.53E-05	0.052543	4.85E-05	0.0002	0.006924	0.002602	0.016871	0.000951	0.001674	0.000585	8.49E-05
Ecotoxicity, freshwater - inorganics	CTUe	0.211877	0.000953	6.82E-05	1.10E-07	0.000155	0.051118	0.001967	3.30E-05	3.90E-05	0.000141	7.44E-06	0.000235	0.000147	7.11E-05	0.08736	6.09E-05	0.049932	4.73E-05	0.0002	0.006864	0.002597	0.006822	0.000825	0.001601	0.000565	6.99E-05
Ecotoxicity, freshwater - organics	CTUe	0.144615	0.000257	3.92E-06	7.04E-09	1.17E-05	0.000194	0.005524	2.26E-06	2.89E-06	8.85E-06	8.07E-07	6.26E-06	4.18E-05	9.85E-06	0.125587	4.46E-06	0.002611	1.27E-06	5.88E-07	5.97E-05	5.20E-06	0.010049	0.000126	7.36E-05	2.03E-05	1.50E-05
Particulate matter	disease inc.	1.03E-09	2.55E-11	9.45E-13	1.37E-15	1.19E-12	1.02E-10	8.57E-12	5.30E-13	1.73E-12	2.36E-12	1.15E-13	1.88E-12	7.62E-12	1.13E-12	2.18E-10	1.02E-12	5.42E-10	3.06E-13	1.93E-13	3.28E-11	8.11E-13	1.39E-11	5.04E-11	8.12E-12	5.13E-12	7.45E-13



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Eutrophication, marine	kg N eq	2.66E-05	2.63E-07	1.84E-08	3.43E-11	1.14E-08	2.19E-06	1.57E-07	1.10E-08	4.06E-08	5.06E-08	2.94E-09	2.04E-08	2.91E-07	2.00E-08	4.02E-06	1.93E-08	1.57E-05	5.14E-09	8.66E-09	6.66E-07	3.86E-08	2.78E-07	6.91E-07	2.06E-06	4.21E-08	2.68E-08
Eutrophication, freshwater	kg P eq	1.83E-05	8.80E-08	4.90E-09	1.21E-11	4.09E-09	3.53E-06	7.27E-08	3.44E-09	2.35E-09	2.19E-08	9.60E-10	9.33E-09	9.58E-09	4.81E-09	1.28E-06	4.17E-09	1.25E-05	1.25E-09	7.13E-09	5.71E-07	1.93E-08	1.01E-07	5.70E-08	9.22E-09	5.67E-09	6.90E-09
Eutrophication, terrestrial	mol N eq	0.00027	2.83E-06	1.57E-07	3.52E-10	9.70E-08	3.07E-05	1.66E-06	1.16E-07	2.16E-07	5.00E-07	3.12E-08	2.23E-07	1.46E-06	2.09E-07	4.13E-05	2.05E-07	0.000148	5.42E-08	1.07E-07	8.95E-06	4.06E-07	2.81E-06	6.39E-06	2.28E-05	4.26E-07	3.05E-07
Human toxicity, cancer	CTUh	2.44E-11	6.36E-13	1.29E-14	1.10E-17	1.19E-14	6.78E-12	5.05E-13	3.92E-15	4.83E-15	1.49E-14	8.95E-16	2.37E-14	1.85E-14	9.25E-15	6.21E-12	5.40E-15	9.12E-12	4.01E-15	3.04E-15	2.35E-13	9.28E-14	4.90E-13	6.19E-14	1.20E-13	3.40E-14	1.16E-14
Human toxicity, cancer - inorganics	CTUh	1.14E-11	6.15E-13	8.25E-15	7.26E-18	9.12E-15	6.60E-12	5.60E-14	2.76E-15	3.53E-15	9.75E-15	5.81E-16	2.17E-14	1.77E-14	6.40E-15	1.07E-12	3.85E-15	2.45E-12	1.02E-15	2.52E-15	2.00E-13	8.99E-14	8.29E-14	6.02E-14	7.70E-14	1.73E-14	5.23E-15
Human toxicity, cancer - organics	CTUh	1.30E-11	2.05E-14	4.63E-15	3.71E-18	2.75E-15	1.87E-13	4.49E-13	1.15E-15	1.29E-15	5.16E-15	3.14E-16	2.01E-15	8.59E-16	2.85E-15	5.14E-12	1.55E-15	6.67E-12	2.99E-15	5.13E-16	3.59E-14	2.91E-15	4.07E-13	1.69E-15	4.28E-14	1.67E-14	6.36E-15
Human toxicity, non-cancer	CTUh	8.09E-10	1.09E-11	2.53E-13	3.82E-16	5.67E-13	5.95E-10	2.14E-12	1.26E-13	5.77E-14	6.67E-13	2.62E-14	3.33E-13	1.68E-13	2.39E-13	4.96E-11	1.51E-13	1.24E-10	5.89E-14	1.18E-13	1.53E-11	2.69E-12	3.93E-12	1.05E-12	9.79E-13	7.63E-13	2.13E-13
Human toxicity, non-cancer - inorganics	CTUh	7.70E-10	1.09E-11	2.47E-13	3.70E-16	5.56E-13	5.66E-10	1.87E-12	1.18E-13	4.88E-14	6.33E-13	2.52E-14	3.16E-13	1.00E-13	2.05E-13	4.46E-11	1.36E-13	1.20E-10	5.63E-14	1.15E-13	1.52E-11	2.68E-12	3.54E-12	5.70E-13	9.24E-13	7.21E-13	1.99E-13
Human toxicity, non-cancer - organics	CTUh	3.95E-11	6.58E-14	6.27E-15	1.15E-17	1.13E-14	2.87E-11	2.76E-13	7.66E-15	8.91E-15	3.46E-14	1.06E-15	1.64E-14	6.72E-14	3.35E-14	5.03E-12	1.49E-14	4.12E-12	2.63E-15	2.76E-15	1.17E-13	1.55E-14	3.90E-13	4.82E-13	5.41E-14	4.15E-14	1.38E-14
Ionising radiation	kBq U-235 eq	0.003176	3.91E-06	6.29E-07	1.79E-09	4.87E-06	5.82E-05	1.33E-05	7.31E-07	8.29E-07	5.09E-06	3.01E-07	2.34E-06	1.53E-07	1.03E-06	0.000265	5.79E-07	0.002753	2.52E-07	2.80E-07	2.13E-05	3.94E-06	3.05E-05	1.74E-07	1.63E-06	1.87E-06	5.64E-06
Land use	Pt	0.083798	0.000587	3.53E-05	7.43E-07	4.71E-05	0.01423	0.000474	2.47E-05	3.37E-05	0.00011	1.28E-05	7.42E-05	2.18E-05	5.37E-05	0.010601	3.29E-05	0.053551	2.03E-05	3.00E-05	0.000216	0.000116	0.000777	1.52E-05	0.000251	0.000594	0.000105
Ozone depletion	kg CFC11 eq	1.53E-09	5.72E-12	3.34E-13	5.94E-15	3.08E-13	6.18E-12	2.35E-11	5.46E-14	1.22E-13	4.47E-13	2.34E-14	2.09E-13	4.13E-13	1.13E-10	3.71E-10	1.12E-13	9.62E-10	2.03E-12	4.15E-14	2.28E-12	2.63E-13	3.06E-11	4.97E-13	4.19E-12	1.79E-12	9.73E-13



Photochemical ozone formation	kg NMV OC eq	9.10E-05	8.47E-07	4.83E-08	1.02E-10	4.04E-08	8.67E-06	7.32E-07	4.38E-08	7.64E-08	1.43E-07	9.24E-09	1.45E-07	4.45E-07	8.32E-08	1.84E-05	8.64E-08	4.75E-05	1.90E-08	2.53E-08	2.06E-06	1.10E-07	1.34E-06	3.56E-06	6.16E-06	2.65E-07	1.31E-07
Resource use, fossils	MJ	0.390242	0.002075	0.000146	2.81E-07	0.000189	0.00673	0.003927	0.000311	0.000439	0.000537	3.17E-05	0.000157	0.002685	0.000538	0.09274	0.00081	0.248844	7.77E-05	3.28E-05	0.002923	0.000248	0.00729	0.014282	0.00339	0.001155	0.000683
Resource use, minerals and metals	kg Sb eq	1.26E-06	1.15E-09	8.74E-11	2.12E-13	2.18E-09	5.78E-07	2.83E-10	9.29E-11	2.06E-11	6.78E-10	1.64E-11	1.31E-09	6.18E-11	1.83E-10	3.34E-08	9.63E-11	1.97E-08	2.64E-11	4.31E-09	6.02E-07	9.29E-09	2.66E-09	7.80E-10	2.67E-10	2.62E-10	7.72E-11
Water use	m ³ depri v.	0.103019	3.41E-05	4.50E-06	3.19E-08	8.92E-05	0.000637	9.60E-05	6.48E-06	2.93E-05	1.00E-05	2.04E-06	3.73E-05	0.000205	1.01E-05	0.002222	3.81E-06	0.099452	6.98E-06	6.58E-07	0.00021	1.68E-05	0.000184	0.000145	7.61E-06	4.38E-06	2.74E-05

Table 22: Normalized results for UC1 iMERMAID scenario, IRIS cradle-to-gate assessment

Normalized results UC1 IRIS cradle-to-gate	Total	Aluminium oxide	Cathode Lithium battery	Zirconium oxide	Cobalt oxide	Copper	Epoxy	Ethylene glycol	Glass fibre	LED	Manganese oxide	Nickel	Nylon	Polyethylene	Polycarbonate	Polypropylene	Silicon	Silicone	Silver	Tin	Zinc	Polyoxymethylene	Polymer	Sea freight	Road freight	Electricity
Acidification	2.91E-06	3.13E-08	1.54E-09	2.96E-12	1.90E-09	8.09E-07	1.72E-08	1.03E-09	2.28E-09	4.65E-09	2.33E-10	2.17E-08	1.37E-08	1.86E-09	3.78E-07	1.83E-09	1.28E-06	4.68E-10	5.27E-10	5.16E-08	2.87E-09	2.67E-08	1.02E-07	1.48E-07	3.04E-09	2.83E-09
Climate change	3.46E-06	2.87E-08	1.85E-09	3.00E-12	1.20E-09	7.32E-08	2.80E-08	1.70E-09	3.95E-09	5.58E-09	4.04E-10	1.40E-09	2.32E-08	3.17E-09	6.14E-07	3.27E-09	2.42E-06	6.69E-10	3.32E-10	3.07E-08	2.19E-09	4.49E-08	1.17E-07	3.67E-08	1.09E-08	5.81E-09
Ecotoxicity, freshwater	6.29E-06	2.13E-08	1.27E-09	2.07E-12	2.93E-09	9.05E-07	1.32E-07	6.21E-10	7.39E-10	2.64E-09	1.45E-10	4.25E-09	3.32E-09	1.43E-09	3.75E-06	1.15E-09	9.26E-07	8.56E-10	3.53E-09	1.22E-07	4.59E-08	2.97E-07	1.68E-08	2.95E-08	1.03E-08	1.50E-09
Particulate matter	1.72E-06	4.28E-08	1.59E-09	2.31E-12	1.99E-09	1.71E-07	1.44E-08	8.90E-10	2.90E-09	3.97E-09	1.93E-10	3.16E-09	1.28E-08	1.89E-09	3.66E-07	1.72E-09	9.10E-07	5.15E-10	3.25E-10	5.51E-08	1.36E-09	2.34E-08	8.46E-08	1.36E-08	8.62E-09	1.25E-09
Eutrophication, marine	1.36E-06	1.34E-08	9.43E-10	1.76E-12	5.83E-10	1.12E-07	8.04E-09	5.61E-10	2.08E-09	2.59E-09	1.51E-10	1.04E-09	1.49E-08	1.02E-09	2.06E-07	9.87E-10	8.04E-07	2.63E-10	4.43E-10	3.41E-08	1.97E-09	1.42E-08	3.54E-08	1.05E-07	2.15E-09	1.37E-09
Eutrophication, freshwater	1.14E-05	5.48E-08	3.05E-09	7.51E-12	2.54E-09	2.20E-06	4.53E-08	2.14E-09	1.46E-09	1.37E-08	5.98E-10	5.81E-09	5.96E-09	2.99E-09	7.96E-07	2.60E-09	7.78E-06	7.77E-10	4.44E-09	3.55E-07	1.20E-08	6.28E-08	3.55E-08	5.74E-09	3.53E-09	4.30E-09

Eutrophication, terrestrial	1.53 E-06	1.60E-08	8.90E-10	1.99E-12	5.49 E-10	1.74E-07	9.39 E-09	6.54E-10	1.22 E-09	2.83 E-09	1.77E-10	1.26 E-09	8.28 E-09	1.18E-09	2.34E-07	1.16E-09	8.38 E-07	3.06E-10	6.06 E-10	5.06 E-08	2.29 E-09	1.59E-08	3.62E-08	1.29E-07	2.41E-09	1.72E-09
Human toxicity, cancer	1.41 E-06	3.69E-08	7.46E-10	6.36E-13	6.88 E-10	3.93E-07	2.92 E-08	2.27E-10	2.80 E-10	8.64 E-10	5.19E-11	1.37 E-09	1.07 E-09	5.36E-10	3.60E-07	3.13E-10	5.29 E-07	2.33E-10	1.76 E-10	1.36 E-08	5.38 E-09	2.84E-08	3.59E-09	6.94E-09	1.97E-09	6.72E-10
Human toxicity, non-cancer	6.29 E-06	8.49E-08	1.97E-09	2.97E-12	4.40 E-09	4.62E-06	1.66 E-08	9.77E-10	4.49 E-10	5.18 E-09	2.04E-10	2.59 E-09	1.30 E-09	1.86E-09	3.85E-07	1.17E-09	9.62 E-07	4.58E-10	9.15 E-10	1.19 E-07	2.09 E-08	3.06E-08	8.17E-09	7.60E-09	5.93E-09	1.66E-09
Ionising radiation	7.53 E-07	9.27E-10	1.49E-10	4.25E-13	1.15 E-09	1.38E-08	3.16 E-09	1.73E-10	1.96 E-10	1.21 E-09	7.14E-11	5.55 E-10	3.61 E-11	2.45E-10	6.28E-08	1.37E-10	6.52 E-07	5.97E-11	6.63 E-11	5.05 E-09	9.33 E-10	7.24E-09	4.11E-11	3.86E-10	4.43E-10	1.34E-09
Land use	1.02 E-07	7.16E-10	4.31E-11	9.06E-13	5.75 E-11	1.74E-08	5.78 E-10	3.01E-11	4.11 E-11	1.35 E-10	1.56E-11	9.06 E-11	2.66 E-11	6.55E-11	1.29E-08	4.02E-11	6.53 E-08	2.47E-11	3.67 E-11	2.44 E-09	1.42 E-10	9.48E-10	1.85E-11	3.06E-10	7.24E-10	1.28E-10
Ozone depletion	2.92 E-08	1.09E-10	6.38E-12	1.14E-13	5.89 E-12	1.18E-10	4.49 E-10	1.04E-12	2.33 E-12	8.55 E-12	4.47E-13	4.00 E-12	7.88 E-12	2.16E-09	7.09E-09	2.14E-12	1.84 E-08	3.89E-11	7.93 E-13	4.36 E-11	5.02 E-12	5.84E-10	9.50E-12	8.00E-11	3.41E-11	1.86E-11
Photochemical ozone formation	2.23 E-06	2.07E-08	1.18E-09	2.50E-12	9.88 E-10	2.12E-07	1.79 E-08	1.07E-09	1.87 E-09	3.50 E-09	2.26E-10	3.54 E-09	1.09 E-08	2.04E-09	4.51E-07	2.11E-09	1.16 E-06	4.65E-10	6.20 E-10	5.04 E-08	2.69 E-09	3.28E-08	8.71E-08	1.51E-07	6.47E-09	3.20E-09
Resource use, fossils	6.00 E-06	3.19E-08	2.25E-09	4.33E-12	2.92 E-09	1.04E-07	6.04 E-08	4.79E-09	6.76 E-09	8.25 E-09	4.87E-10	2.41 E-09	4.13 E-08	8.28E-09	1.43E-06	1.25E-08	3.83 E-06	1.19E-09	5.04 E-10	4.50 E-08	3.81 E-09	1.12E-07	2.20E-07	5.22E-08	1.78E-08	1.05E-08
Resource use, minerals and metals	1.98 E-05	1.81E-08	1.37E-09	3.33E-12	3.42 E-08	9.09E-06	4.45 E-09	1.46E-09	3.25 E-10	1.07 E-08	2.57E-10	2.06 E-08	9.71 E-10	2.88E-09	5.24E-07	1.51E-09	3.10 E-07	4.15E-10	6.78 E-08	9.46 E-06	1.46 E-07	4.17E-08	1.23E-08	4.20E-09	4.12E-09	1.21E-09
Water use	8.98 E-06	2.97E-09	3.92E-10	2.78E-12	7.78 E-09	5.55E-08	8.37 E-09	5.65E-10	2.55 E-09	8.72 E-10	1.78E-10	3.25 E-09	1.79 E-08	8.84E-10	1.94E-07	3.32E-10	8.67 E-06	6.09E-10	5.74 E-11	-	1.46 E-09	1.60E-08	1.26E-08	6.64E-10	3.82E-10	2.39E-09

Table 23: Weighted results for UC1 iMERMAID scenario, IRIS cradle-to-gate assessment

Weighted results UC1 IRIS cradle-to-gate	Unit	Total	Aluminium oxide	Cathode Li-Ion battery	Zirconium oxide	Cobalt oxide	Copper	Epoxy	Ethylene glycol	Glass fibre	LED	Manganese oxide	Nickel	Nylon	Polyethylene	Polycarbonate	Polypropylene	Silicon	Silicone	Silver	Tin	Zinc	Polyoxymethylene	Polymethyl	Sea freight	Road freight	Electricity
Acidification	μPt	4.66E+00	2.25E-02	1.24E-03	2.53E-06	4.41E-03	9.75E-01	2.07E-02	1.26E-03	2.32E-03	4.35E-03	2.43E-04	4.56E-03	1.35E-02	2.42E-03	5.11E-01	2.44E-03	2.17E+00	4.99E-04	5.58E-03	7.51E-01	1.43E-02	3.87E-02	6.70E-02	3.90E-02	6.06E-03	3.21E-03
Climate change	μPt	1.80E-01	1.94E-03	9.55E-05	1.84E-07	1.18E-04	5.02E-02	1.07E-03	6.36E-05	1.41E-04	2.88E-04	1.45E-05	1.35E-03	8.51E-04	1.16E-04	2.35E-02	1.13E-04	7.96E-02	2.90E-05	3.27E-05	3.20E-03	1.78E-04	1.65E-03	6.34E-03	9.20E-03	1.89E-04	1.75E-04
Ecotoxicity, freshwater	μPt	7.29E-01	6.05E-03	3.89E-04	6.32E-07	2.52E-04	1.54E-02	5.91E-03	3.59E-04	8.31E-04	1.17E-03	8.51E-05	2.95E-04	4.89E-03	6.68E-04	1.29E-01	6.88E-04	5.10E-01	1.41E-04	6.99E-05	6.47E-03	4.61E-04	9.45E-03	2.47E-02	7.73E-03	2.29E-03	1.22E-03
Particulate matter	μPt	1.21E-01	4.10E-04	2.44E-05	3.98E-08	5.63E-05	1.74E-02	2.54E-03	1.19E-05	1.42E-05	5.06E-05	2.79E-06	8.15E-05	6.38E-05	2.74E-05	7.21E-02	2.21E-05	1.78E-02	1.64E-05	6.77E-05	2.34E-03	8.81E-04	5.71E-03	3.22E-04	5.67E-04	1.98E-04	2.87E-05
Eutrophication, marine	μPt	1.55E-01	3.84E-03	1.42E-04	2.07E-07	1.78E-04	1.53E-02	1.29E-03	7.97E-05	2.60E-04	3.55E-04	1.73E-05	2.83E-04	1.15E-03	1.70E-04	3.28E-02	1.54E-04	8.16E-02	4.61E-05	2.91E-05	4.93E-03	1.22E-04	2.09E-03	7.58E-03	1.22E-03	7.72E-04	1.12E-04
Eutrophication, freshwater	μPt	4.04E-02	3.98E-04	2.79E-05	5.20E-08	1.73E-05	3.32E-03	2.38E-04	1.66E-05	6.16E-05	7.67E-05	4.46E-06	3.08E-05	4.41E-04	3.03E-05	6.09E-03	2.92E-05	2.38E-02	7.79E-06	1.31E-05	1.01E-03	5.84E-05	4.21E-04	1.05E-03	3.12E-03	6.37E-05	4.06E-05
Eutrophication, terrestrial	μPt	3.19E-01	1.53E-03	8.53E-05	2.10E-07	7.12E-05	6.16E-02	1.27E-03	6.00E-05	4.09E-05	3.82E-04	1.67E-05	1.63E-04	1.67E-04	8.38E-05	2.23E-02	7.27E-05	2.18E-01	2.18E-05	1.24E-04	9.95E-03	3.37E-04	1.76E-03	9.93E-04	1.61E-04	9.88E-05	1.20E-04
Human toxicity, cancer	μPt	5.67E-02	5.93E-04	3.30E-05	7.38E-08	2.04E-05	6.44E-03	3.48E-04	2.43E-05	4.54E-05	1.05E-04	6.56E-06	4.69E-05	3.07E-04	4.38E-05	8.67E-03	4.31E-05	3.11E-02	1.14E-05	2.25E-05	1.88E-03	8.51E-05	5.90E-04	1.34E-03	4.78E-03	8.94E-05	6.39E-05
Human toxicity, non-cancer	μPt	3.01E-02	7.85E-04	1.59E-05	1.35E-08	1.46E-05	8.37E-03	6.23E-04	4.84E-06	5.96E-06	1.84E-05	1.10E-06	2.93E-05	2.29E-05	1.14E-05	7.66E-03	6.67E-06	1.13E-02	4.95E-06	3.75E-06	2.91E-04	1.15E-04	6.05E-04	7.64E-05	1.48E-04	4.19E-05	1.43E-05
Ionising radiation	μPt	1.16E-01	1.56E-03	3.62E-05	5.46E-08	8.10E-05	8.50E-02	3.06E-04	1.80E-05	8.25E-06	9.54E-05	3.75E-06	4.76E-05	2.39E-05	3.42E-05	7.09E-03	2.16E-05	1.77E-02	8.42E-06	1.68E-05	2.19E-03	3.85E-04	5.62E-04	1.50E-04	1.40E-04	1.09E-04	3.05E-05
Land use	μPt	3.77E-02	4.64E-05	7.47E-06	2.13E-08	5.78E-05	6.91E-04	1.58E-04	8.68E-06	9.84E-06	6.05E-05	3.58E-06	2.78E-05	1.81E-06	1.23E-05	3.15E-03	6.87E-06	3.27E-02	2.99E-06	3.32E-06	2.53E-04	4.67E-05	3.62E-04	2.06E-06	1.93E-05	2.22E-05	6.69E-05
Ozone depletion	μPt	8.12E-03	5.69E-05	3.42E-06	7.20E-08	4.57E-06	1.38E-03	4.59E-05	2.39E-06	3.27E-06	1.07E-05	1.24E-06	7.19E-06	2.11E-06	5.20E-06	1.03E-03	3.19E-06	5.19E-03	1.96E-06	2.91E-06	1.94E-04	1.12E-05	7.53E-05	1.47E-06	2.43E-05	5.75E-05	1.02E-05
Photochemical ozone formation	μPt	1.84E-03	6.89E-06	4.03E-07	7.16E-09	3.71E-07	7.45E-06	2.83E-05	6.58E-08	1.47E-07	5.39E-07	2.82E-08	2.52E-07	4.97E-07	1.36E-04	4.47E-04	1.35E-07	1.16E-03	2.45E-06	5.01E-08	2.75E-06	3.17E-07	3.69E-05	5.99E-07	5.05E-06	2.15E-06	1.17E-06
Resource use, fossils	μPt	1.06E-01	9.91E-04	5.65E-05	1.20E-07	4.72E-05	1.01E-02	8.56E-04	5.13E-05	8.94E-05	1.67E-04	1.08E-05	1.69E-04	5.20E-04	9.73E-05	2.16E-02	1.01E-04	5.56E-02	2.22E-05	2.96E-05	2.41E-03	1.29E-04	1.57E-03	4.16E-03	7.20E-03	3.09E-04	1.53E-04

Resource use, minerals and metals	μPt	4.99E-01	2.66E-03	1.87E-04	3.60E-07	2.43E-04	8.61E-03	5.03E-03	3.99E-04	5.63E-04	6.87E-04	4.05E-05	2.01E-04	3.44E-03	6.89E-04	1.19E-01	1.04E-03	3.18E-01	9.94E-05	4.19E-05	3.74E-03	3.17E-04	9.33E-03	1.83E-02	4.34E-03	1.48E-03	8.74E-04
Water use	μPt	1.49E+00	1.36E-03	1.04E-04	2.51E-07	2.58E-03	6.86E-01	3.36E-04	1.10E-04	2.45E-05	8.05E-04	1.94E-05	1.56E-03	7.33E-05	2.18E-04	3.96E-02	1.14E-04	2.34E-02	3.14E-05	5.12E-03	7.14E-01	1.10E-02	3.15E-03	9.26E-04	3.17E-04	3.11E-04	9.17E-05

Table 24: Characterized results for UC1 iMERMAID scenario according to the Environmental Footprint method, version 3.1

Characterized results UC1 iMERMAID scenario	Unit	Total	*UC1_Socamex_Operation_After	*IRIS_Cradle-to-Gate	Socamex_Electricity_Consumption	IRIS_Electricity_Consumption	Sludge treatment	IRIS_EoL
Acidification	mol H+ eq	4.42E-02	6.33E-06	1.62E-04	3.17E-02	1.23E-02	7.63E-06	4.04E-07
Climate change	kg CO2 eq	8.80E+00	1.84E-01	2.62E-02	6.19E+00	2.40E+00	3.78E-04	7.34E-05
Climate change - Biogenic	kg CO2 eq	1.54E-02	0.00E+00	1.51E-04	1.10E-02	4.28E-03	1.08E-07	1.71E-07
Climate change - Fossil	kg CO2 eq	8.72E+00	1.84E-01	2.60E-02	6.13E+00	2.38E+00	3.78E-04	7.31E-05
Climate change - Land use and LU change	kg CO2 eq	6.19E-02	0.00E+00	3.67E-05	4.46E-02	1.73E-02	6.84E-08	1.54E-07
Ecotoxicity, freshwater	CTUe	2.53E+01	1.97E-03	3.56E-01	1.79E+01	6.96E+00	6.79E-02	2.97E-04
Ecotoxicity, freshwater - inorganics	CTUe	2.07E+01	0.00E+00	2.12E-01	1.47E+01	5.71E+00	6.79E-02	2.69E-04
Ecotoxicity, freshwater - organics	CTUe	4.59E+00	1.97E-03	1.45E-01	3.20E+00	1.24E+00	1.74E-05	2.81E-05
Particulate matter	disease inc.	1.84E-07	1.80E-12	1.03E-09	1.32E-07	5.13E-08	4.98E-11	3.91E-12
Eutrophication, marine	kg N eq	8.52E-03	3.33E-06	2.66E-05	6.11E-03	2.37E-03	8.74E-06	7.96E-08
Eutrophication, freshwater	kg P eq	1.72E-03	0.00E+00	1.83E-05	1.23E-03	4.76E-04	3.49E-06	3.33E-08
Eutrophication, terrestrial	mol N eq	8.74E-02	3.64E-05	2.70E-04	6.27E-02	2.44E-02	3.43E-05	8.55E-07
Human toxicity, cancer	CTUh	3.27E-09	0.00E+00	2.44E-11	2.34E-09	9.09E-10	3.61E-12	4.06E-14
Human toxicity, cancer - inorganics	CTUh	1.58E-09	0.00E+00	1.14E-11	1.13E-09	4.38E-10	3.57E-12	2.84E-14
Human toxicity, cancer - organics	CTUh	1.69E-09	0.00E+00	1.30E-11	1.21E-09	4.70E-10	3.74E-14	1.21E-14
Human toxicity, non-cancer	CTUh	6.75E-08	2.90E-10	8.09E-10	4.72E-08	1.83E-08	9.44E-10	2.43E-12
Human toxicity, non-cancer - inorganics	CTUh	6.47E-08	0.00E+00	7.70E-10	4.54E-08	1.76E-08	9.44E-10	2.38E-12
Human toxicity, non-cancer - organics	CTUh	2.80E-09	2.90E-10	3.95E-11	1.78E-09	6.92E-10	5.13E-14	4.52E-14

Ionising radiation	kBq U-235 eq	7.52E+00	0.00E+00	3.18E-03	5.41E+00	2.10E+00	1.41E-06	9.34E-06
Land use	Pt	2.60E+01	0.00E+00	8.38E-02	1.87E+01	7.26E+00	5.26E-04	3.22E-04
Ozone depletion	kg CFC11 eq	1.92E-07	0.00E+00	1.53E-09	1.37E-07	5.32E-08	9.16E-13	5.61E-13
Photochemical ozone formation	kg NMVOC eq	3.07E-02	7.09E-05	9.10E-05	2.20E-02	8.56E-03	1.10E-06	2.46E-07
Resource use, fossils	MJ	2.35E+02	0.00E+00	3.90E-01	1.69E+02	6.56E+01	7.92E-04	9.40E-04
Resource use, minerals and metals	kg Sb eq	2.33E-05	0.00E+00	1.26E-06	1.59E-05	6.18E-06	6.01E-10	6.44E-10
Water use	m3 depriv.	5.70E+00	0.00E+00	1.03E-01	4.03E+00	1.57E+00	-1.02E-03	1.24E-05

Table 25: Normalised results for UC1 iMERMAID scenario according to the Environmental Footprint method, version 3.1

Normalized results UC1 iMERMAID scenario	Total	*UC1_Socamex_Operation_After	*IRIS_Cradle-to_Gate	Socamex_Electricity_Consumption	IRIS_Electricity_Consumption	Sludge treatment	IRIS_EoL
Acidification	7.96E-04	1.14E-07	2.91E-06	5.71E-04	2.22E-04	1.37E-07	7.27E-09
Climate change	1.17E-03	2.43E-05	3.46E-06	8.19E-04	3.18E-04	5.01E-08	9.72E-09
Ecotoxicity, freshwater	4.46E-04	3.47E-08	6.29E-06	3.16E-04	1.23E-04	1.20E-06	5.24E-09
Particulate matter	3.10E-04	3.02E-09	1.72E-06	2.22E-04	8.62E-05	8.37E-08	6.56E-09
Eutrophication, marine	4.36E-04	1.70E-07	1.36E-06	3.12E-04	1.21E-04	4.47E-07	4.07E-09
Eutrophication, freshwater	1.07E-03	0.00E+00	1.14E-05	7.62E-04	2.96E-04	2.17E-06	2.07E-08
Eutrophication, terrestrial	4.95E-04	2.06E-07	1.53E-06	3.55E-04	1.38E-04	1.94E-07	4.84E-09
Human toxicity, cancer	1.90E-04	0.00E+00	1.41E-06	1.35E-04	5.27E-05	2.09E-07	2.35E-09
Human toxicity, non-cancer	5.25E-04	2.25E-06	6.29E-06	3.66E-04	1.42E-04	7.34E-06	1.88E-08
Ionising radiation	1.78E-03	0.00E+00	7.53E-07	1.28E-03	4.98E-04	3.35E-10	2.21E-09
Land use	3.17E-05	0.00E+00	1.02E-07	2.28E-05	8.85E-06	6.42E-10	3.93E-10
Ozone depletion	3.66E-06	0.00E+00	2.92E-08	2.62E-06	1.02E-06	1.75E-11	1.07E-11
Photochemical ozone formation	7.52E-04	1.73E-06	2.23E-06	5.39E-04	2.09E-04	2.70E-08	6.02E-09
Resource use, fossils	3.61E-03	0.00E+00	6.00E-06	2.60E-03	1.01E-03	1.22E-08	1.45E-08

Resource use, minerals and metals	3.67E-04	0.00E+00	1.98E-05	2.50E-04	9.71E-05	9.44E-09	1.01E-08
Water use	4.97E-04	0.00E+00	8.98E-06	3.52E-04	1.37E-04	-8.91E-08	1.08E-09

Table 26: Weighted results for UC1 iMERMAID scenario according to the Environmental Footprint method, version 3.1

Weighted results UC1 iMERMAID scenario	Unit	Total	*UC1_Socamex_Operation_After	*IRIS_Cradle-to-Gate	Socamex_Electricity_Consumption	IRIS_Electricity_Consumption	Sludge treatment	IRIS_EoL
Total	μPt	9.04E+02	5.27E+00	4.66E+00	6.44E+02	2.50E+02	2.66E-01	6.95E-03
Acidification	μPt	4.93E+01	7.06E-03	1.80E-01	3.54E+01	1.38E+01	8.52E-03	4.51E-04
Climate change	μPt	2.45E+02	5.13E+00	7.29E-01	1.72E+02	6.70E+01	1.05E-02	2.05E-03
Ecotoxicity, freshwater	μPt	8.56E+00	6.67E-04	1.21E-01	6.06E+00	2.36E+00	2.30E-02	1.01E-04
Particulate matter	μPt	2.77E+01	2.70E-04	1.55E-01	1.99E+01	7.72E+00	7.50E-03	5.88E-04
Eutrophication, marine	μPt	1.29E+01	5.04E-03	4.04E-02	9.25E+00	3.60E+00	1.32E-02	1.21E-04
Eutrophication, freshwater	μPt	3.00E+01	0.00E+00	3.19E-01	2.13E+01	8.30E+00	6.08E-02	5.81E-04
Eutrophication, terrestrial	μPt	1.84E+01	7.65E-03	5.67E-02	1.32E+01	5.12E+00	7.21E-03	1.79E-04
Human toxicity, cancer	μPt	4.04E+00	0.00E+00	3.01E-02	2.89E+00	1.12E+00	4.46E-03	5.01E-05
Human toxicity, non-cancer	μPt	9.65E+00	4.14E-02	1.16E-01	6.74E+00	2.62E+00	1.35E-01	3.47E-04
Ionising radiation	μPt	8.93E+01	0.00E+00	3.77E-02	6.42E+01	2.50E+01	1.68E-05	1.11E-04
Land use	μPt	2.52E+00	0.00E+00	8.12E-03	1.81E+00	7.03E-01	5.10E-05	3.12E-05
Ozone depletion	μPt	2.31E-01	0.00E+00	1.84E-03	1.65E-01	6.42E-02	1.10E-06	6.76E-07
Photochemical ozone formation	μPt	3.60E+01	8.29E-02	1.06E-01	2.58E+01	1.00E+01	1.29E-03	2.88E-04
Resource use, fossils	μPt	3.00E+02	0.00E+00	4.99E-01	2.16E+02	8.40E+01	1.01E-03	1.20E-03
Resource use, minerals and metals	μPt	2.77E+01	0.00E+00	1.49E+00	1.89E+01	7.33E+00	7.13E-04	7.65E-04
Water use	μPt	4.23E+01	0.00E+00	7.64E-01	2.99E+01	1.16E+01	-7.58E-03	9.17E-05

Annex II Use Case 2: Secondary datasets used and results

Table 27: Material, process and transport datasets and assumptions used for modelling UC2 baseline scenario.

Datasets used for baseline scenario, Socamex	Input/output	Selected material/process dataset	Transportation distance [km]	Selected transport dataset
Electricity	Input	Ecoinvent: market for electricity, low voltage, TUN		
Sludge treatment	Output	Ecoinvent: treatment of raw sewage sludge, municipal incineration, GLO	10	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4
Direct emissions	Output	Calculations for methane (CH ₄) and nitrous oxide (N ₂ O) are based on data provided by Opalia and follow the IPCC methodology.		

Table 28: Material, process and transport datasets used for modelling UC2 iMERMAID scenario, EDEN cradle-to-gate.

Datasets used for EDEN, cradle-to-gate	Input/output	Selected material/process dataset	Transportation distance [km]
Metals	Input	Steel, chromium steel 18/8	
Electronics / Electrical	Input	Silicon, electronics grade	
Electronics / Electrical	Input	Light emitting diode	
Electronics / Electrical	Input	Cable, unspecified	
Chemicals	Input	Chemical, inorganic	
Chemicals	Input	Isopropanol	
Chemicals	Input	Epoxy resin	
Chemicals	Input	Methyl methacrylate	
Chemicals	Input	UpPhoto Resin (Bisphenol A, powder (RER))	
Polymer / Plastic	Input	Polydimethylsiloxane	
Polymer / Plastic	Input	Ethylene vinyl acetate copolymer	
Polymer / Plastic	Input	Polyvinylchloride, bulk polymerised	

Polymer / Plastic	Input	Flexdym sheet (Butyl acrylate (RER))	
Inorganic / Glass	Input	Tempering, flat glass	
Transportation	Input	Transport, freight, sea, container ship	106,253
Transportation	Input	Transport, freight, lorry, lorry 16–32 metric ton, EUROS	8,251
Electricity	Input	market for electricity, medium voltage; FR	

Table 29: Material, energy, and process datasets used for modelling UC2 iMERMAID scenario, ENIG cradle-to-gate.

Datasets used for ENIG, cradle-to-gate	Input/output	Selected material/process dataset	Transportation distance [km]
Water tank	Input	Polyvinylchloride, bulk polymerised (GLO)	Based on the market consumption mix defined in the corresponding ecoinvent dataset, as no specific supplier information was provided.
Butterfly valve	Input	Polyvinylchloride, bulk polymerised (GLO)	Based on the market consumption mix defined in the corresponding ecoinvent dataset, as no specific supplier information was provided.
Check valve	Input	Polyvinylchloride, bulk polymerised (GLO)	Based on the market consumption mix defined in the corresponding ecoinvent dataset, as no specific supplier information was provided.
Level indicator	Input	Steel, chromium steel 18/8 (RoW)	Based on the market consumption mix defined in the corresponding ecoinvent dataset, as no specific supplier information was provided.
Level switch HH	Input	Steel, chromium steel 18/8 (RoW)	Based on the market consumption mix defined in the corresponding ecoinvent dataset, as no specific supplier information was provided.
Level switch LH	Input	Steel, chromium steel 18/8 (RoW)	Based on the market consumption mix defined in the corresponding ecoinvent dataset, as no specific supplier information was provided.
Feed pump	Input	Steel, chromium steel 18/8 (RoW)	Based on the market consumption mix defined in the corresponding ecoinvent dataset, as no specific supplier information was provided.
Pressure transmitter	Input	Electronics, for control units (GLO)	Based on the market consumption mix defined in the corresponding ecoinvent dataset, as no specific supplier information was provided.
Pressure indicator	Input	Electronics, for control units (GLO)	Based on the market consumption mix defined in the corresponding ecoinvent dataset, as no specific supplier information was provided.
Flowmeter	Input	Electronics, for control units (GLO)	Based on the market consumption mix defined in the corresponding ecoinvent dataset, as no specific supplier information was provided.
Microfilter	Input	Polypropylene, granulate (RoW)	Based on the market consumption mix defined in the corresponding ecoinvent dataset, as no specific supplier information was provided.

Housing	Input	Polypropylene, granulate (RoW)	Based on the market consumption mix defined in the corresponding ecoinvent dataset, as no specific supplier information was provided.
Conductivity meter	Input	Cable, three-conductor cable (GLO)	Based on the market consumption mix defined in the corresponding ecoinvent dataset, as no specific supplier information was provided.
Electricity	Input	market for electricity, medium voltage; TN	

Table 30: Characterized results for UC2 baseline scenario according to the Environmental Footprint method, version 3.1.

Characterized results UC2 Opalia baseline scenario	Unit	Total	Operation, direct emissions	Waste collection service	Electricity	Treatment of sewage sludge
Acidification	mol H+ eq	6.49E-03	3.45E-08	5.19E-07	6.49E-03	3.84E-06
Climate change	kg CO2 eq	7.11E+00	1.99E+00	9.49E-05	5.12E+00	5.47E-04
Climate change - Biogenic	kg CO2 eq	5.24E-04	0.00E+00	9.42E-09	5.24E-04	2.50E-07
Climate change - Fossil	kg CO2 eq	7.11E+00	1.99E+00	9.48E-05	5.11E+00	5.47E-04
Climate change - Land use and LU change	kg CO2 eq	3.49E-04	0.00E+00	1.20E-08	3.49E-04	1.06E-07
Ecotoxicity, freshwater	CTUe	5.09E+00	2.14E-02	6.00E-04	5.06E+00	9.92E-04
Ecotoxicity, freshwater - Inorganics	CTUe	4.00E+00	0.00E+00	5.77E-04	4.00E+00	9.38E-04
Ecotoxicity, freshwater - Organics	CTUe	1.09E+00	2.14E-02	2.27E-05	1.06E+00	5.44E-05
Particulate matter	disease inc.	2.68E-08	9.79E-15	1.24E-11	2.68E-08	2.56E-11
Eutrophication, marine	kg N eq	1.58E-03	1.81E-08	2.25E-07	1.58E-03	2.47E-06
Eutrophication, freshwater	kg P eq	2.26E-04	0.00E+00	1.77E-09	2.24E-04	1.74E-06
Eutrophication, terrestrial	mol N eq	1.74E-02	1.99E-07	2.44E-06	1.74E-02	1.74E-05
Human toxicity, cancer	CTUh	9.77E-10	0.00E+00	1.39E-14	9.77E-10	6.81E-13
Human toxicity, cancer - Inorganics	CTUh	5.76E-10	0.00E+00	6.37E-15	5.75E-10	5.61E-13

Human toxicity, cancer - organics	CTUh	4.02E-10	0.00E+00	7.58E-15	4.02E-10	1.20E-13
Human toxicity, non-cancer	CTUh	3.92E-08	3.14E-09	2.42E-13	3.61E-08	1.75E-11
Human toxicity, non-cancer - inorganics	CTUh	3.38E-08	0.00E+00	1.97E-13	3.38E-08	1.74E-11
Human toxicity, non-cancer - organics	CTUh	5.43E-09	3.14E-09	4.44E-14	2.29E-09	9.24E-14
Ionising radiation	kBq U-235 eq	8.86E-03	0.00E+00	4.07E-07	8.86E-03	4.12E-06
Land use	Pt	2.89E+00	0.00E+00	1.37E-04	2.89E+00	9.71E-04
Ozone depletion	kg CFC11 eq	1.46E-07	0.00E+00	1.49E-12	1.46E-07	1.29E-11
Photochemical ozone formation	kg NMVOC eq	1.23E-02	6.76E-04	9.55E-07	1.16E-02	4.36E-06
Resource use, fossils	MJ	8.06E+01	0.00E+00	1.23E-03	8.06E+01	2.61E-03
Resource use, minerals and metals	kg Sb eq	3.01E-05	0.00E+00	6.09E-11	3.01E-05	5.66E-10
Water use	m ³ depriv.	2.59E-01	0.00E+00	2.32E-06	2.59E-01	-1.18E-06

Table 31: Normalized results for UC2 baseline scenario according to the Environmental Footprint method, version 3.1.

Normalized results UC2 Opalia Baseline scenario	Total	Operation, direct emissions	Waste collection service	Electricity	Treatment of sewage sludge
Acidification	1.17E-04	6.21E-10	9.33E-09	1.17E-04	6.90E-08
Climate change	9.41E-04	2.64E-04	1.26E-08	6.77E-04	7.24E-08
Ecotoxicity, freshwater	8.97E-05	3.77E-07	1.06E-08	8.93E-05	1.75E-08
Particulate matter	4.50E-05	1.64E-11	2.08E-08	4.49E-05	4.29E-08
Eutrophication, marine	8.09E-05	9.27E-10	1.15E-08	8.08E-05	1.26E-07
Eutrophication, freshwater	1.40E-04	0.00E+00	1.10E-09	1.39E-04	1.09E-06

<i>Eutrophication, terrestrial</i>	9.86E-05	1.12E-09	1.38E-08	9.84E-05	9.83E-08
<i>Human toxicity, cancer</i>	5.67E-05	0.00E+00	8.08E-10	5.66E-05	3.95E-08
<i>Human toxicity, non-cancer</i>	3.05E-04	2.44E-05	1.88E-09	2.80E-04	1.36E-07
<i>Ionising radiation</i>	2.10E-06	0.00E+00	9.65E-11	2.10E-06	9.77E-10
<i>Land use</i>	3.53E-06	0.00E+00	1.67E-10	3.53E-06	1.19E-09
<i>Ozone depletion</i>	2.79E-06	0.00E+00	2.84E-11	2.79E-06	2.46E-10
<i>Photochemical ozone formation</i>	3.01E-04	1.65E-05	2.34E-08	2.84E-04	1.07E-07
<i>Resource use, fossils</i>	1.24E-03	0.00E+00	1.89E-08	1.24E-03	4.02E-08
<i>Resource use, minerals and metals</i>	4.73E-04	0.00E+00	9.57E-10	4.73E-04	8.89E-09
<i>Water use</i>	2.26E-05	0.00E+00	2.02E-10	2.26E-05	-1.02E-10

Table 32: Weighted results for UC2 baseline scenario according to the Environmental Footprint method, version 3.1.

Weighted results UC2 Opalia Baseline scenario	Unit	Total	Operation, direct emissions	Waste collection service	Electricity	Treatment of sewage sludge
<i>Acidification</i>	μPt	7.24E+00	3.85E-05	5.79E-04	7.24E+00	4.28E-03
<i>Climate change</i>	μPt	1.98E+02	5.56E+01	2.64E-03	1.43E+02	1.53E-02
<i>Ecotoxicity, freshwater</i>	μPt	1.72E+00	7.23E-03	2.03E-04	1.71E+00	3.36E-04
<i>Particulate matter</i>	μPt	4.03E+00	1.47E-06	1.86E-03	4.03E+00	3.85E-03
<i>Eutrophication, marine</i>	μPt	2.40E+00	2.75E-05	3.41E-04	2.39E+00	3.74E-03
<i>Eutrophication, freshwater</i>	μPt	3.93E+00	0.00E+00	3.08E-05	3.90E+00	3.04E-02
<i>Eutrophication, terrestrial</i>	μPt	3.66E+00	4.17E-05	5.12E-04	3.65E+00	3.65E-03
<i>Human toxicity, cancer</i>	μPt	1.21E+00	0.00E+00	1.72E-05	1.21E+00	8.41E-04
<i>Human toxicity, non-cancer</i>	μPt	5.61E+00	4.49E-01	3.45E-05	5.16E+00	2.51E-03

<i>Ionising radiation</i>	µPt	1.05E-01	0.00E+00	4.83E-06	1.05E-01	4.90E-05
<i>Land use</i>	µPt	2.80E-01	0.00E+00	1.33E-05	2.80E-01	9.41E-05
<i>Ozone depletion</i>	µPt	1.76E-01	0.00E+00	1.79E-06	1.76E-01	1.55E-05
<i>Photochemical ozone formation</i>	µPt	1.44E+01	7.90E-01	1.12E-03	1.36E+01	5.10E-03
<i>Resource use, fossils</i>	µPt	1.03E+02	0.00E+00	1.57E-03	1.03E+02	3.34E-03
<i>Resource use, minerals and metals</i>	µPt	3.57E+01	0.00E+00	7.23E-05	3.57E+01	6.71E-04
<i>Water use</i>	µPt	1.92E+00	0.00E+00	1.72E-05	1.92E+00	-8.72E-06

Table 33: Characterized results for UC2 iMERMAID scenario, EDEN cradle-to-gate assessment

Characterized UC2 EDEN cradle-to-gate	Unit	Total	UpPhoto Resin	Tempering, flat glass	Isopropanol	Inorganic chemical	Polydimethylsiloxane	Ethylene vinyl acetate copolymer	Flexdym sheet	Silicon, electronics grade	Methyl methacrylate	Steel	Polyvinylchloride	Epoxy resin	Road freight	Sea freight	LED	Cables	Electricity
Acidification	mol H+ eq	3.82E-04	3.73E-07	8.65E-09	9.12E-07	4.48E-07	2.34E-06	3.41E-08	1.44E-06	1.48E-04	4.78E-05	7.88E-06	1.26E-07	1.86E-06	1.37E-05	2.04E-05	7.85E-05	4.84E-05	9.12E-06
Climate change	kg CO2 eq	8.59E-02	9.29E-05	1.28E-06	2.10E-04	5.14E-05	3.82E-04	9.26E-06	2.83E-04	5.42E-02	8.26E-03	1.38E-03	2.77E-05	4.12E-04	4.20E-03	6.86E-04	1.28E-02	7.38E-04	2.14E-03
Climate change - Biogenic	kg CO2 eq	7.24E-04	1.25E-07	5.55E-09	2.05E-07	1.98E-07	2.33E-06	1.40E-08	2.83E-07	6.77E-04	6.01E-06	2.30E-06	7.09E-08	4.77E-07	1.21E-06	1.23E-07	2.27E-05	3.01E-06	7.72E-06
Climate change - Fossil	kg CO2 eq	8.51E-02	9.27E-05	1.28E-06	2.10E-04	5.12E-05	3.80E-04	9.24E-06	2.82E-04	5.35E-02	8.25E-03	1.37E-03	2.76E-05	4.12E-04	4.19E-03	6.85E-04	1.28E-02	7.34E-04	2.13E-03
Climate change - Land use and LU change	kg CO2 eq	1.06E-04	4.51E-08	2.79E-10	4.51E-08	5.65E-08	3.57E-07	4.97E-09	1.46E-07	7.55E-05	1.17E-08	1.38E-06	2.67E-08	2.60E-07	2.04E-06	5.29E-07	2.28E-05	1.28E-06	1.22E-06
Ecotoxicity, freshwater	CTUe	3.81E-01	4.74E-03	7.58E-06	3.68E-04	6.58E-04	2.36E-02	3.18E-05	1.05E-03	1.70E-01	1.57E-02	5.63E-03	1.51E-04	1.49E-02	2.93E-02	4.14E-03	4.55E-02	5.49E-02	1.02E-02
Ecotoxicity, freshwater - Inorganics	CTUe	3.46E-01	1.87E-04	7.45E-06	2.78E-04	6.43E-04	2.35E-02	1.73E-05	9.73E-04	1.61E-01	1.34E-02	5.35E-03	1.43E-04	3.87E-03	2.83E-02	3.96E-03	4.28E-02	5.47E-02	6.82E-03

Ecotoxicity, freshwater organics	CTUe	3.45E-02	4.55E-03	1.25E-07	9.01E-05	1.56E-05	8.12E-05	1.45E-05	7.61E-05	8.39E-03	2.38E-03	2.77E-04	8.18E-06	1.11E-02	1.07E-03	1.82E-04	2.69E-03	2.38E-04	3.41E-03
Particulate matter	disease inc.	2.76E-09	3.69E-12	8.96E-14	8.56E-12	3.47E-12	3.28E-11	3.38E-13	1.45E-11	8.31E-10	4.25E-10	1.12E-10	1.21E-12	1.63E-11	3.34E-10	2.01E-11	7.18E-10	1.16E-10	1.24E-10
Eutrophication, marine	kg N eq	8.13E-05	6.46E-08	1.48E-09	1.14E-07	5.14E-08	4.60E-07	6.69E-09	2.21E-07	3.97E-05	8.63E-06	1.39E-06	2.46E-08	3.03E-07	4.70E-06	5.10E-06	1.54E-05	2.46E-06	2.70E-06
Eutrophication, freshwater	kg P eq	6.96E-05	2.27E-08	1.04E-10	2.30E-08	1.90E-08	9.39E-08	1.49E-09	7.71E-08	5.72E-05	3.53E-07	5.05E-07	7.90E-09	1.47E-07	2.93E-07	2.28E-08	6.67E-06	3.79E-06	4.21E-07
Eutrophication, terrestrial	mol N eq	7.32E-04	6.76E-07	1.77E-08	1.22E-06	6.71E-07	4.89E-06	6.99E-08	2.32E-06	3.28E-04	6.34E-05	1.46E-05	2.59E-07	3.25E-06	4.97E-05	5.64E-05	1.52E-04	3.39E-05	2.00E-05
Human toxicity, cancer	CTUh	5.61E-11	1.93E-13	2.40E-16	4.42E-14	4.78E-14	3.14E-13	2.10E-15	7.74E-14	2.90E-11	5.97E-13	9.55E-12	1.48E-14	1.01E-12	1.90E-12	2.96E-13	4.53E-12	7.25E-12	1.32E-12
Human toxicity, cancer inorganics	CTUh	2.76E-11	1.88E-14	1.25E-16	2.75E-14	3.27E-14	8.97E-14	1.47E-15	5.06E-14	6.68E-12	5.86E-13	8.24E-12	7.45E-15	1.10E-13	9.18E-13	1.90E-13	2.96E-12	7.03E-12	6.86E-13
Human toxicity, cancer organics	CTUh	2.85E-11	1.74E-13	1.15E-16	1.67E-14	1.51E-14	2.24E-13	6.27E-16	2.68E-14	2.23E-11	1.07E-14	1.32E-12	7.33E-15	8.97E-13	9.86E-13	1.06E-13	1.57E-12	2.21E-13	6.33E-13
Human toxicity, non-cancer	CTUh	1.28E-09	7.90E-13	5.07E-15	1.13E-12	1.17E-12	5.51E-12	6.88E-14	2.34E-12	3.17E-10	9.65E-12	3.38E-11	3.52E-13	4.18E-12	4.19E-11	2.42E-12	2.03E-10	6.33E-10	2.78E-11
Human toxicity, non-cancer inorganics	CTUh	1.22E-09	6.47E-13	4.72E-15	1.02E-12	1.13E-12	5.14E-12	5.69E-14	2.21E-12	3.06E-10	5.35E-12	3.32E-11	3.32E-13	3.63E-12	3.94E-11	2.29E-12	1.92E-10	6.02E-10	2.66E-11
Human toxicity, non-cancer organics	CTUh	6.22E-11	1.43E-13	3.56E-16	1.11E-13	4.43E-14	3.74E-13	1.19E-14	1.28E-13	1.11E-11	4.29E-12	5.45E-13	1.95E-14	5.48E-13	2.49E-12	1.34E-13	1.05E-11	3.06E-11	1.19E-12
Ionising radiation	kBq U-235 eq	2.64E-02	6.76E-06	3.29E-08	8.68E-06	3.08E-06	2.29E-05	5.74E-07	1.48E-05	1.00E-02	1.17E-06	1.23E-04	1.76E-06	3.21E-05	7.96E-05	4.03E-06	1.55E-03	7.24E-05	1.45E-02
Land use	Pt	2.76E-01	1.65E-04	2.75E-06	1.97E-04	2.60E-04	1.75E-03	1.40E-05	7.76E-04	1.69E-01	1.18E-04	7.75E-03	6.64E-05	9.73E-04	3.54E-02	6.21E-04	3.36E-02	1.56E-02	9.57E-03
Ozone depletion	kg CFC11 eq	3.21E-08	1.23E-12	3.91E-14	2.47E-12	3.45E-12	2.83E-08	7.97E-14	4.02E-12	3.40E-09	2.91E-12	1.51E-11	1.15E-11	4.77E-11	9.12E-11	1.04E-11	1.36E-10	7.74E-12	8.63E-11
Photochemical ozone formation	kg NMVOC eq	2.46E-04	3.83E-07	5.33E-09	8.92E-07	1.71E-07	1.57E-06	3.23E-08	9.62E-07	1.08E-04	3.18E-05	5.01E-06	9.26E-08	1.42E-06	2.04E-05	1.52E-05	4.35E-05	9.80E-06	7.03E-06
Resource use, fossils	MJ	1.53E+00	2.40E-03	1.55E-05	6.21E-03	5.47E-04	4.71E-03	3.04E-04	5.78E-03	7.90E-01	1.34E-01	1.59E-02	5.94E-04	7.89E-03	5.95E-02	8.39E-03	1.63E-01	1.10E-02	3.18E-01

Resource use, minerals and metals	kg Sb eq	9.70E-07	6.34E-10	4.93E-12	9.55E-10	1.10E-09	1.82E-09	5.11E-11	1.38E-09	6.40E-08	9.38E-09	3.75E-08	2.60E-10	5.66E-10	1.35E-08	6.62E-10	2.06E-07	6.15E-07	1.73E-08
Water use	m ³ depriv.	3.28E-02	5.13E-05	2.04E-07	6.75E-05	4.15E-05	6.87E-05	6.69E-06	4.34E-04	2.55E-02	1.44E-03	2.86E-04	-6.42E-06	1.93E-04	2.42E-04	1.88E-05	3.04E-03	7.30E-04	6.87E-04

Table 34: Normalized results for UC2 iMERMAID scenario, EDEN cradle-to-gate assessment

Normalized UC2 EDEN cradle-to-gate	Total	UpPhoto Resin	Tempering, flat glass	Isopropanol	Inorganic chemical	Polydimethylsiloxane	Ethylene vinyl acetate copolymer	Flexdym sheet	Silicon, electronics grade	Methyl methacrylate	Steel	Polyvinylchloride	Epoxy resin	Road freight	Sea freight	LED	Cables	Electricity
Acidification	6.87E-06	6.71E-09	1.56E-10	1.64E-08	8.06E-09	4.21E-08	6.14E-10	2.60E-08	2.67E-06	8.61E-07	1.42E-07	2.27E-09	3.34E-08	2.46E-07	3.67E-07	1.41E-06	8.71E-07	1.64E-07
Climate change	1.14E-05	1.23E-08	1.70E-10	2.78E-08	6.81E-09	5.06E-08	1.23E-09	3.74E-08	7.18E-06	1.09E-06	1.82E-07	3.66E-09	5.46E-08	5.56E-07	9.08E-08	1.69E-06	9.78E-08	2.83E-07
Ecotoxicity, freshwater	6.71E-06	8.35E-08	1.34E-10	6.49E-09	1.16E-08	4.17E-07	5.61E-10	1.85E-08	2.99E-06	2.78E-07	9.92E-08	2.66E-09	2.63E-07	5.17E-07	7.30E-08	8.02E-07	9.68E-07	1.80E-07
Particulate matter	4.63E-06	6.20E-09	1.51E-10	1.44E-08	5.82E-09	5.51E-08	5.68E-10	2.43E-08	1.40E-06	7.13E-07	1.88E-07	2.03E-09	2.73E-08	5.61E-07	3.38E-08	1.21E-06	1.94E-07	2.07E-07
Eutrophication, marine	4.16E-06	3.30E-09	7.59E-11	5.84E-09	2.63E-09	2.35E-08	3.42E-10	1.13E-08	2.03E-06	4.42E-07	7.10E-08	1.26E-09	1.55E-08	2.41E-07	2.61E-07	7.88E-07	1.26E-07	1.38E-07
Eutrophication, freshwater	4.33E-05	1.41E-08	6.50E-11	1.43E-08	1.18E-08	5.84E-08	9.25E-10	4.80E-08	3.56E-05	2.20E-07	3.14E-07	4.91E-09	9.15E-08	1.83E-07	1.42E-08	4.15E-06	2.36E-06	2.62E-07
Eutrophication, terrestrial	4.14E-06	3.83E-09	1.00E-10	6.89E-09	3.79E-09	2.77E-08	3.95E-10	1.31E-08	1.86E-06	3.58E-07	8.28E-08	1.47E-09	1.84E-08	2.81E-07	3.19E-07	8.60E-07	1.92E-07	1.13E-07
Human toxicity, cancer	3.25E-06	1.12E-08	1.39E-11	2.56E-09	2.77E-09	1.82E-08	1.22E-10	4.48E-09	1.68E-06	3.46E-08	5.54E-07	8.57E-10	5.84E-08	1.10E-07	1.72E-08	2.63E-07	4.20E-07	7.65E-08
Human toxicity, non-cancer	9.97E-06	6.14E-09	3.94E-11	8.80E-09	9.11E-09	4.28E-08	5.34E-10	1.82E-08	2.46E-06	7.49E-08	2.62E-07	2.73E-09	3.25E-08	3.25E-07	1.88E-08	1.58E-06	4.91E-06	2.16E-07
Ionising radiation	6.26E-06	1.60E-09	7.80E-12	2.06E-09	7.29E-10	5.43E-09	1.36E-10	3.52E-09	2.37E-06	2.77E-10	2.92E-08	4.17E-10	7.61E-09	1.89E-08	9.55E-10	3.67E-07	1.72E-08	3.43E-06
Land use	3.36E-07	2.02E-10	3.35E-12	2.40E-10	3.18E-10	2.14E-09	1.71E-11	9.47E-10	2.06E-07	1.44E-10	9.45E-09	8.10E-11	1.19E-09	4.32E-08	7.57E-10	4.10E-08	1.90E-08	1.17E-08

Ozone depletion	6.14E-07	2.36E-11	7.47E-13	4.71E-11	6.58E-11	5.41E-07	1.52E-12	7.68E-11	6.50E-08	5.56E-11	2.88E-10	2.20E-10	9.11E-10	1.74E-09	1.98E-10	2.60E-09	1.48E-10	1.65E-09
Photochemical ozone formation	6.03E-06	9.38E-09	1.30E-10	2.18E-08	4.18E-09	3.85E-08	7.92E-10	2.35E-08	2.64E-06	7.77E-07	1.23E-07	2.27E-09	3.48E-08	5.00E-07	3.73E-07	1.06E-06	2.40E-07	1.72E-07
Resource use, fossils	2.35E-05	3.69E-08	2.38E-10	9.56E-08	8.41E-09	7.25E-08	4.68E-09	8.89E-08	1.21E-05	2.06E-06	2.44E-07	9.14E-09	1.21E-07	9.15E-07	1.29E-07	2.51E-06	1.69E-07	4.90E-06
Resource use, minerals and metals	1.52E-05	9.96E-09	7.75E-11	1.50E-08	1.72E-08	2.86E-08	8.03E-10	2.17E-08	1.01E-06	1.48E-07	5.90E-07	4.09E-09	8.90E-09	2.12E-07	1.04E-08	3.24E-06	9.66E-06	2.72E-07
Water use	2.86E-06	4.48E-09	1.78E-11	5.89E-09	3.62E-09	5.99E-09	5.84E-10	3.78E-08	2.22E-06	1.26E-07	2.49E-08	-5.60E-10	1.68E-08	2.11E-08	1.64E-09	2.65E-07	6.37E-08	5.99E-08

Table 35: Weighted results for UC2 iMERMAID scenario, EDEN cradle-to-gate assessment

Weighted UC2 EDEN cradle-to-gate	Unit	Total	UpPhoto Resin	Tempering, flat glass	Isopropanol	Inorganic chemical	Polydimethylsiloxane	Ethylene vinyl acetate copolymer	Flexdym sheet	Silicon, electronics grade	Methyl methacrylate	Steel	Polyvinylchloride	Epoxy resin	Road freight	Sea freight	LED	Cables	Electricity
Acidification	μPt	9.12E+00	1.09E-02	1.04E-04	2.01E-02	6.03E-03	7.59E-02	9.67E-04	2.83E-02	4.61E+00	6.18E-01	1.72E-01	2.61E-03	4.10E-02	3.46E-01	9.66E-02	1.32E+00	1.05E+00	7.27E-01
Climate change	μPt	4.26E-01	4.16E-04	9.65E-06	1.02E-03	5.00E-04	2.61E-03	3.81E-05	1.61E-03	1.65E-01	5.34E-02	8.80E-03	1.41E-04	2.07E-03	1.53E-02	2.28E-02	8.76E-02	5.40E-02	1.02E-02
Ecotoxicity, freshwater	μPt	2.40E+00	2.59E-03	3.58E-05	5.85E-03	1.43E-03	1.07E-02	2.58E-04	7.88E-03	1.51E+00	2.30E-01	3.84E-02	7.72E-04	1.15E-02	1.17E-01	1.91E-02	3.57E-01	2.06E-02	5.95E-02
Particulate matter	μPt	1.29E-01	1.60E-03	2.57E-06	1.25E-04	2.23E-04	8.00E-03	1.08E-05	3.55E-04	5.75E-02	5.33E-03	1.90E-03	5.11E-05	5.05E-03	9.93E-03	1.40E-03	1.54E-02	1.86E-02	3.46E-03
Eutrophication, marine	μPt	4.15E-01	5.56E-04	1.35E-05	1.29E-03	5.22E-04	4.94E-03	5.09E-05	2.18E-03	1.25E-01	6.39E-02	1.69E-02	1.82E-04	2.45E-03	5.02E-02	3.02E-03	1.08E-01	1.74E-02	1.86E-02
Eutrophication, freshwater	μPt	1.23E-01	9.78E-05	2.25E-06	1.73E-04	7.79E-05	6.96E-04	1.01E-05	3.34E-04	6.01E-02	1.31E-02	2.10E-03	3.73E-05	4.58E-04	7.12E-03	7.72E-03	2.33E-02	3.72E-03	4.10E-03
Eutrophication, terrestrial	μPt	1.21E+00	3.95E-04	1.82E-06	4.01E-04	3.31E-04	1.64E-03	2.59E-05	1.34E-03	9.96E-01	6.15E-03	8.80E-03	1.38E-04	2.56E-03	5.11E-03	3.97E-04	1.16E-01	6.61E-02	7.34E-03
Human toxicity, cancer	μPt	1.54E-01	1.42E-04	3.72E-06	2.56E-04	1.41E-04	1.03E-03	1.47E-05	4.86E-04	6.89E-02	1.33E-02	3.07E-03	5.44E-05	6.82E-04	1.04E-02	1.18E-02	3.19E-02	7.12E-03	4.19E-03

Human toxicity, non-cancer	μPt	6.93E-02	2.38E-04	2.96E-07	5.46E-05	5.90E-05	3.87E-04	2.59E-06	9.55E-05	3.57E-02	7.37E-04	1.18E-02	1.83E-05	1.24E-03	2.35E-03	3.66E-04	5.60E-03	8.95E-03	1.63E-03
Ionising radiation	μPt	1.83E-01	1.13E-04	7.25E-07	1.62E-04	1.68E-04	7.88E-04	9.83E-06	3.34E-04	4.53E-02	1.38E-03	4.83E-03	5.03E-05	5.98E-04	5.98E-03	3.46E-04	2.90E-02	9.04E-02	3.97E-03
Land use	μPt	3.14E-01	8.02E-05	3.91E-07	1.03E-04	3.65E-05	2.72E-04	6.81E-06	1.76E-04	1.19E-01	1.39E-05	1.46E-03	2.09E-05	3.81E-04	9.44E-04	4.78E-05	1.84E-02	8.59E-04	1.72E-01
Ozone depletion	μPt	2.67E-02	1.60E-05	2.66E-07	1.91E-05	2.52E-05	1.70E-04	1.36E-06	7.52E-05	1.63E-02	1.14E-05	7.51E-04	6.43E-06	9.43E-05	3.43E-03	6.01E-05	3.25E-03	1.51E-03	9.27E-04
Photochemical ozone formation	μPt	3.87E-02	1.49E-06	4.71E-08	2.97E-06	4.15E-06	3.41E-02	9.61E-08	4.85E-06	4.10E-03	3.51E-06	1.82E-05	1.39E-05	5.75E-05	1.10E-04	1.25E-05	1.64E-04	9.33E-06	1.04E-04
Resource use, fossils	μPt	2.88E-01	4.48E-04	6.24E-06	1.04E-03	2.00E-04	1.84E-03	3.78E-05	1.12E-03	1.26E-01	3.71E-02	5.86E-03	1.08E-04	1.67E-03	2.39E-02	1.78E-02	5.08E-02	1.15E-02	8.22E-03
Resource use, minerals and metals	μPt	1.96E+00	3.07E-03	1.98E-05	7.95E-03	7.00E-04	6.03E-03	3.89E-04	7.40E-03	1.01E+00	1.71E-01	2.03E-02	7.60E-04	1.01E-02	7.61E-02	1.07E-02	2.09E-01	1.40E-02	4.08E-01
Water use	μPt	1.15E+00	7.52E-04	5.85E-06	1.13E-03	1.30E-03	2.16E-03	6.06E-05	1.64E-03	7.59E-02	1.11E-02	4.45E-02	3.09E-04	6.72E-04	1.60E-02	7.85E-04	2.45E-01	7.29E-01	2.06E-02

Table 36: Characterized results for UC2 iMERMAID scenario, ENIG cradle-to-gate assessment

Characterized UC2 ENIG cradle-to-gate	Unit	Total	Sodium hypochlorite	Water	Water Tank	Butterfly valve	Check valve	Level indicator	Level switch HH	Level switch LH	Feed pump	Pressure transmitter	Pressure indicator	Flowmeter	Microfilter	Housing	Water pump	Conductivity meter	Electricity
Acidification	mol H+ eq	1.08E-02	1.73E-03	1.41E-05	1.49E-03	3.88E-04	1.66E-05	5.76E-05	5.76E-05	5.76E-05	1.92E-05	4.24E-04	5.30E-04	2.12E-03	3.84E-06	2.56E-05	3.09E-03	8.03E-04	1.46E-05
Climate change	kg CO2 eq	1.33E+00	2.91E-01	2.68E-03	3.22E-01	8.38E-02	3.58E-03	1.02E-02	1.02E-02	1.02E-02	3.39E-03	5.25E-02	6.57E-02	2.63E-01	9.39E-04	6.26E-03	1.75E-01	1.43E-02	1.15E-02
Climate change - Biogenic	kg CO2 eq	2.75E-03	4.16E-04	4.22E-06	8.01E-04	2.08E-04	8.90E-06	1.51E-05	1.51E-05	1.51E-05	5.02E-06	1.30E-04	1.62E-04	6.48E-04	1.34E-06	8.94E-06	2.61E-04	5.27E-05	1.18E-06
Climate change - Fossil	kg CO2 eq	1.32E+00	2.90E-01	2.67E-03	3.21E-01	8.35E-02	3.57E-03	1.01E-02	1.01E-02	1.01E-02	3.38E-03	5.23E-02	6.54E-02	2.62E-01	9.38E-04	6.25E-03	1.75E-01	1.43E-02	1.15E-02
Climate change - Land use and LU change	kg CO2 eq	1.83E-03	4.13E-04	3.53E-06	3.32E-04	8.63E-05	3.69E-06	1.07E-05	1.07E-05	1.07E-05	3.58E-06	9.92E-05	1.24E-04	4.96E-04	3.26E-07	2.18E-06	2.15E-04	2.25E-05	7.87E-07
Ecotoxicity, freshwater	CTUe	3.27E+01	1.56E+01	1.17E-02	1.80E+00	4.68E-01	2.00E-02	4.06E-02	4.06E-02	4.06E-02	1.35E-02	1.45E+00	1.82E+00	7.27E+00	2.48E-03	1.65E-02	3.27E+00	9.06E-01	1.14E-02
Ecotoxicity, freshwater - Inorganics	CTUe	3.23E+01	1.55E+01	1.09E-02	1.68E+00	4.37E-01	1.87E-02	3.86E-02	3.86E-02	3.86E-02	1.29E-02	1.43E+00	1.79E+00	7.14E+00	2.40E-03	1.60E-02	3.23E+00	9.02E-01	9.02E-03

Ecotoxicity, freshwater - organics	CTUe	4.29E-01	3.24E-02	8.43E-04	1.20E-01	3.11E-02	1.33E-03	2.09E-03	2.09E-03	2.09E-03	6.96E-04	2.57E-02	3.21E-02	1.28E-01	8.08E-05	5.39E-04	4.36E-02	4.36E-03	2.40E-03
Particulate matter	disease inc.	7.99E-08	1.35E-08	1.80E-10	1.47E-08	3.82E-09	1.63E-10	8.22E-10	8.22E-10	8.22E-10	2.74E-10	3.25E-09	4.07E-09	1.63E-08	3.70E-11	2.47E-10	1.89E-08	1.99E-09	6.03E-11
Eutrophication, marine	kg N eq	1.57E-03	3.01E-04	2.88E-06	3.03E-04	7.89E-05	3.37E-06	1.03E-05	1.03E-05	1.03E-05	3.45E-06	7.42E-05	9.27E-05	3.71E-04	6.90E-07	4.60E-06	2.58E-04	4.22E-05	3.56E-06
Eutrophication, freshwater	kg P eq	1.09E-03	1.57E-04	9.65E-07	8.99E-05	2.34E-05	9.99E-07	3.47E-06	3.47E-06	3.47E-06	1.16E-06	7.00E-05	8.75E-05	3.50E-04	1.72E-07	1.15E-06	2.36E-04	6.27E-05	5.05E-07
Eutrophication, terrestrial	mol N eq	1.73E-02	3.10E-03	2.94E-05	3.20E-03	8.32E-04	3.56E-05	1.10E-04	1.10E-04	1.10E-04	3.65E-05	8.21E-04	1.03E-03	4.10E-03	7.33E-06	4.89E-05	3.11E-03	5.76E-04	3.92E-05
Human toxicity, cancer	CTUh	2.68E-09	1.59E-10	6.31E-12	1.73E-10	4.49E-11	1.92E-12	6.61E-11	6.61E-11	6.61E-11	2.20E-11	7.08E-11	8.86E-11	3.54E-10	1.96E-13	1.30E-12	1.44E-09	1.20E-10	2.20E-12
Human toxicity, cancer - Inorganics	CTUh	2.08E-09	1.23E-10	4.25E-12	8.68E-11	2.26E-11	9.64E-13	5.70E-11	5.70E-11	5.70E-11	1.90E-11	5.20E-11	6.50E-11	2.60E-10	1.45E-13	9.68E-13	1.16E-09	1.16E-10	1.30E-12
Human toxicity, cancer - organics	CTUh	6.01E-10	3.61E-11	2.06E-12	8.59E-11	2.23E-11	9.55E-13	9.07E-12	9.07E-12	9.07E-12	3.02E-12	1.88E-11	2.35E-11	9.41E-11	5.04E-14	3.36E-13	2.81E-10	3.87E-12	9.06E-13
Human toxicity, non-cancer	CTUh	8.34E-08	6.85E-09	8.91E-11	4.07E-09	1.06E-09	4.52E-11	2.39E-10	2.39E-10	2.39E-10	7.96E-11	2.82E-09	3.53E-09	1.41E-08	5.78E-12	3.85E-11	3.95E-08	1.04E-08	8.13E-11
Human toxicity, non-cancer - Inorganics	CTUh	8.03E-08	6.72E-09	8.81E-11	3.83E-09	9.97E-10	4.26E-11	2.35E-10	2.35E-10	2.35E-10	7.82E-11	2.74E-09	3.43E-09	1.37E-08	5.25E-12	3.50E-11	3.79E-08	9.89E-09	7.62E-11
Human toxicity, non-cancer - organics	CTUh	3.09E-09	1.33E-10	1.04E-12	2.35E-10	6.10E-11	2.61E-12	3.94E-12	3.94E-12	3.94E-12	1.31E-12	7.87E-11	9.84E-11	3.94E-10	5.28E-13	3.52E-12	1.56E-09	5.02E-10	5.16E-12
Ionising radiation	kBq U-235 eq	1.19E-01	3.60E-02	2.34E-04	2.00E-02	5.19E-03	2.22E-04	6.03E-04	6.03E-04	6.03E-04	2.01E-04	5.84E-03	7.30E-03	2.92E-02	1.69E-05	1.13E-04	1.16E-02	1.29E-03	2.00E-05
Land use	Pt	6.26E+00	9.65E-01	6.65E-03	8.55E-01	2.22E-01	9.50E-03	5.40E-02	5.40E-02	5.40E-02	1.80E-02	3.33E-01	4.17E-01	1.67E+00	9.66E-04	6.44E-03	1.32E+00	2.63E-01	6.52E-03
Ozone depletion	kg CFC11 eq	3.33E-07	1.45E-07	5.19E-10	1.30E-07	3.37E-08	1.44E-09	9.97E-11	9.97E-11	9.97E-11	3.32E-11	2.68E-09	3.35E-09	1.34E-08	3.69E-12	2.46E-11	2.76E-09	1.42E-10	3.29E-10
Photochemical ozone formation	kg NMVOC eq	5.38E-03	8.02E-04	9.46E-06	1.13E-03	2.94E-04	1.26E-05	3.69E-05	3.69E-05	3.69E-05	1.23E-05	2.44E-04	3.05E-04	1.22E-03	3.12E-06	2.08E-05	1.02E-03	1.69E-04	2.62E-05
Resource use, fossils	MJ	2.04E+01	3.57E+00	3.20E-02	6.83E+00	1.78E+00	7.59E-02	1.11E-01	1.11E-01	1.11E-01	3.71E-02	6.88E-01	8.60E-01	3.44E+00	3.07E-02	2.05E-01	2.05E+00	2.44E-01	1.82E-01
Resource use, minerals and metals	kg Sb eq	1.80E-04	5.59E-07	1.22E-08	2.96E-06	7.70E-07	3.29E-08	2.58E-07	2.58E-07	2.58E-07	8.59E-08	1.82E-05	2.28E-05	9.12E-05	3.63E-09	2.42E-08	3.25E-05	1.01E-05	6.79E-08
Water use	m3 depriv.	4.58E-01	3.00E-01	8.81E-02	-7.15E-02	-1.86E-02	-7.94E-04	2.03E-03	2.03E-03	2.03E-03	6.76E-04	1.08E-02	1.35E-02	5.39E-02	4.25E-05	2.84E-04	6.21E-02	1.26E-02	5.84E-04

Table 37: Normalized results for UC2 IMERMAID scenario, ENIG cradle-to-gate assessment

Normalized UC2 ENIG cradle-to-gate	Total	Sodium hypochlorite	Water	Water Tank	Butterfly valve	Check valve	Level indicator	Level switch HH	Level switch LH	Feed pump	Pressure transmitter	Pressure indicator	Flowmeter	Microfilter	Housing	Water pump	Conductivity meter	Electricity
Acidification	1.95E-04	3.12E-05	2.54E-07	2.69E-05	6.99E-06	2.99E-07	1.04E-06	1.04E-06	1.04E-06	3.46E-07	7.63E-06	9.54E-06	3.82E-05	6.92E-08	4.61E-07	5.55E-05	1.45E-05	2.63E-07

Climate change	1.76E-04	3.85E-05	3.54E-07	4.27E-05	1.11E-05	4.74E-07	1.35E-06	1.35E-06	4.49E-07	6.96E-06	8.70E-06	3.48E-05	1.24E-07	8.29E-07	2.32E-05	1.90E-06	1.53E-06
Ecotoxicity, freshwater	5.77E-04	2.74E-04	2.06E-07	3.17E-05	8.25E-06	3.53E-07	7.17E-07	7.17E-07	2.39E-07	2.56E-05	3.21E-05	1.28E-04	4.37E-08	2.91E-07	5.77E-05	1.60E-05	2.01E-07
Particulate matter	1.34E-04	2.26E-05	3.02E-07	2.47E-05	6.42E-06	2.74E-07	1.38E-06	1.38E-06	4.60E-07	5.47E-06	6.83E-06	2.73E-05	6.22E-08	4.15E-07	3.18E-05	3.35E-06	1.01E-07
Eutrophication, marine	8.04E-05	1.54E-05	1.47E-07	1.55E-05	4.04E-06	1.73E-07	5.29E-07	5.29E-07	1.76E-07	3.80E-06	4.74E-06	1.90E-05	3.53E-08	2.35E-07	1.32E-05	2.16E-06	1.82E-07
Eutrophication, freshwater	6.79E-04	9.78E-05	6.01E-07	5.59E-05	1.45E-05	6.22E-07	2.16E-06	2.16E-06	7.19E-07	4.36E-05	5.45E-05	2.18E-04	1.07E-07	7.15E-07	1.47E-04	3.90E-05	3.14E-07
Eutrophication, terrestrial	9.78E-05	1.75E-05	1.66E-07	1.81E-05	4.71E-06	2.01E-07	6.20E-07	6.20E-07	2.07E-07	4.64E-06	5.80E-06	2.32E-05	4.15E-08	2.77E-07	1.76E-05	3.26E-06	2.22E-07
Human toxicity, cancer	1.55E-04	9.21E-06	3.66E-07	1.00E-05	2.60E-06	1.11E-07	3.83E-06	3.83E-06	1.28E-06	4.11E-06	5.13E-06	2.05E-05	1.13E-08	7.56E-08	8.34E-05	6.93E-06	1.28E-07
Human toxicity, non-cancer	6.48E-04	5.32E-05	6.92E-07	3.16E-05	8.22E-06	3.51E-07	1.85E-06	1.85E-06	6.18E-07	2.19E-05	2.74E-05	1.10E-04	4.49E-08	2.99E-07	3.07E-04	8.07E-05	6.32E-07
Ionising radiation	2.82E-05	8.52E-06	5.55E-08	4.73E-06	1.23E-06	5.26E-08	1.43E-07	1.43E-07	4.77E-08	1.38E-06	1.73E-06	6.92E-06	4.00E-09	2.67E-08	2.74E-06	3.07E-07	4.73E-09
Land use	7.63E-06	1.18E-06	8.12E-09	1.04E-06	2.71E-07	1.16E-08	6.59E-08	6.59E-08	2.20E-08	4.07E-07	5.08E-07	2.03E-06	1.18E-09	7.86E-09	1.61E-06	3.21E-07	7.95E-09
Ozone depletion	6.37E-06	2.77E-06	9.92E-09	2.48E-06	6.45E-07	2.75E-08	1.90E-09	1.90E-09	6.35E-10	5.12E-08	6.40E-08	2.56E-07	7.05E-11	4.70E-10	5.27E-08	2.71E-09	6.29E-09
Photochemical ozone formation	1.32E-04	1.96E-05	2.31E-07	2.77E-05	7.20E-06	3.08E-07	9.02E-07	9.02E-07	3.01E-07	5.98E-06	7.47E-06	2.99E-05	7.64E-08	5.09E-07	2.50E-05	4.13E-06	6.41E-07
Resource use, fossils	3.13E-04	5.49E-05	4.92E-07	1.05E-04	2.73E-05	1.17E-06	1.71E-06	1.71E-06	5.70E-07	1.06E-05	1.32E-05	5.29E-05	4.73E-07	3.15E-06	3.15E-05	3.76E-06	2.79E-06
Resource use, minerals and metals	2.83E-03	8.79E-06	1.91E-07	4.65E-05	1.21E-05	5.17E-07	4.05E-06	4.05E-06	1.35E-06	2.87E-04	3.59E-04	1.43E-03	5.70E-08	3.80E-07	5.10E-04	1.59E-04	1.07E-06
Water use	3.99E-05	2.62E-05	7.68E-06	-6.23E-06	-1.62E-06	-6.92E-08	1.77E-07	1.77E-07	5.89E-08	9.40E-07	1.18E-06	4.70E-06	3.71E-09	2.47E-08	5.42E-06	1.10E-06	5.10E-08

Table 38: Weighted results for UC2 iMERMAID scenario, ENIG cradle-to-gate assessment

Weighted UC2 ENIG cradle-to-gate	Unit	Total	Sodium hypochlorite	Water	Water Tank	Butterfly valve	Check valve	Level indicator	Level switch HH	Level switch LH	Feed pump	Pressure transmitter	Pressure indicator	Flowmeter	Microfilter	Housing	Water pump	Conductivity meter	Electricity
Total	µPt	3.64E+02	3.14E+01	8.93E-01	3.05E+01	7.93E+00	3.39E-01	1.22E+00	1.22E+00	1.22E+00	4.06E-01	2.79E+01	3.49E+01	1.40E+02	9.14E-02	6.10E-01	6.79E+01	1.74E+01	7.37E-01
Acidification	µPt	1.21E+01	1.94E+00	1.58E-02	1.67E+00	4.33E-01	1.85E-02	6.43E-02	6.43E-02	6.43E-02	2.14E-02	4.73E-01	5.92E-01	2.37E+00	4.29E-03	2.86E-02	3.44E+00	8.96E-01	1.63E-02
Climate change	µPt	3.70E+01	8.10E+00	7.46E-02	8.98E+00	2.34E+00	9.98E-02	2.84E-01	2.84E-01	2.84E-01	9.45E-02	1.47E+00	1.83E+00	7.33E+00	2.62E-02	1.75E-01	4.89E+00	3.99E-01	3.22E-01
Ecotoxicity, freshwater	µPt	1.11E+01	5.26E+00	3.96E-03	6.09E-01	1.58E-01	6.77E-03	1.38E-02	1.38E-02	1.38E-02	4.59E-03	4.92E-01	6.15E-01	2.46E+00	8.39E-04	5.59E-03	1.11E+00	3.07E-01	3.87E-03
Particulate matter	µPt	1.20E+01	2.03E+00	2.70E-02	2.21E+00	5.75E-01	2.46E-02	1.24E-01	1.24E-01	1.24E-01	4.12E-02	4.90E-01	6.12E-01	2.45E+00	5.57E-03	3.72E-02	2.85E+00	3.00E-01	9.08E-03

Eutrophication, marine	μPt	2.38E+00	4.56E-01	4.36E-03	4.60E-01	1.19E-01	5.11E-03	1.57E-02	1.57E-02	1.57E-02	5.22E-03	1.12E-01	1.40E-01	5.62E-01	1.05E-03	6.97E-03	3.91E-01	6.39E-02	5.39E-03
Eutrophication, freshwater	μPt	1.90E+01	2.74E+00	1.68E-02	1.57E+00	4.07E-01	1.74E-02	6.04E-02	6.04E-02	6.04E-02	2.01E-02	1.22E+00	1.52E+00	6.10E+00	3.00E-03	2.00E-02	4.10E+00	1.09E+00	8.80E-03
Eutrophication, terrestrial	μPt	3.63E+00	6.50E-01	6.17E-03	6.72E-01	1.75E-01	7.46E-03	2.30E-02	2.30E-02	2.30E-02	7.66E-03	1.72E-01	2.15E-01	8.61E-01	1.54E-03	1.03E-02	6.53E-01	1.21E-01	8.23E-03
Human toxicity, cancer	μPt	3.31E+00	1.96E-01	7.79E-03	2.13E-01	5.54E-02	2.37E-03	8.15E-02	8.15E-02	8.15E-02	2.72E-02	8.75E-02	1.09E-01	4.37E-01	2.41E-04	1.61E-03	1.78E+00	1.48E-01	2.72E-03
Human toxicity, non-cancer	μPt	1.19E+01	9.79E-01	1.27E-02	5.82E-01	1.51E-01	6.46E-03	3.41E-02	3.41E-02	3.41E-02	1.14E-02	4.03E-01	5.04E-01	2.02E+00	8.26E-04	5.50E-03	5.65E+00	1.49E+00	1.16E-02
Ionising radiation	μPt	1.41E+00	4.27E-01	2.78E-03	2.37E-01	6.16E-02	2.63E-03	7.16E-03	7.16E-03	7.16E-03	2.39E-03	6.93E-02	8.66E-02	3.47E-01	2.00E-04	1.34E-03	1.37E-01	1.54E-02	2.37E-04
Land use	μPt	6.06E-01	9.35E-02	6.45E-04	8.28E-02	2.15E-02	9.21E-04	5.24E-03	5.24E-03	5.24E-03	1.75E-03	3.23E-02	4.04E-02	1.61E-01	9.36E-05	6.24E-04	1.28E-01	2.55E-02	6.31E-04
Ozone depletion	μPt	4.02E-01	1.75E-01	6.26E-04	1.56E-01	4.07E-02	1.74E-03	1.20E-04	1.20E-04	1.20E-04	4.01E-05	3.23E-03	4.04E-03	1.62E-02	4.45E-06	2.97E-05	3.32E-03	1.71E-04	3.97E-04
Photochemical ozone formation	μPt	6.30E+00	9.38E-01	1.11E-02	1.32E+00	3.44E-01	1.47E-02	4.31E-02	4.31E-02	4.31E-02	1.44E-02	2.86E-01	3.57E-01	1.43E+00	3.65E-03	2.43E-02	1.20E+00	1.98E-01	3.06E-02
Resource use, fossils	μPt	2.61E+01	4.57E+00	4.09E-02	8.74E+00	2.27E+00	9.72E-02	1.42E-01	1.42E-01	1.42E-01	4.75E-02	8.81E-01	1.10E+00	4.40E+00	3.93E-02	2.62E-01	2.62E+00	3.12E-01	2.32E-01
Resource use, minerals and metals	μPt	2.14E+02	6.63E-01	1.44E-02	3.51E+00	9.14E-01	3.90E-02	3.06E-01	3.06E-01	3.06E-01	1.02E-01	2.17E+01	2.71E+01	1.08E+02	4.30E-03	2.87E-02	3.85E+01	1.20E+01	8.06E-02
Water use	μPt	3.40E+00	2.23E+00	6.54E-01	-5.30E-01	-1.38E-01	-5.89E-03	1.50E-02	1.50E-02	1.50E-02	5.01E-03	8.00E-02	1.00E-01	4.00E-01	3.16E-04	2.10E-03	4.61E-01	9.37E-02	4.34E-03

Table 39: Characterized results for UC2 iMERMAID scenario (cradle-to-grave) according to the Environmental Footprint method, version 3.1.

Characterized results for UC2 iMERMAID scenario	Unit	Total	Opalia Operation	ENIG cradle-to-gate	EDEN cradle-to-gate	ENIG operation	EDEN operation	ENIG EoL	EDEN EoL
Acidification	mol H+ eq	2.38E-02	6.49E-03	1.08E-02	3.82E-04	5.25E-03	8.66E-04	2.76E-06	1.06E-06
Climate change	kg CO2 eq	1.33E+01	7.11E+00	1.33E+00	8.59E-02	4.14E+00	6.83E-01	4.86E-04	3.21E-03
Climate change - Biogenic	kg CO2 eq	4.48E-03	5.24E-04	2.75E-03	7.24E-04	4.24E-04	6.99E-05	1.01E-06	2.78E-08
Climate change - Fossil	kg CO2 eq	1.33E+01	7.11E+00	1.32E+00	8.51E-02	4.14E+00	6.83E-01	4.84E-04	3.21E-03
Climate change - Land use and LU change	kg CO2 eq	2.62E-03	3.49E-04	1.83E-03	1.06E-04	2.83E-04	4.66E-05	9.89E-07	8.99E-08
Ecotoxicity, freshwater	CTUe	4.30E+01	5.09E+00	3.27E+01	3.81E-01	4.10E+00	6.76E-01	2.44E-03	2.99E-02
Ecotoxicity, freshwater - Inorganics	CTUe	4.05E+01	4.00E+00	3.23E+01	3.46E-01	3.24E+00	5.34E-01	2.18E-03	2.97E-02
Ecotoxicity, freshwater - organics	CTUe	2.55E+00	1.09E+00	4.29E-01	3.45E-02	8.62E-01	1.42E-01	2.60E-04	1.73E-04
Particulate matter	disease inc.	1.35E-07	2.68E-08	7.99E-08	2.76E-09	2.17E-08	3.57E-09	3.18E-11	5.19E-10

Eutrophication, marine	kg N eq	4.72E-03	1.58E-03	1.57E-03	8.13E-05	1.28E-03	2.11E-04	6.26E-07	1.09E-06
Eutrophication, freshwater	kg P eq	1.60E-03	2.26E-04	1.09E-03	6.96E-05	1.81E-04	2.99E-05	1.97E-07	2.55E-08
Eutrophication, terrestrial	mol N eq	5.19E-02	1.74E-02	1.73E-02	7.32E-04	1.41E-02	2.32E-03	6.72E-06	5.23E-06
Human toxicity, cancer	CTUh	4.64E-09	9.77E-10	2.68E-09	5.61E-11	7.91E-10	1.30E-10	2.65E-13	2.15E-12
Human toxicity, cancer - inorganics	CTUh	3.23E-09	5.76E-10	2.08E-09	2.76E-11	4.66E-10	7.68E-11	1.78E-13	3.34E-13
Human toxicity, cancer - organics	CTUh	1.41E-09	4.02E-10	6.01E-10	2.85E-11	3.25E-10	5.36E-11	8.72E-14	1.81E-12
Human toxicity, non-cancer	CTUh	1.58E-07	3.92E-08	8.34E-08	1.28E-09	2.92E-08	4.82E-09	1.44E-11	6.53E-11
Human toxicity, non-cancer - inorganics	CTUh	1.47E-07	3.38E-08	8.03E-08	1.22E-09	2.74E-08	4.51E-09	1.41E-11	6.47E-11
Human toxicity, non-cancer - organics	CTUh	1.07E-08	5.43E-09	3.09E-09	6.22E-11	1.85E-09	3.06E-10	3.16E-13	5.70E-13
Ionising radiation	kBq U-235 eq	1.63E-01	8.86E-03	1.19E-01	2.64E-02	7.17E-03	1.18E-03	5.45E-05	1.56E-06
Land use	Pt	1.21E+01	2.89E+00	6.26E+00	2.76E-01	2.34E+00	3.86E-01	4.15E-03	7.88E-04
Ozone depletion	kg CFC11 eq	6.49E-07	1.46E-07	3.33E-07	3.21E-08	1.18E-07	1.95E-08	4.80E-12	5.02E-12
Photochemical ozone formation	kg NMVOC eq	2.89E-02	1.23E-02	5.38E-03	2.46E-04	9.40E-03	1.55E-03	2.03E-06	1.84E-06
Resource use, fossils	MJ	1.78E+02	8.06E+01	2.04E+01	1.53E+00	6.52E+01	1.08E+01	6.74E-03	8.16E-04
Resource use, minerals and metals	kg Sb eq	2.40E-04	3.01E-05	1.80E-04	9.70E-07	2.44E-05	4.02E-06	3.82E-09	7.14E-11
Water use	m3 depriv.	9.94E-01	2.59E-01	4.58E-01	3.28E-02	2.10E-01	3.46E-02	1.17E-04	6.60E-05

Table 40: Normalized results for UC2 iMERMAID scenario (cradle-to-grave) according to the Environmental Footprint method, version 3.1.

Normalize results for UC2 iMERMAID scenario	Total	Opalia Operation	ENIG cradle-to-gate	EDEN cradle-to-gate	ENIG operation	EDEN operation	ENIG EoL	EDEN EoL
Acidification	4.29E-04	1.17E-04	1.95E-04	6.87E-06	9.46E-05	1.56E-05	4.96E-08	1.91E-08
Climate change	1.77E-03	9.41E-04	1.76E-04	1.14E-05	5.49E-04	9.04E-05	6.43E-08	4.25E-07
Ecotoxicity, freshwater	7.58E-04	8.97E-05	5.77E-04	6.71E-06	7.23E-05	1.19E-05	4.30E-08	5.27E-07
Particulate matter	2.27E-04	4.50E-05	1.34E-04	4.63E-06	3.64E-05	6.00E-06	5.34E-08	8.71E-07
Eutrophication, marine	2.42E-04	8.09E-05	8.04E-05	4.16E-06	6.54E-05	1.08E-05	3.20E-08	5.58E-08

Eutrophication, freshwater	9.95E-04	1.40E-04	6.79E-04	4.33E-05	1.13E-04	1.86E-05	1.23E-07	1.58E-08
Eutrophication, terrestrial	2.93E-04	9.86E-05	9.78E-05	4.14E-06	7.97E-05	1.31E-05	3.80E-08	2.96E-08
Human toxicity, cancer	2.69E-04	5.67E-05	1.55E-04	3.25E-06	4.58E-05	7.56E-06	1.54E-08	1.24E-07
Human toxicity, non-cancer	1.23E-03	3.05E-04	6.48E-04	9.97E-06	2.27E-04	3.74E-05	1.12E-07	5.07E-07
Ionising radiation	3.85E-05	2.10E-06	2.82E-05	6.26E-06	1.70E-06	2.80E-07	1.29E-08	3.69E-10
Land use	1.48E-05	3.53E-06	7.63E-06	3.36E-07	2.86E-06	4.71E-07	5.06E-09	9.61E-10
Ozone depletion	1.24E-05	2.79E-06	6.37E-06	6.14E-07	2.26E-06	3.73E-07	9.17E-11	9.59E-11
Photochemical ozone formation	7.07E-04	3.01E-04	1.32E-04	6.03E-06	2.30E-04	3.79E-05	4.97E-08	4.51E-08
Resource use, fossils	2.75E-03	1.24E-03	3.13E-04	2.35E-05	1.00E-03	1.65E-04	1.04E-07	1.25E-08
Resource use, minerals and metals	3.77E-03	4.73E-04	2.83E-03	1.52E-05	3.83E-04	6.32E-05	6.00E-08	1.12E-09
Water use	8.67E-05	2.26E-05	3.99E-05	2.86E-06	1.83E-05	3.02E-06	1.02E-08	5.76E-09

Table 41: Weighted results for UC2 iMERMAID scenario (cradle-to-grave) according to the Environmental Footprint method, version 3.1.

Weighted results for UC2 iMERMAID scenario	Unit	Total	Opalia Operation	ENIG cradle-to-gate	EDEN cradle-to-gate	ENIG operation	EDEN operation	ENIG EoL	EDEN EoL
Acidification	μPt	2.66E+01	7.24E+00	1.21E+01	4.26E-01	5.86E+00	9.67E-01	3.07E-03	1.18E-03
Climate change	μPt	3.72E+02	1.98E+02	3.70E+01	2.40E+00	1.16E+02	1.90E+01	1.35E-02	8.95E-02
Ecotoxicity, freshwater	μPt	1.46E+01	1.72E+00	1.11E+01	1.29E-01	1.39E+00	2.29E-01	8.25E-04	1.01E-02
Particulate matter	μPt	2.04E+01	4.03E+00	1.20E+01	4.15E-01	3.26E+00	5.38E-01	4.78E-03	7.81E-02
Eutrophication, marine	μPt	7.16E+00	2.40E+00	2.38E+00	1.23E-01	1.94E+00	3.19E-01	9.48E-04	1.65E-03
Eutrophication, freshwater	μPt	2.78E+01	3.93E+00	1.90E+01	1.21E+00	3.16E+00	5.21E-01	3.44E-03	4.44E-04
Eutrophication, terrestrial	μPt	1.09E+01	3.66E+00	3.63E+00	1.54E-01	2.96E+00	4.88E-01	1.41E-03	1.10E-03
Human toxicity, cancer	μPt	5.73E+00	1.21E+00	3.31E+00	6.93E-02	9.77E-01	1.61E-01	3.27E-04	2.65E-03
Human toxicity, non-cancer	μPt	2.26E+01	5.61E+00	1.19E+01	1.83E-01	4.18E+00	6.89E-01	2.05E-03	9.34E-03
Ionising radiation	μPt	1.93E+00	1.05E-01	1.41E+00	3.14E-01	8.52E-02	1.40E-02	6.47E-04	1.85E-05



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Land use	μPt	1.18E+00	2.80E-01	6.06E-01	2.67E-02	2.27E-01	3.74E-02	4.02E-04	7.63E-05
Ozone depletion	μPt	7.83E-01	1.76E-01	4.02E-01	3.87E-02	1.43E-01	2.35E-02	5.79E-06	6.05E-06
Photochemical ozone formation	μPt	3.38E+01	1.44E+01	6.30E+00	2.88E-01	1.10E+01	1.81E+00	2.37E-03	2.16E-03
Resource use, fossils	μPt	2.28E+02	1.03E+02	2.61E+01	1.96E+00	8.35E+01	1.38E+01	8.63E-03	1.04E-03
Resource use, minerals and metals	μPt	2.84E+02	3.57E+01	2.14E+02	1.15E+00	2.89E+01	4.77E+00	4.53E-03	8.48E-05
Water use	μPt	7.38E+00	1.92E+00	3.40E+00	2.43E-01	1.56E+00	2.57E-01	8.72E-04	4.90E-04
Total	μPt	1.07E+03	3.84E+02	3.64E+02	9.12E+00	2.65E+02	4.36E+01	4.79E-02	1.98E-01

Annex III Use Case 3: Secondary datasets used and results

Table 42: Material, process and transport datasets and assumptions used for modeling UC3 baseline scenario.

Datasets used for baseline scenario, SMAT	Input/output	Selected material/process dataset	Transportation distance [km]	Selected transport dataset
Sludge treatment	Output	Ecoinvent: treatment of raw sewage sludge, municipal incineration, GLO Ecoinvent, drying, sewage sludge, CH Ecoinvent: treatment of sewage sludge by anaerobic digestion, CH	5.585e-3	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4
Chemicals	Input	Ecoinvent: peracetic acid production, from acetic acid and hydrogen peroxide, RER; For aluminium sulphate, 8%: Ecoinvent: aluminium sulfate production, powder, RER, and market for tap water, RER	Aluminum sulphate: 0,007146 Paracetic acid: 2,584e-05	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4
Electricity	Input	Ecoinvent: electricity production, wind, >3MW turbine, onshore, IT Ecoinvent: electricity voltage transformation from high to medium voltage, IT Ecoinvent: electricity voltage transformation from medium to low voltage, IT		
Direct emissions	Output	Data from SMAT for 2024		

Table 43: Material, process and transport datasets and assumptions used for modeling UC3 iMERMAID scenario.

Datasets used for Scavenger, cradle-to-gate	Input/output	Lifetime [years]	Selected material/process dataset	Comments material dataset selection	Transportation distance [km]	Selected transport dataset	Comments transport dataset
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Reactor piping	Input	20	Ecoinvent: Process dataset, PVC production; polyvinyl chloride production, suspension polymerisation, RER; Ecoinvent: Process dataset pipes production: extrusion, plastic pipes, RER*	Suspension polymerization is the most widespread production technique for PVC (about 90%). It was preferred to emission polymerization due to higher representativity for PVC production	250	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	Transport of PVC to processing modelled according to PEF assumption: 130 km by truck (>32 t, EURO 4) for transport within Europe, from supplier to factory; Transport from pipe production to factory assumed by lorry
PA12	Input	2	Ecoinvent: plastic granulate production, unspecified, recycled, formal sector, IN	material specific dataset considering recycling not available, data for Europe not available	25	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	
Ion exchanger	Input	2	Ecoinvent: ion-exchanger production for water treatment, CH	no dataset for Finland or RER available, best geographical proxy in Ecoinvent	2000	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4; Ecoinvent: transport, freight, sea, container ship, heavy fuel oil"	equal share of road and sea transport assumed
Bolts and Nuts	Input	2	Oekobaodat: Stainless steel screws; Stainless steel		50	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	
Gasket	Input	2	EPD: EPDM gaskets (International Rubber Co)		25	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	
Electricity	Input		Ecoinvent; market for electricity, low voltage; FI				
Production waste	Output		Ecoinvent: treatment of municipal solid waste, municipal incineration; FI		25	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	
Datasets used for supporting	<i>Input/output</i>	<i>Lifetime [years]</i>	<i>Selected material/process dataset</i>	<i>Comments material dataset selection</i>	<i>Transportation distance [km]</i>	<i>Selected transport dataset</i>	<i>Comments transport dataset</i>

components, cradle-to-gate							
Support frame	Input	20	steel production, electric, chromium steel 18/8, RER; metal working, average for steel product manufacturing, RER	modelled according to main material composition	40	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	
Pump	Input	20	carbon fibre reinforced plastic, injection moulded, GLO; silicon carbide production, ROW; synthetic rubber production, ROW	modelled according to main material composition	19000	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4; Ecoinvent: transport, freight, sea, container ship, heavy fuel oil	Provenience unknown, assumption according to PEF
Pipes	Input	20	polyvinyl chloride production, suspension polymerisation, RER; extrusion, plastic pipes, RER	modelled according to main material composition	1000	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4; Ecoinvent: transport, freight, sea, container ship, heavy fuel oil	equal share of road and sea transport assumed
Valves	Input	20	see EPD for butterfly valves (GF Piping Systems, 2022)	Data used: generic product	2000	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4; Ecoinvent: transport, freight, sea, container ship, heavy fuel oil	equal share of road and sea transport assumed
Measurement instruments	Input	20	see EPD of generic instrument (ABB, 2022)	Data used: generic product	1000	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	
Automation components	Input	20	see EPD (Siemens, 2024)	Data used: specific product	50	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	

Datasets used installation and transportation	<i>Input/output</i>	<i>Lifetime [years]</i>	<i>Selected material/process dataset</i>	<i>Comments material dataset selection</i>	<i>Transportation distance [km]</i>	<i>Selected transport dataset</i>	<i>Comments transport dataset</i>
<i>Cardboard box</i>	Input		corrugated board box production, RER		50	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	
<i>Pallet</i>	Input		EUR-flat pallet production, RER		50	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	
<i>Waste cardboard box</i>	Output		market for waste paperboard, IT		50	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	
<i>Waste Pallet</i>	Output		market for municipal solid waste, IT		50	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	
<i>Scavenger transportation to installation</i>	Transport only				3000	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4; Ecoinvent: transport, freight, sea, container ship, heavy fuel oil	Estimated distance from manufacturing to installation location in UC3. Modal split: 2000 km sea transport, 1000 m road transport
Datasets used Scavenger use phase	<i>Input/output</i>	<i>Lifetime [years]</i>	<i>Selected material/process dataset</i>	<i>Comments material dataset selection</i>	<i>Transportation distance [km]</i>	<i>Selected transport dataset</i>	<i>Comments transport dataset</i>
<i>Electricity</i>	Input		electricity production, wind, >3MW turbine, onshore, IT; electricity voltage transformation from high to medium voltage, IT; electricity				

			<i>voltage transformation from medium to low voltage</i>				
<i>Regenerant</i>	<i>Input</i>		<i>chlor-alkali electrolysis, average production, RER; market for water, deionised, Europe</i>	<i>95% dilution rate</i>	20	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	
<i>Eluent</i>	<i>Input</i>		<i>sulfuric acid production, RER; market for water, deionised, Europe</i>	<i>50% dilution rate</i>	20	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	
<i>Water</i>	<i>Input</i>		<i>tap water production, underground water without treatment</i>				
<i>Metals waste</i>	<i>Output</i>		<i>treatment of waste copper, municipal incineration, Europe</i>		50	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	
<i>Chemicals waste</i>	<i>Output</i>		<i>treatment of municipal solid waste, sanitary landfill, IT</i>		50	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	
Datasets used for end-of-life Scavenger and supporting components	<i>Input/output</i>	<i>Lifetime [years]</i>	<i>Selected material/process dataset</i>	<i>Comments material dataset selection</i>	<i>Transportation distance [km]</i>	<i>Selected transport dataset</i>	<i>Comments transport dataset</i>
<i>Supporting components: treatment of electronic waste</i>	<i>Output</i>		<i>treatment of waste electric and electronic equipment, shredding, GLO</i>		50	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	



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<i>Supporting components: treatment of other waste</i>	Output		market for municipal solid waste, IT		50	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	
<i>Scavenger: waste treatment</i>	Output		market for municipal solid waste, IT		50	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	

Table 44: Characterized results for UC3 baseline scenario according to the Environmental Footprint method, version 3.1.

Characterised results Baseline scenario SMAT	UC3	Total impact category	Chemicals: aluminium sulphate	Chemicals: peracetic acid	Direct emissions	Electricity consumption	Sludge treatment
acidification (accumulated exceedance (AE)) [mol H ⁺ -Eq]		0.000717	1.16E-04	2.52E-04		0.0002471	1.03E-04
climate change (global warming potential (GWP100)) [kg CO ₂ -Eq]		0.7904	0.005903	0.08396	0.5785	0.06891	0.05312
climate change: biogenic (global warming potential (GWP100)) [kg CO ₂ -Eq]		0.01171	7.96E-06	2.66E-04		0.000172	0.01127
climate change: fossil (global warming potential (GWP100)) [kg CO ₂ -Eq]		0.7786	0.005886	0.08365	0.5785	0.06872	0.04184
climate change: land use and land use change (global warming potential (GWP100)) [kg CO ₂ -Eq]		7.54E-05	8.66E-06	4.46E-05		1.53E-05	6.83E-06
ecotoxicity: freshwater (comparative toxic unit for ecosystems (CTUe)) [CTUe]		1.112	0.02982	0.6982		0.1491	0.2349
ecotoxicity: freshwater. inorganics (comparative toxic unit for ecosystems (CTUe)) [CTUe]		0.9944	0.02664	0.6188		0.1176	0.2313
ecotoxicity: freshwater. organics (comparative toxic unit for ecosystems (CTUe)) [CTUe]		0.1175	0.003179	0.07935		0.03142	0.003571
energy resources: non-renewable (abiotic depletion potential (ADP): fossil fuels) [MJ. net calorific value]		3.347	0.08867	1.464		1.144	0.6508

<i>eutrophication: freshwater (fraction of nutrients reaching freshwater end compartment (P)) [kg P-Eq]</i>	5.42E-05	3.78E-06	1.82E-05		1.78E-05	1.44E-05
<i>eutrophication: marine (fraction of nutrients reaching marine end compartment (N)) [kg N-Eq]</i>	0.000196	7.13E-06	4.90E-05		4.41E-05	9.54E-05
<i>eutrophication: terrestrial (accumulated exceedance (AE)) [mol N-Eq]</i>	0.001395	7.45E-05	0.000486		0.0004617	0.000373
<i>human toxicity: carcinogenic (comparative toxic unit for human (CTUh)) [CTUh]</i>	1.55E-10	3.80E-12	1.67E-11		1.23E-10	1.18E-11
<i>human toxicity: carcinogenic. inorganics (comparative toxic unit for human (CTUh)) [CTUh]</i>	2.08E-11	2.13E-12	7.33E-12		6.11E-12	5.26E-12
<i>human toxicity: carcinogenic. organics (comparative toxic unit for human (CTUh)) [CTUh]</i>	1.35E-10	1.67E-12	9.37E-12		1.17E-10	6.53E-12
<i>human toxicity: non-carcinogenic (comparative toxic unit for human (CTUh)) [CTUh]</i>	1.83E-09	1.41E-10	8.26E-10		5.20E-10	3.38E-10
<i>human toxicity: non-carcinogenic. inorganics (comparative toxic unit for human (CTUh)) [CTUh]</i>	1.45E-09	1.36E-10	5.29E-10		4.89E-10	3.00E-10
<i>human toxicity: non-carcinogenic. organics (comparative toxic unit for human (CTUh)) [CTUh]</i>	3.72E-10	5.28E-12	2.97E-10		3.17E-11	3.74E-11
<i>ionising radiation: human health (human exposure efficiency relative to u235) [kBq U235-Eq]</i>	0.02396	0.001455	0.005681		0.009608	0.007214
<i>land use (soil quality index) [dimensionless]</i>	0.6039	0.02839	0.1673		0.1923	0.2159

<i>material resources: metals/minerals (abiotic depletion potential (ADP): elements (ultimate reserves)) [kg Sb-Eq]</i>	1.32E-06	1.21E-07	5.79E-07		4.44E-07	1.75E-07
<i>ozone depletion (ozone depletion potential (ODP)) [kg CFC-11-Eq]</i>	4.72E-09	8.27E-11	1.90E-09		1.63E-09	1.10E-09
<i>particulate matter formation (impact on human health) [disease incidence]</i>	5.96E-09	9.37E-10	3.15E-09		1.12E-09	7.59E-10
<i>photochemical oxidant formation: human health (tropospheric ozone concentration increase) [kg NMVOC-Eq]</i>	6.14E-04	2.71E-05	2.63E-04		0.0001865	0.000137
<i>water use (user deprivation potential (deprivation-weighted water consumption)) [m³ world Eq deprived]</i>	0.1261	0.006725	0.06096		0.04039	0.01801
<i>acidification (accumulated exceedance (AE)) [mol H⁺-Eq]</i>	0.000717	1.16E-04	2.52E-04		0.0002471	1.03E-04
<i>climate change (global warming potential (GWP100)) [kg CO₂-Eq]</i>	0.7904	0.005903	0.08396	0.5785	0.06891	0.05312

Table 45: Normalised results for UC3 baseline scenario according to the Environmental Footprint method, version 3.1

Normalised results UC3 Baseline scenario SMAT	Total impact category	Chemicals: aluminium sulphate	Chemicals: peracetic acid	Direct emissions	Electricity consumption	Sludge treatment
acidification	1.291E-05	2.08208E-06	4.54E-06	0	4.45E-06	1.84E-06
climate change	0.000104646	7.81535E-07	1.11E-05	7.66E-05	9.12E-06	7.03E-06
ecotoxicity: freshwater	56716.59		ecotoxicity: freshwater	1.96063E-05	5.25772E-07	1.23E-05
energy resources: non-renewable	5.14889E-05	1.36406E-06	2.25E-05	0	1.76E-05	1E-05
eutrophication: freshwater	3.37181E-05	2.35243E-06	1.13E-05	0	1.11E-05	8.97E-06
eutrophication: marine	1.00025E-05	3.64693E-07	2.51E-06	0	2.26E-06	4.88E-06
eutrophication: terrestrial	7.89228E-06	4.21374E-07	2.75E-06	0	2.61E-06	2.11E-06
human toxicity: carcinogenic	9.00139E-06	2.20311E-07	9.68E-07	0	7.13E-06	6.83E-07
human toxicity: non-carcinogenic	1.41841E-05	1.09604E-06	6.42E-06	0	4.04E-06	2.62E-06
ionising radiation: human health	5.67751E-06	3.44773E-07	1.35E-06	0	2.28E-06	1.71E-06
land use	7.36914E-07	3.46432E-08	2.04E-07	0	2.35E-07	2.63E-07
material resources: metals/minerals	2.07316E-05	1.8987E-06	9.1E-06	0	6.98E-06	2.75E-06
ozone depletion	9.01078E-08	1.5798E-09	3.63E-08	0	3.12E-08	2.11E-08
particulate matter formation	1.00157E-05	1.57382E-06	5.29E-06	0	1.87E-06	1.28E-06
photochemical oxidant formation: human health	1.50248E-05	6.63743E-07	6.44E-06	0	4.56E-06	3.36E-06
water use	1.09951E-05	5.86378E-07	5.32E-06	0	3.52E-06	1.57E-06

Table 46: Weighted results for UC3 baseline scenario according to the Environmental Footprint method, version 3.1

Weighted results scenario	UC3	Baseline	Total impact category	Chemicals: aluminium sulphate	Chemicals: peracetic acid	Direct emissions	Electricity consumption	Sludge treatment
acidification			0.800416901	0.129088703	0.281273	0	0.275694	0.114361
climate change			22.03844925	0.164591303	2.341028	16.13011	1.921394	1.481127
ecotoxicity: freshwater			0.376440145	0.010094825	0.236358	0	0.050474	0.07952
energy resources: non-renewable			4.283879263	0.113490163	1.873797	0	1.464224	0.832969
eutrophication: freshwater			0.944106787	0.065867915	0.316619	0	0.310346	0.2511
eutrophication: marine			0.296072972	0.010794927	0.074162	0	0.066772	0.144402
eutrophication: terrestrial			0.292803599	0.015632984	0.101946	0	0.096909	0.078333
human toxicity: carcinogenic			0.191729532	0.00469262	0.020617	0	0.151853	0.014556
human toxicity: non-carcinogenic			0.260987363	0.020167205	0.118102	0	0.074366	0.048296
ionising radiation: human health			0.284443015	0.017273146	0.067442	0	0.114062	0.085642
land use			0.058511002	0.002750666	0.016209	0	0.018632	0.020918
material resources: metals/minerals			1.565237449	0.143351542	0.687209	0	0.527363	0.20767
ozone depletion			0.005685805	9.96854E-05	0.00229	0	0.001967	0.00133
particulate matter formation			0.897404392	0.14101424	0.474362	0	0.167802	0.114241
photochemical oxidant formation: human health			1.50248E-05	6.63743E-07	6.44E-06	0	4.56E-06	3.36E-06
water use			1.09951E-05	5.86378E-07	5.32E-06	0	3.52E-06	1.57E-06

Table 47: Characterized results for UC3 iMERMAID scenario, Scavenger cradle-to-gate assessment

Characterised results UC3 Scavenger cradle-to-gate	Total impact category	Reactor piping	PA12	Ion exchanger	Bolts and Nuts	Gasket	Transport of components to production site	Electricity	Production waste
acidification (accumulated exceedance (AE)) [mol H ⁺ -Eq]	7.6724E-06	1.56322E-06	1.27299E-07	2.90632E-06	1.98759E-07	6.6092E-10	4.30877E-07	2.41782E-06	2.74483E-08
climate change (global warming potential (GWP100)) [kg CO ₂ -Eq]	0.001642355	0.000293218	3.6477E-05	0.00069092	2.88483E-05	1.81609E-07	8.50722E-05	0.000479368	2.82701E-05
climate change: biogenic (global warming potential (GWP100)) [kg CO ₂ -Eq]	4.07387E-06	4.49138E-07	9.6954E-09	2.18678E-06	1.77448E-08	-4.9023E-09	2.79366E-08	1.24828E-06	1.39195E-07
climate change: fossil (global warming potential (GWP100)) [kg CO ₂ -Eq]	0.001630979	0.000292126	3.6431E-05	0.000688506	2.88069E-05	1.86207E-07	8.50145E-05	0.000471782	2.81264E-05
climate change: land use and land use change (global warming potential (GWP100)) [kg CO ₂ -Eq]	7.24775E-06	6.37356E-07	3.70805E-08	1.59828E-07	2.72966E-08	5.09195E-10	2.84339E-08	6.35632E-06	9.22414E-10
ecotoxicity: freshwater (comparative toxic unit for ecosystems (CTUe)) [CTUe]	0.004926835	0.000736782	0.000200575	0.00212092	0	1.45977E-06	0.000142444	0.001607471	0.000117184
ecotoxicity: freshwater. inorganics (comparative toxic unit for ecosystems (CTUe)) [CTUe]	0.004688619	0.000724713	0.00019546	0.001920345	0	0	0.000136263	0.001594828	0.000117011
ecotoxicity: freshwater. organics (comparative toxic unit for ecosystems (CTUe)) [CTUe]	0.000236389	1.18851E-05	5.12816E-06	0.000200201	0	0	6.17676E-06	1.28103E-05	1.87184E-07
energy resources: non-renewable (abiotic depletion potential (ADP): fossil fuels) [MJ. net calorific value]	0.036206283	0.005651724	0.000398448	0.012506897	0	0	0.001225168	0.016385057	3.89885E-05

<i>eutrophication: freshwater (fraction of nutrients reaching freshwater end compartment (P)) [kg P-Eq]</i>	5.2483E-07	2.1023E-07	1.9454E-08	7.7092E-08	5.18483E-11	2.21839E-11	5.87559E-09	2.0931E-07	2.79368E-09
<i>eutrophication: marine (fraction of nutrients reaching marine end compartment (N)) [kg N-Eq]</i>	1.42818E-06	2.67126E-07	2.82931E-08	4.83218E-07	1.97379E-08	1.33908E-10	1.48875E-07	4.32069E-07	4.87241E-08
<i>eutrophication: terrestrial (accumulated exceedance (AE)) [mol N-Eq]</i>	1.51733E-05	2.58908E-06	2.75632E-07	4.07184E-06	1.82414E-06	1.28736E-09	1.62699E-06	4.65402E-06	1.30345E-07
<i>human toxicity: carcinogenic (comparative toxic unit for human (CTUh)) [CTUh]</i>	2.0974E-12	1.07931E-13	9.02874E-15	1.78075E-12	0	5.64943E-17	1.39731E-14	1.78908E-13	6.75862E-15
<i>human toxicity: carcinogenic. inorganics (comparative toxic unit for human (CTUh)) [CTUh]</i>	2.01178E-13	3.53448E-14	4.25575E-15	4.72701E-14	0	0	6.38795E-15	1.02126E-13	5.7931E-15
<i>human toxicity: carcinogenic. organics (comparative toxic unit for human (CTUh)) [CTUh]</i>	1.89653E-12	7.25862E-14	4.77529E-15	1.73378E-12	0	0	7.58513E-15	7.68391E-14	9.67241E-16
<i>human toxicity: non-carcinogenic (comparative toxic unit for human (CTUh)) [CTUh]</i>	1.73706E-11	2.19023E-12	4.68103E-13	3.90517E-12	0	1.44828E-15	7.78606E-13	9.73563E-12	2.91379E-13
<i>human toxicity: non-carcinogenic. inorganics (comparative toxic unit for human (CTUh)) [CTUh]</i>	1.58592E-11	2.11609E-12	4.5592E-13	3.03218E-12	0	0	7.3069E-13	9.23563E-12	2.88678E-13
<i>human toxicity: non-carcinogenic. organics (comparative toxic unit for human (CTUh)) [CTUh]</i>	1.50652E-12	7.3908E-14	1.21609E-14	8.71897E-13	0	0	4.79052E-14	4.97931E-13	2.71609E-15
<i>ionising radiation: human health (human exposure efficiency relative to u235) [kBq U235-Eq]</i>	0.001020266	0.000129253	8.60345E-07	4.61897E-05	0	4.21264E-09	1.36526E-06	0.000842529	0.000000065

<i>land use (soil quality index) [dimensionless]</i>	0.012751312	0.004877586	6.78161E-05	0.000900115	0	0	0.001203674	0.005678736	2.33851E-05
<i>material resources: metals/minerals (abiotic depletion potential (ADP): elements (ultimate reserves)) [kg Sb-Eq]</i>	1.52061E-08	9.02299E-10	1.11724E-10	4.52011E-09	0	0	2.31995E-10	9.43103E-09	8.98276E-12
<i>ozone depletion (ozone depletion potential (ODP)) [kg CFC-11-Eq]</i>	1.76109E-08	7.93678E-12	3.38161E-13	1.75934E-08	1.8869E-16	0	1.83345E-12	7.28161E-12	6.89655E-14
<i>particulate matter formation (impact on human health) [disease incidence]</i>	6.04309E-11	1.06437E-11	7.86207E-13	2.58563E-11	0	1.18391E-14	8.46017E-12	1.43966E-11	2.76149E-13
<i>photochemical oxidant formation: human health (tropospheric ozone concentration increase) [kg NMVOC-Eq]</i>	4.72456E-06	8.3046E-07	9.18391E-08	1.72989E-06	6.32069E-08	0	5.85328E-07	1.38851E-06	3.53333E-08
<i>water use (user deprivation potential (deprivation-weighted water consumption)) [m³ world Eq deprived]</i>	0.001347077	0.000512241	6.32759E-06	0.000400057	5.34621E-06	4.37356E-08	7.22493E-06	0.000412241	3.59425E-06
<i>acidification (accumulated exceedance (AE)) [mol H⁺-Eq]</i>	7.6724E-06	1.56322E-06	1.27299E-07	2.90632E-06	1.98759E-07	6.6092E-10	4.30877E-07	2.41782E-06	2.74483E-08
<i>climate change (global warming potential (GWP100)) [kg CO₂-Eq]</i>	0.001642355	0.000293218	3.6477E-05	0.00069092	2.88483E-05	1.81609E-07	8.50722E-05	0.000479368	2.82701E-05

Table 48: Normalised results for UC3 IMERMAID scenario, Scavenger cradle-to-gate assessment

Normalised results UC3 Scavenger cradle-to-gate	Total impact category	Reactor piping	PA12	Ion exchanger	Bolts and Nuts	Gasket	Transport of components to production site	Electricity	Production waste
acidification	1.38068E-07	2.81308E-08	2.2908E-09	5.23006E-08	3.57675E-09	1.18936E-11	7.75383E-09	4.35097E-08	4.93945E-10
climate change	2.17442E-07	3.8821E-08	4.82942E-09	9.14752E-08	3.8194E-09	2.40444E-11	1.12632E-08	6.34665E-08	3.74286E-09
ecotoxicity: freshwater	8.68676E-08	1.29906E-08	3.53644E-09	3.7395E-08	0	2.5738E-11	2.5115E-09	2.83422E-08	2.06613E-09
energy resources: non-renewable	5.56983E-07	8.69439E-08	6.12957E-09	1.92401E-07	0	0	1.88475E-08	2.52061E-07	5.99784E-10
eutrophication: freshwater	3.2662E-07	1.30833E-07	1.21069E-08	4.7977E-08	3.2267E-11	1.38058E-11	3.65658E-09	1.30261E-07	1.7386E-09
eutrophication: marine	7.30706E-08	1.36671E-08	1.44757E-09	2.47231E-08	1.00986E-09	6.85121E-12	7.61695E-09	2.21062E-08	2.4929E-09
eutrophication: terrestrial	8.58439E-08	1.46478E-08	1.5594E-09	2.30366E-08	1.03201E-08	7.28328E-12	9.20477E-09	2.63304E-08	7.37432E-10
human toxicity: carcinogenic	1.21568E-07	6.25582E-09	5.23317E-10	1.03214E-07	0	3.27448E-12	8.09898E-10	1.03697E-08	3.91738E-10
human toxicity: non-carcinogenic	1.34932E-07	1.70134E-08	3.63616E-09	3.03348E-08	0	1.125E-11	6.0481E-09	7.56249E-08	2.26339E-09
ionising radiation: human health	2.4176E-07	3.06275E-08	2.03865E-10	1.0945E-08	0	9.98218E-13	3.23508E-10	1.99644E-07	1.54022E-11
land use	1.55599E-08	5.95192E-09	8.27532E-11	1.09837E-09	0	0	1.46879E-09	6.92953E-09	2.85358E-11
material resources: metals/minerals	2.39005E-07	1.4182E-08	1.75604E-09	7.10457E-08	0	0	3.64642E-09	1.48234E-07	1.41188E-10
ozone depletion	3.36417E-07	1.51615E-10	6.45982E-12	3.36084E-07	3.6045E-15	0	3.5024E-11	1.39099E-10	1.31743E-12
particulate matter formation	1.01502E-07	1.78775E-08	1.32054E-09	4.34292E-08	0	1.98854E-11	1.421E-08	2.4181E-08	4.63831E-10
photochemical oxidant formation: human health	1.1563E-07	2.03249E-08	2.2477E-09	4.23377E-08	1.54694E-09	0	1.43255E-08	3.39827E-08	8.64758E-10



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<i>water use</i>	<i>1.17457E-07</i>	<i>4.46643E-08</i>	<i>5.51726E-10</i>	<i>3.48825E-08</i>	<i>4.66156E-10</i>	<i>3.81347E-12</i>	<i>6.29969E-10</i>	<i>3.59449E-08</i>	<i>3.13396E-10</i>
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Table 49: Weighted results for UC3 IMERMAID scenario, Scavenger cradle-to-gate assessment

Weighted results UC3 Scavenger cradle-to-gate	Total impact category	Reactor piping	PA12	Ion exchanger	Bolts and Nuts	Gasket	Transport of components to production site	Electricity	Production waste
acidification	8.56024E-09	1.74411E-09	1.4203E-10	3.24264E-09	2.21759E-10	7.37401E-13	4.80738E-10	2.6976E-09	3.06246E-11
climate change	4.57932E-08	8.17571E-09	1.01708E-09	1.92647E-08	8.04366E-10	5.06375E-12	2.37204E-09	1.3366E-08	7.88246E-10
ecotoxicity: freshwater	1.66786E-09	2.49419E-10	6.78996E-11	7.17985E-10	0	4.94169E-13	4.82209E-11	5.4417E-10	3.96697E-11
energy resources: non-renewable	4.6341E-08	7.23373E-09	5.0998E-10	1.60078E-08	0	0	1.56811E-09	2.09715E-08	4.9902E-11
eutrophication: freshwater	9.14535E-09	3.66333E-09	3.38994E-10	1.34336E-09	9.03476E-13	3.86563E-13	1.02384E-10	3.64731E-09	4.86809E-11
eutrophication: marine	2.16289E-09	4.04547E-10	4.28482E-11	7.31805E-10	2.98919E-11	2.02796E-13	2.25462E-10	6.54342E-10	7.37898E-11
eutrophication: terrestrial	3.18481E-09	5.43435E-10	5.78538E-11	8.54659E-10	3.82878E-10	2.7021E-13	3.41497E-10	9.76856E-10	2.73587E-11
human toxicity: carcinogenic	2.5894E-09	1.33249E-10	1.11467E-11	2.19847E-09	0	6.97464E-14	1.72508E-11	2.20875E-10	8.34403E-12
human toxicity: non-carcinogenic	2.48275E-09	3.13046E-10	6.69053E-11	5.5816E-10	0	2.07E-13	1.11285E-10	1.3915E-09	4.16464E-11
ionising radiation: human health	1.21122E-08	1.53444E-09	1.02137E-11	5.48344E-10	0	5.00107E-14	1.62077E-11	1.00021E-08	7.71653E-13
land use	1.23546E-09	4.72582E-10	6.5706E-12	8.72108E-11	0	0	1.16622E-10	5.50205E-10	2.26574E-12
material resources: metals/minerals	1.80449E-08	1.07074E-09	1.32581E-10	5.36395E-09	0	0	2.75305E-10	1.11917E-08	1.06597E-11
ozone depletion	2.12279E-08	9.56688E-12	4.07614E-13	2.12069E-08	2.27444E-16	0	2.21001E-12	8.77715E-12	8.31301E-14
particulate matter formation	9.09458E-09	1.60183E-09	1.18321E-10	3.89126E-09	0	1.78173E-12	1.27322E-09	2.16662E-09	4.15592E-11
photochemical oxidant formation: human health	5.52712E-09	9.71531E-10	1.0744E-10	2.02374E-09	7.39439E-11	0	6.84758E-10	1.62437E-09	4.13355E-11



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<i>water use</i>	<i>9.99557E-09</i>	<i>3.80093E-09</i>	<i>4.69519E-11</i>	<i>2.9685E-09</i>	<i>3.96699E-11</i>	<i>3.24527E-13</i>	<i>5.36104E-11</i>	<i>3.05891E-09</i>	<i>2.667E-11</i>
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Table 50: Characterized results for UC3 iMERMAID scenario, cradle-to-grave

Characterised results UC3 Scavenger cradle-to-gate	Total impact category	Scavenger Cradle-to-gate	Supporting components cradle-to-gate	Installation and of and supporting components	SMAT plant use phase	Scavenger use phase	End-of-life Scavenger and supporting components
acidification (accumulated exceedance (AE)) [mol H ⁺ -Eq]	1.91E-03	7.67E-06	6.18E-06	1.65E-05	7.17E-04	1.17E-03	8.72E-08
climate change (global warming potential (GWP100)) [kg CO ₂ -Eq]	9.60E-01	1.71E-03	1.18E-03	3.22E-03	7.90E-01	1.63E-01	5.25E-05
climate change: biogenic (global warming potential (GWP100)) [kg CO ₂ -Eq]	1.88E-02	4.25E-06	7.42E-06	5.54E-05	1.17E-02	7.02E-03	1.20E-06
climate change: fossil (global warming potential (GWP100)) [kg CO ₂ -Eq]	9.41E-01	1.70E-03	1.17E-03	3.16E-03	7.79E-01	1.56E-01	5.13E-05
climate change: land use and land use change (global warming potential (GWP100)) [kg CO ₂ -Eq]	1.73E-04	7.56E-06	1.27E-06	4.14E-06	7.54E-05	8.46E-05	5.41E-09
ecotoxicity: freshwater (comparative toxic unit for ecosystems (CTUe)) [CTUe]	1.88E+00	5.14E-03	1.39E-02	8.75E-03	1.11E+00	7.39E-01	1.69E-04

ecotoxicity: freshwater. inorganics (comparative toxic unit for ecosystems (CTUe)) [CTUe]	1.70E+00	4.89E-03	1.38E-02	7.97E-03	9.94E-01	6.83E-01	1.68E-04
ecotoxicity: freshwater. organics (comparative toxic unit for ecosystems (CTUe)) [CTUe]	1.75E-01	2.47E-04	1.05E-04	7.84E-04	1.18E-01	5.60E-02	1.01E-06
energy resources: non-renewable (abiotic depletion potential (ADP): fossil fuels) [MJ. net calorific value]	6.01E+00	3.78E-02	1.47E-02	4.65E-02	3.35E+00	2.56E+00	1.87E-04
eutrophication: freshwater (fraction of nutrients reaching freshwater end compartment (P)) [kg P-Eq]	1.15E-04	5.47E-07	1.08E-06	3.81E-07	5.42E-05	5.92E-05	3.92E-09
eutrophication: marine (fraction of nutrients reaching marine end compartment (N)) [kg N-Eq]	3.61E-04	1.49E-06	1.20E-06	5.76E-06	1.96E-04	1.57E-04	6.18E-08
eutrophication: terrestrial (accumulated exceedance (AE)) [mol N-Eq]	2.64E-03	1.58E-05	1.18E-05	6.10E-05	1.40E-03	1.15E-03	3.31E-07
human toxicity: carcinogenic (comparative toxic unit)	6.24E-10	2.19E-12	1.50E-12	2.54E-12	1.55E-10	4.63E-10	1.73E-14

<i>for human (CTUh) [CTUh]</i>							
<i>human toxicity: carcinogenic. inorganics (comparative toxic unit for human (CTUh)) [CTUh]</i>	4.02E-11	2.10E-13	1.10E-12	2.88E-13	2.08E-11	1.78E-11	1.51E-14
<i>human toxicity: carcinogenic. organics (comparative toxic unit for human (CTUh)) [CTUh]</i>	5.84E-10	1.98E-12	4.02E-13	2.25E-12	1.35E-10	4.45E-10	2.24E-15
<i>human toxicity: non- carcinogenic (comparative toxic unit for human (CTUh)) [CTUh]</i>	3.40E-09	1.81E-11	2.30E-11	3.20E-11	1.83E-09	1.50E-09	6.38E-13
<i>human toxicity: non- carcinogenic. inorganics (comparative toxic unit for human (CTUh)) [CTUh]</i>	2.92E-09	1.65E-11	2.25E-11	2.96E-11	1.45E-09	1.40E-09	6.21E-13
<i>human toxicity: non- carcinogenic. organics (comparative toxic unit for human (CTUh)) [CTUh]</i>	4.74E-10	1.57E-12	4.84E-13	2.49E-12	3.72E-10	9.78E-11	1.73E-14
<i>ionising radiation: human health (human exposure efficiency relative to u235) [kBq U235-Eq]</i>	5.12E-02	1.06E-03	1.34E-04	9.56E-05	2.40E-02	2.59E-02	2.86E-07

<i>land use (soil quality index) [dimensionless]</i>	1.36E+00	1.33E-02	6.83E-03	2.08E-01	6.04E-01	5.31E-01	1.72E-04
<i>material resources: metals/minerals (abiotic depletion potential (ADP): elements (ultimate reserves)) [kg Sb-Eq]</i>	3.34E-06	1.59E-08	2.80E-08	9.88E-09	1.32E-06	1.97E-06	1.92E-10
<i>ozone depletion (ozone depletion potential (ODP)) [kg CFC-11-Eq]</i>	2.80E-08	1.84E-08	1.18E-11	7.04E-11	4.72E-09	4.81E-09	2.91E-13
<i>particulate matter formation (impact on human health) [disease incidence]</i>	1.34E-08	6.30E-11	9.19E-11	3.04E-10	5.96E-09	6.99E-09	1.31E-12
<i>photochemical oxidant formation: human health (tropospheric ozone concentration increase) [kg NMVOC-Eq]</i>	1.12E-03	4.93E-06	3.80E-06	2.20E-05	6.14E-04	4.73E-04	1.06E-07
<i>water use (user deprivation potential (deprivation-weighted water consumption)) [m³ world Eq deprived]</i>	2.50E-01	1.41E-03	4.97E-04	5.68E-04	1.26E-01	1.22E-01	5.44E-06
<i>acidification (accumulated exceedance (AE)) [mol H⁺-Eq]</i>	1.91E-03	7.67E-06	6.18E-06	1.65E-05	7.17E-04	1.17E-03	8.72E-08



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<i>climate change (global warming potential (GWP100)) [kg CO2-Eq]</i>	<i>9.60E-01</i>	<i>1.71E-03</i>	<i>1.18E-03</i>	<i>3.22E-03</i>	<i>7.90E-01</i>	<i>1.63E-01</i>	<i>5.25E-05</i>
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Table 51: Normalised results for UC3 iMERMAID scenario, cradle-to-grave.

Normalised results UC3 Scavenger cradle-to-gate	Total impact category	Scavenger Cradle-to-gate	Supporting components cradle-to-gate	Installation and transportation of Scavenger and supporting components	SMAT plant use phase	Scavenger use phase	End-of-life Scavenger and supporting components
acidification	3.44E-05	1.38E-07	1.11E-07	2.97E-07	1.29E-05	2.1E-05	1.57E-09
climate change	0.000127	2.27E-07	1.56E-07	4.27E-07	0.000105	2.16E-05	6.96E-09
ecotoxicity: freshwater	3.31E-05	9.06E-08	2.45E-07	1.54E-07	1.96E-05	1.3E-05	2.98E-09
energy resources: non-renewable	9.25E-05	5.81E-07	2.26E-07	7.15E-07	5.15E-05	3.94E-05	2.88E-09
eutrophication: freshwater	7.18E-05	3.41E-07	6.75E-07	2.37E-07	3.37E-05	3.68E-05	2.44E-09
eutrophication: marine	1.85E-05	7.62E-08	6.13E-08	2.94E-07	1E-05	8.04E-06	3.16E-09
eutrophication: terrestrial	1.49E-05	8.95E-08	6.66E-08	3.45E-07	7.89E-06	6.53E-06	1.87E-09
human toxicity: carcinogenic	3.62E-05	1.27E-07	8.7E-08	1.47E-07	9E-06	2.68E-05	1E-09
human toxicity: non-carcinogenic	2.64E-05	1.41E-07	1.79E-07	2.49E-07	1.42E-05	1.16E-05	4.96E-09
ionising radiation: human health	1.21E-05	2.52E-07	3.18E-08	2.27E-08	5.68E-06	6.14E-06	6.77E-11
land use	1.66E-06	1.62E-08	8.33E-09	2.54E-07	7.37E-07	6.48E-07	2.1E-10
material resources: metals/minerals	5.26E-05	2.49E-07	4.4E-07	1.55E-07	2.07E-05	3.1E-05	3.02E-09
ozone depletion	5.34E-07	3.51E-07	2.26E-10	1.34E-09	9.01E-08	9.19E-08	5.56E-12
particulate matter formation	2.25E-05	1.06E-07	1.54E-07	5.11E-07	1E-05	1.17E-05	2.2E-09



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<i>photochemical oxidant formation: human health</i>	<i>2.73E-05</i>	<i>1.21E-07</i>	<i>9.3E-08</i>	<i>5.38E-07</i>	<i>1.5E-05</i>	<i>1.16E-05</i>	<i>2.6E-09</i>
<i>water use</i>	<i>2.18E-05</i>	<i>1.23E-07</i>	<i>4.34E-08</i>	<i>4.95E-08</i>	<i>1.1E-05</i>	<i>1.06E-05</i>	<i>4.74E-10</i>

Table 52: Weighted results for UC3 IMERMAID scenario, Scavenger cradle-to-grave.

Weighted results UC3 Scavenger cradle-to-gate	Total impact category	Scavenger Cradle-to-gate	Supporting components cradle-to-gate	Installation and of and supporting components	SMAT plant use phase	Scavenger use phase	End-of-life Scavenger supporting components
acidification	2.135286912	0.008560243	0.006895495	0.018388432	0.800416901	1.300928501	9.73395E-05
climate change	26.76074281	0.047764184	0.032776576	0.089838905	22.03844925	4.550449036	0.001464851
ecotoxicity: freshwater	0.636098785	0.001739644	0.004695765	0.002961944	0.376440145	0.250204057	5.72299E-05
energy resources: non-renewable	7.692418437	0.048335541	0.018789801	0.059469068	4.283879263	3.281704939	0.000239825
eutrophication: freshwater	2.010487328	0.009538964	0.018896117	0.006643411	0.944106787	1.031233659	6.83906E-05
eutrophication: marine	0.546871799	0.002255985	0.001814749	0.008716063	0.296072972	0.237918486	9.35427E-05
eutrophication: terrestrial	0.553681011	0.003321883	0.002472388	0.012794766	0.292803599	0.242218891	6.94848E-05
human toxicity: carcinogenic	0.770803873	0.002700856	0.001853861	0.003136836	0.191729532	0.571361414	2.13738E-05
human toxicity: non-carcinogenic	0.485641109	0.002589606	0.003287474	0.004578646	0.260987363	0.214106829	9.11908E-05
ionising radiation: human health	0.607279779	0.012633484	0.001591227	0.001134781	0.284443015	0.307473877	3.39381E-06
land use	0.132072765	0.001288631	0.000661528	0.020137395	0.058511002	0.051457515	1.66944E-05
material resources: metals/minerals	3.968220911	0.018821535	0.033248804	0.011728846	1.565237449	2.338956037	0.000228239
ozone depletion	0.033724781	0.022141612	1.42707E-05	8.48366E-05	0.005685805	0.005797906	3.50589E-07
particulate matter formation	2.017876183	0.009486014	0.013829848	0.045747659	0.897404392	1.051210746	0.000197524
photochemical oxidant formation: human health	1.306996777	0.005765008	0.004443295	0.025715848	0.718183949	0.552764157	0.000124519



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<i>water use</i>	1.855611617	0.010425783	0.003691413	0.004214946	0.93568599	0.901553115	4.03698E-05
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Annex IV Use Case 5: Secondary datasets used and results

Table 53: Material, process and transport datasets and assumptions used for modeling UC5 baseline scenario.

Datasets used for UC5 baseline scenario, ESDAK	Input/output	Lifetime [years]	Selected material/process dataset	Comments material dataset selection	Transportation distance [km]	Selected transport dataset	Comments transport dataset
Chemicals for pH regulation – NaOH	Input		chlor-alkali electrolysis, average production, RER			Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4; Ecoinvent: transport, freight, sea, container ship, heavy fuel oil	ESDAK data on transport: 160 km by truck and 325 km by ship
Chemicals for pH regulation – EDTA Na	Input		ethylenediaminetetraacetic acid production, alkaline cyanomethylation of ethylenediamine, Europe			see above	see above
Chemicals for pH regulation – C6H8O7	Input		citric acid production, RER			see above	see above
Chemicals for RO pretreatment – Sulphuric Acid H ₂ SO ₄ 98%	Input		sulfuric acid production, RER			see above	see above
Chemicals for RO membrane cleaning – Antiscalant	Input		sodium triphosphate production, RER polyacrylamide production, GLO	Material composition based on literature (Yu et al., 2020) No information on mass distribution between material available. Assumption: 50%-50%		see above	see above

Electricity	Input		market for electricity, medium voltage, GR	measurements and calculations from ESDAK			
Oil waste	Output		treatment of waste mineral oil, hazardous waste incineration, RER		25	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4	ESDAK data
RO membranes	Input	1		Estimate for RO membrane production based on components, assembly assumed to take place in Europe	540	Ecoinvent: transport, freight, lorry, >32 metric ton, diesel, EURO 4; Ecoinvent: transport, freight, sea, container ship, heavy fuel oil; Ecoinvent: market for transport, freight, train, fleet average	Assumptions for transport within Europe according to PEF Guidance: 130km via lorry, 240 km via train, 270 km via ferry (European Commission, 2021)
RO membranes – Ultrathin barrier layer	Input		glass fibre reinforced plastic production, polyamide, injection moulded, RER	Material estimate based on (DuPont, 2025a)	540	see above	see above
RO membranes – Microporous Interlayer	input		polysulfone production, for membrane filtration production, GLO	Material estimate based on (DuPont, 2025a)	540	see above	see above
RO membranes – Support web	Input		polyester resin production, unsaturated, RER	Material estimate based on (DuPont, 2025a)	540	see above	see above
RO membranes – Glue	Input		polyurethane adhesive production, GLO	Material estimate based on (DuPont, 2025a)	540	see above	see above
RO membranes – Permeate tube	Input		polypropylene production, granulate, RER injection moulding, RER*	Material estimate based on (DuPont, 2025a)	540	see above	see above
RO membranes – Pressure vessel	Input		glass fibre reinforced plastic production, polyamide, injection moulded, RER	Material estimate based on (CodeLine, n.d.)	540	see above	see above



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<i>RO membranes - Endcap</i>	<i>Input</i>		<i>polypropylene production, granulate, RER; injection moulding, RER</i>	<i>Material estimate based on (DuPont, 2025a)</i>	<i>540</i>	<i>see above</i>	<i>see above</i>
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Table 54: Characterized results for UC5 baseline scenario according to the Environmental Footprint method, version 3.1.

Characterised results UC5 baseline scenario – ESDAK	Total impact category	Chemicals for pH calibration and chlorination	Chemicals for RO	Electricity 1st and 2nd stage treatment	Electricity RO1	Electricity RO2	EoL RO1&RO2	Cradle-to-Gate RO1&RO2
acidification (accumulated exceedance (AE)) [mol H+-Eq]	0.1152	0.0001684	0.06686	4.12E-03	0.01899	0.01899	5.94E-07	0.000235
climate change (global warming potential (GWP100)) [kg CO2-Eq]	10.69	0.03615	0.9673	0.9129	4.21	4.21	0.004645	0.05756
climate change: biogenic (global warming potential (GWP100)) [kg CO2-Eq]	0.005474	8.93E-05	0.001826	3.39E-04	0.001565	0.001565	3.19E-08	4.20E-05
climate change: fossil (global warming potential (GWP100)) [kg CO2-Eq]	10.68	0.036	0.9627	0.9122	4.207	4.207	0.004645	0.05748
climate change: land use and land use change (global warming potential (GWP100)) [kg CO2-Eq]	0.00725	6.01E-05	0.002785	4.15E-04	0.001914	0.001914	1.34E-08	3.45E-05
ecotoxicity: freshwater (comparative toxic unit for ecosystems (CTUe)) [CTUe]	43.35	0.4069	21.38	1.952	9.002	9.002	0.000878	1.246
ecotoxicity: freshwater. inorganics (comparative toxic unit for ecosystems (CTUe)) [CTUe]	42.11	0.4045	20.57	1.936	8.926	8.926	0.0008753	1.006
ecotoxicity: freshwater. organics (comparative toxic unit for ecosystems (CTUe)) [CTUe]	1.237	0.002348	0.807	0.0164	0.07563	0.07563	2.70E-06	0.2407

<i>energy resources: non-renewable (abiotic depletion potential (ADP): fossil fuels) [MJ. net calorific value]</i>	153.3	0.5932	12.96	13.18	60.8	60.8	0.0004564	1.158
<i>eutrophication: freshwater (fraction of nutrients reaching freshwater end compartment (P)) [kg P-Eq]</i>	1.11E-02	2.93E-05	4.66E-04	1.03E-03	0.004757	0.004757	6.76E-09	1.30E-05
<i>eutrophication: marine (fraction of nutrients reaching marine end compartment (N)) [kg N-Eq]</i>	8.91E-03	3.62E-05	1.16E-03	5.99E-04	0.002763	0.002763	2.89E-07	4.88E-05
<i>eutrophication: terrestrial (accumulated exceedance (AE)) [mol N-Eq]</i>	0.07317	0.0003192	0.01178	0.004271	0.0197	0.0197	3.05E-06	0.0004364
<i>human toxicity: carcinogenic (comparative toxic unit for human (CTUh)) [CTUh]</i>	3.38E-09	2.88E-10	8.73E-10	2.05E-10	9.46E-10	9.46E-10	1.37E-13	6.17E-11
<i>human toxicity: carcinogenic. inorganics (comparative toxic unit for human (CTUh)) [CTUh]</i>	1.93E-09	6.10E-12	3.12E-10	1.53E-10	7.07E-10	7.07E-10	1.24E-13	5.25E-12
<i>human toxicity: carcinogenic. organics (comparative toxic unit for human (CTUh)) [CTUh]</i>	1.45E-09	2.82E-10	5.62E-10	5.17E-11	2.39E-10	2.39E-10	1.39E-14	5.64E-11
<i>human toxicity: non-carcinogenic (comparative toxic unit for human (CTUh)) [CTUh]</i>	1.02E-07	4.90E-10	2.21E-08	7.58E-09	3.49E-08	3.49E-08	6.60E-12	5.47E-10
<i>human toxicity: non-carcinogenic. inorganics (comparative toxic unit for human (CTUh)) [CTUh]</i>	9.88E-08	4.65E-10	2.10E-08	7.39E-09	3.41E-08	3.41E-08	6.58E-12	3.70E-10
<i>human toxicity: non-carcinogenic. organics (comparative toxic unit for human (CTUh)) [CTUh]</i>	3.39E-09	2.58E-11	1.15E-09	1.89E-10	8.73E-10	8.73E-10	1.10E-14	1.78E-10

<i>ionising radiation: human health (human exposure efficiency relative to u235) [kBq U235-Eq]</i>	0.325	0.01007	0.09561	0.02084	0.09609	0.09609	5.13E-07	0.003419
<i>land use (soil quality index) [dimensionless]</i>	13.7	0.1551	6.424	0.549	2.532	2.532	0.0001209	0.1365
<i>material resources: metals/minerals (abiotic depletion potential (ADP): elements (ultimate reserves)) [kg Sb-Eq]</i>	4.30E-05	1.17E-06	2.71E-05	1.34E-06	6.17E-06	6.17E-06	1.23E-10	4.94E-07
<i>ozone depletion (ozone depletion potential (ODP)) [kg CFC-11-Eq]</i>	4.59E-07	2.02E-09	2.30E-08	4.18E-08	1.93E-07	1.93E-07	6.31E-13	1.65E-09
<i>particulate matter formation (impact on human health) [disease incidence]</i>	6.60E-07	1.31E-09	4.38E-07	1.98E-08	9.15E-08	9.15E-08	3.09E-12	2.64E-09
<i>photochemical oxidant formation: human health (tropospheric ozone concentration increase) [kg NMVOC-Eq]</i>	0.0315	9.89E-05	0.007404	1.86E-03	0.008572	0.008572	7.55E-07	0.000223
<i>water use (user deprivation potential (deprivation-weighted water consumption)) [m³ world Eq deprived]</i>	6.122	0.01513	4.436	0.1595	0.7358	0.7358	0.0001207	0.02508

Table 55: Normalised results for UC5 baseline scenario according to the Environmental Footprint method, version 3.1.

Normalised results UC5 baseline Scenario – ESDAK	Total impact category	Chemicals for pH calibration	Chemicals for RO pretreatment and membrane cleaning	Electricity	Oil for pumps	Oil waste	RO membranes	Transport
acidification	2.07E-03	3.03E-06	1.20E-03	7.41E-05	3.42E-04	3.42E-04	1.07E-08	4.23E-06
climate change	1.42E-03	4.79E-06	1.28E-04	1.21E-04	5.57E-04	5.57E-04	6.15E-07	7.62E-06
ecotoxicity: freshwater	7.64E-04	7.17E-06	3.77E-04	3.44E-05	1.59E-04	1.59E-04	1.55E-08	2.20E-05
energy resources: non-renewable	2.36E-03	9.13E-06	1.99E-04	2.03E-04	9.35E-04	9.35E-04	7.02E-09	1.78E-05
eutrophication: freshwater	6.89E-03	1.83E-05	2.90E-04	6.42E-04	2.96E-03	2.96E-03	4.21E-09	8.08E-06
eutrophication: marine	4.56E-04	1.85E-06	5.96E-05	3.07E-05	1.41E-04	1.41E-04	1.48E-08	2.50E-06
eutrophication: terrestrial	4.14E-04	1.81E-06	6.66E-05	2.42E-05	1.11E-04	1.11E-04	1.72E-08	2.47E-06
human toxicity: carcinogenic	1.96E-04	1.67E-05	5.06E-05	1.19E-05	5.48E-05	5.48E-05	7.96E-09	3.57E-06
human toxicity: non-carcinogenic	7.94E-04	3.81E-06	1.72E-04	5.88E-05	2.71E-04	2.71E-04	5.12E-08	4.25E-06
ionising radiation: human health	7.70E-05	2.39E-06	2.27E-05	4.94E-06	2.28E-05	2.28E-05	1.21E-10	8.10E-07
land use	1.67E-05	1.89E-07	7.84E-06	6.70E-07	3.09E-06	3.09E-06	1.48E-10	1.67E-07
material resources: metals/minerals	6.75E-04	1.84E-05	4.26E-04	2.10E-05	9.69E-05	9.69E-05	1.93E-09	7.76E-06
ozone depletion	8.77E-06	3.86E-08	4.40E-07	7.99E-07	3.68E-06	3.68E-06	1.21E-11	3.14E-08



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<i>particulate matter formation</i>	<i>1.11E-03</i>	<i>2.19E-06</i>	<i>7.36E-04</i>	<i>3.33E-05</i>	<i>1.54E-04</i>	<i>1.54E-04</i>	<i>5.18E-09</i>	<i>4.44E-06</i>
<i>photochemical oxidant formation: human health</i>	<i>7.71E-04</i>	<i>2.42E-06</i>	<i>1.81E-04</i>	<i>4.55E-05</i>	<i>2.10E-04</i>	<i>2.10E-04</i>	<i>1.85E-08</i>	<i>5.46E-06</i>
<i>water use</i>	<i>5.34E-04</i>	<i>1.32E-06</i>	<i>3.87E-04</i>	<i>1.39E-05</i>	<i>6.42E-05</i>	<i>6.42E-05</i>	<i>1.05E-08</i>	<i>2.19E-06</i>

Table 56: Weighted results for UC5 baseline scenario according to the Environmental Footprint method, version 3.1.

Weighted results UC5 baseline Scenario – ESDAK	Total impact category	Chemicals for pH calibration	Chemicals for RO pretreatment and membrane cleaning	Electricity	Oil for pumps	Oil waste	RO membranes	Transport
acidification	1.29E+02	1.88E-01	7.46E+01	4.59E+00	2.12E+01	2.12E+01	6.63E-04	2.62E-01
climate change	2.98E+02	1.01E+00	2.70E+01	2.55E+01	1.17E+02	1.17E+02	1.30E-01	1.60E+00
ecotoxicity: freshwater	1.47E+01	1.38E-01	7.24E+00	6.61E-01	3.05E+00	3.05E+00	2.97E-04	4.22E-01
energy resources: non-renewable	1.96E+02	7.59E-01	1.66E+01	1.69E+01	7.78E+01	7.78E+01	5.84E-04	1.48E+00
eutrophication: freshwater	1.93E+02	5.11E-01	8.11E+00	1.80E+01	8.29E+01	8.29E+01	1.18E-04	2.26E-01
eutrophication: marine	1.35E+01	5.48E-02	1.76E+00	9.07E-01	4.18E+00	4.18E+00	4.37E-04	7.40E-02
eutrophication: terrestrial	1.54E+01	6.70E-02	2.47E+00	8.96E-01	4.13E+00	4.13E+00	6.40E-04	9.16E-02
human toxicity: carcinogenic	4.17E+00	3.55E-01	1.08E+00	2.53E-01	1.17E+00	1.17E+00	1.70E-04	7.61E-02
human toxicity: non-carcinogenic	1.46E+01	7.01E-02	3.16E+00	1.08E+00	4.99E+00	4.99E+00	9.43E-04	7.82E-02
ionising radiation: human health	3.86E+00	1.20E-01	1.14E+00	2.47E-01	1.14E+00	1.14E+00	6.09E-06	4.06E-02
land use	1.33E+00	1.50E-02	6.22E-01	5.32E-02	2.45E-01	2.45E-01	1.17E-05	1.32E-02
material resources: metals/minerals	5.10E+01	1.39E+00	3.21E+01	1.59E+00	7.32E+00	7.32E+00	1.46E-04	5.86E-01
ozone depletion	5.54E-01	2.43E-03	2.77E-02	5.04E-02	2.32E-01	2.32E-01	7.61E-07	1.98E-03



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<i>particulate matter formation</i>	9.94E+01	1.96E-01	6.60E+01	2.99E+00	1.38E+01	1.38E+01	4.64E-04	3.98E-01
<i>photochemical oxidant formation: human health</i>	3.69E+01	1.16E-01	8.66E+00	2.17E+00	1.00E+01	1.00E+01	8.84E-04	2.61E-01
<i>water use</i>	4.54E+01	1.12E-01	3.29E+01	1.18E+00	5.46E+00	5.46E+00	8.96E-04	1.86E-01

Table 57: Characterized results for UC5 iMERMAID scenario according to the Environmental Footprint method, version 3.1.

Characterised results UC5 baseline scenario – ESDAK	Total impact category	Electricity 1st and 2nd stage	Electricity MF	Electricity pre-filtration	Pre-filtration membrane	Transport	Multifluidic system Cradle-to-gate	Multifluidic system EoL
<i>acidification (accumulated exceedance (AE)) [mol H⁺-Eq]</i>	9.25E-03	4.12E-03	0.002399	0.002346	1.52E-07	2.30E-08	0.000382	0.00000106
<i>climate change (global warming potential (GWP100)) [kg CO₂-Eq]</i>	2.05E+00	0.9129	0.5318	0.5202	4.49E-05	1.20E-06	0.0859	0.00321
<i>climate change: biogenic (global warming potential (GWP100)) [kg CO₂-Eq]</i>	1.45E-03	3.39E-04	0.0001976	0.0001933	4.71E-08	3.40E-10	0.000724	2.78E-08
<i>climate change: fossil (global warming potential (GWP100)) [kg CO₂-Eq]</i>	2.05E+00	0.9122	0.5313	0.5198	4.48E-05	1.20E-06	0.0851	0.00321
<i>climate change: land use and land use change (global warming potential (GWP100)) [kg CO₂-Eq]</i>	1.00E-03	4.15E-04	0.0002418	0.0002365	3.64E-08	7.45E-10	0.000106	8.99E-08
<i>ecotoxicity: freshwater (comparative toxic unit for ecosystems (CTUe)) [CTUe]</i>	4.61E+00	1.952	1.137	1.112	0.0002442	1.87E-06	0.381	0.0299
<i>ecotoxicity: freshwater. inorganics (comparative toxic unit for ecosystems (CTUe)) [CTUe]</i>	4.54E+00	1.936	1.127	1.103	0.0002306	1.79E-06	0.346	0.0297
<i>ecotoxicity: freshwater. organics (comparative toxic unit for ecosystems (CTUe)) [CTUe]</i>	7.00E-02	0.0164	0.009553	0.009345	1.35E-05	8.29E-08	0.0345	0.000173

<i>energy resources: non-renewable (abiotic depletion potential (ADP): fossil fuels) [MJ. net calorific value]</i>	2.99E+01	13.18	7.679	7.513	0.001066	1.59E-05	1.53	0.000816
<i>eutrophication: freshwater (fraction of nutrients reaching freshwater end compartment (P)) [kg P-Eq]</i>	2.30E-03	1.03E-03	0.0006009	0.0005878	1.53E-08	1.22E-10	0.0000813	0.00000109
<i>eutrophication: marine (fraction of nutrients reaching marine end compartment (N)) [kg N-Eq]</i>	1.36E-03	5.99E-04	0.000349	0.0003414	3.23E-08	6.18E-09	0.0000696	2.55E-08
<i>eutrophication: terrestrial (accumulated exceedance (AE)) [mol N-Eq]</i>	9.93E-03	0.004271	0.002488	0.002434	3.17E-07	6.83E-08	0.000732	0.00000523
<i>human toxicity: carcinogenic (comparative toxic unit for human (CTUh)) [CTUh]</i>	5.00E-10	2.05E-10	1.19E-10	1.17E-10	7.82E-14	2.53E-16	5.61E-11	2.15E-12
<i>human toxicity: carcinogenic. inorganics (comparative toxic unit for human (CTUh)) [CTUh]</i>	3.58E-10	1.53E-10	8.93E-11	8.74E-11	5.83E-15	1.56E-16	2.76E-11	3.34E-13
<i>human toxicity: carcinogenic. organics (comparative toxic unit for human (CTUh)) [CTUh]</i>	1.42E-10	5.17E-11	3.01E-11	2.95E-11	7.24E-14	9.70E-17	2.85E-11	1.81E-12
<i>human toxicity: non-carcinogenic (comparative toxic unit for human (CTUh)) [CTUh]</i>	1.77E-08	7.58E-09	4.41E-09	4.32E-09	4.53E-13	6.43E-15	1.28E-09	6.53E-11
<i>human toxicity: non-carcinogenic. inorganics (comparative toxic unit for human (CTUh)) [CTUh]</i>	1.72E-08	7.39E-09	4.30E-09	4.21E-09	4.18E-13	6.04E-15	1.22E-09	6.47E-11
<i>human toxicity: non-carcinogenic. organics (comparative toxic unit for human (CTUh)) [CTUh]</i>	4.70E-10	1.89E-10	1.10E-10	1.08E-10	3.46E-14	3.93E-16	6.22E-11	5.7E-13

<i>ionising radiation: human health (human exposure efficiency relative to u235) [kBq U235-Eq]</i>	7.13E-02	0.02084	0.01214	0.01187	6.02E-06	4.52E-08	0.0264	0.00000156
<i>land use (soil quality index) [dimensionless]</i>	1.46E+00	0.549	0.3198	0.3128	0.0001264	6.95E-06	0.276	0.000788
<i>material resources: metals/minerals (abiotic depletion potential (ADP): elements (ultimate reserves)) [kg Sb-Eq]</i>	3.85E-06	1.34E-06	7.79E-07	7.62E-07	6.72E-10	2.17E-12	0.00000097	7.14E-11
<i>ozone depletion (ozone depletion potential (ODP)) [kg CFC-11-Eq]</i>	1.22E-07	4.18E-08	2.44E-08	2.38E-08	1.73E-11	1.95E-14	3.21E-08	5.02E-12
<i>particulate matter formation (impact on human health) [disease incidence]</i>	4.60E-08	1.98E-08	1.16E-08	1.13E-08	1.05E-12	6.94E-14	2.76E-09	5.19E-10
<i>photochemical oxidant formation: human health (tropospheric ozone concentration increase) [kg NMVOC-Eq]</i>	4.25E-03	1.86E-03	0.001083	0.001059	1.70E-07	1.91E-08	0.000246	0.00000184
<i>water use (user deprivation potential (deprivation-weighted water consumption)) [m³ world Eq deprived]</i>	3.76E-01	0.1595	0.09293	0.09091	2.58E-05	1.04E-07	0.0328	0.000066

Table 58: Normalised results for UC5 iMERMAID scenario according to the Environmental Footprint method, version 3.1.

Normalised results UC5 baseline Scenario – ESDAK	Total impact category	Electricity 1st and 2nd stage	Electricity MF	Electricity pre-filtration	Pre-filtration membrane	Transport	Multifluidic system Cradle-to-gate	Multifluidic system EoL
acidification	0.00016639	7.41053E-05	4.31711E-05	4.22174E-05	2.73711E-09	4.14256E-10	6.87427E-06	1.90752E-08
climate change	0.000271949	0.000120865	7.04083E-05	6.88725E-05	5.94459E-09	1.58743E-10	1.13728E-05	4.24992E-07
ecotoxicity: freshwater	8.13192E-05	3.44167E-05	2.0047E-05	1.96063E-05	4.30562E-09	3.30062E-11	6.71761E-06	5.27183E-07
energy resources: non-renewable	0.00046003	0.000202756	0.000118131	0.000115577	1.63989E-08	2.44753E-10	2.35369E-05	1.2553E-08
eutrophication: freshwater	0.001433303	0.00064225	0.000373961	0.000365808	9.54662E-09	7.60493E-11	5.05958E-05	6.78345E-07
eutrophication: marine	6.95396E-05	3.06521E-05	1.78561E-05	1.74672E-05	1.65463E-09	3.16037E-10	3.56098E-06	1.30467E-09
eutrophication: terrestrial	5.61829E-05	2.41634E-05	1.4076E-05	1.37705E-05	1.79457E-09	3.86241E-10	4.14133E-06	2.9589E-08
human toxicity: carcinogenic	2.89533E-05	1.18821E-05	6.92058E-06	6.76988E-06	4.53431E-09	1.46526E-11	3.25163E-06	1.24617E-07
human toxicity: non-carcinogenic	0.000137116	5.88492E-05	3.42795E-05	3.35338E-05	3.51728E-09	4.99706E-11	9.94285E-06	5.07241E-07
ionising radiation: human health	1.6885E-05	4.9382E-06	2.87667E-06	2.81269E-06	1.42601E-09	1.07081E-11	6.25568E-06	3.69654E-10
land use	1.77977E-06	6.69922E-07	3.90239E-07	3.81697E-07	1.54241E-10	8.48568E-12	3.36791E-07	9.61564E-10
material resources: metals/minerals	6.04965E-05	2.10145E-05	1.22456E-05	1.19784E-05	1.05576E-08	3.41074E-11	1.52462E-05	1.12224E-09
ozone depletion	2.33288E-06	7.98688E-07	4.65344E-07	4.55219E-07	3.30669E-10	3.71549E-13	6.13199E-07	9.5896E-11
particulate matter formation	7.72467E-05	3.3324E-05	1.94166E-05	1.89967E-05	1.75858E-09	1.16533E-10	4.6358E-06	8.71731E-07



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<i>photochemical formation: human health</i>	<i>oxidant</i>	<i>0.000103992</i>	<i>4.54977E-05</i>	<i>2.65057E-05</i>	<i>2.59183E-05</i>	<i>4.15574E-09</i>	<i>4.68193E-10</i>	<i>6.02068E-06</i>	<i>4.50327E-08</i>
<i>water use</i>		<i>3.28051E-05</i>	<i>1.39074E-05</i>	<i>8.10292E-06</i>	<i>7.92679E-06</i>	<i>2.25134E-09</i>	<i>9.07687E-12</i>	<i>2.85996E-06</i>	<i>5.75479E-09</i>

Table 59: Weighted results for UC5 iMERMAID scenario according to the Environmental Footprint method, version 3.1.

Weighted results UC5 baseline Scenario – ESDAK	Total impact category	Electricity 1st and 2nd stage	Electricity MF	Electricity pre-filtration	Pre-filtration membrane	Transport	Multifluidic system Cradle-to-gate	Multifluidic system EoL
acidification	20.20498969	10.31620137	4.594531363	2.676610184	2.617477071	0.000169701	2.56839E-11	4.26205E-07
climate change	112.0604119	57.27253429	25.4540743	14.82799508	14.5045563	0.001251931	3.34313E-11	2.39512E-06
ecotoxicity: freshwater	2.983555678	1.561328181	0.660801406	0.384903278	0.376440145	8.26679E-05	6.33719E-13	1.28978E-07
energy resources: non-renewable	74.5896257	38.27448107	16.8692945	9.828475908	9.616009831	0.001364391	2.03635E-11	1.95827E-06
eutrophication: freshwater	78.82927136	40.13247505	17.98298642	10.4709075	10.24263509	0.000267305	2.12938E-12	1.41668E-06
eutrophication: marine	4.011291067	2.058372024	0.907300858	0.528539475	0.517029733	4.8977E-05	9.35469E-12	1.05405E-07
eutrophication: terrestrial	4.014018856	2.084387058	0.89646177	0.522218891	0.510884558	6.65787E-05	1.43295E-11	1.53643E-07
human toxicity: carcinogenic	1.161496659	0.616705489	0.253087921	0.147408282	0.144198386	9.65808E-05	3.12101E-13	6.92597E-08
human toxicity: non-carcinogenic	4.853594857	2.522938715	1.082825992	0.630743282	0.61702215	6.4718E-05	9.19459E-13	1.82948E-07
ionising radiation: human health	1.37845218	0.845940451	0.247403691	0.14412096	0.140915634	7.14432E-05	5.36477E-13	3.1341E-07
land use	0.255809807	0.141314036	0.05319182	0.030984962	0.030306742	1.22467E-05	6.73763E-13	2.67412E-08
material resources: metals/minerals	7.983799147	4.567485426	1.586597779	0.924546245	0.904372601	0.000797096	2.57511E-12	1.15108E-06
ozone depletion	0.255710141	0.147204551	0.050397182	0.029363199	0.028724345	2.08652E-05	2.34448E-14	3.86929E-08
particulate matter formation	13.34912185	6.921303441	2.985829806	1.739727447	1.702103584	0.000157569	1.04414E-11	4.15367E-07



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<i>photochemical oxidant formation: human health</i>	9.651670154	4.97081671	2.174790621	1.266970544	1.238893635	0.000198644	2.23796E-11	2.87788E-07
<i>water use</i>	5.339552162	2.791712454	1.183520344	0.68955828	0.674569495	0.000191589	7.72442E-13	2.43382E-07

Table 60: Characterized results for UC5 Alternative improvement scenario according to the Environmental Footprint method, version 3.1.

Characterised results UC5 baseline scenario – ESDAK	Total impact category	Electricity 1st and 2nd stage	Electricity MF	Electricity pre-filtration	Pre-filtration membrane	Transport	Multifluidic system Cradle-to-gate	Multifluidic system EoL
<i>acidification (accumulated exceedance (AE)) [mol H+-Eq]</i>	9.25E-03	4.12E-03	0.002399	0.002346	1.52E-07	2.30E-08	0.000382	0.00000106
<i>climate change (global warming potential (GWP100)) [kg CO2-Eq]</i>	2.05E+00	0.9129	0.5318	0.5202	4.49E-05	1.20E-06	0.0859	0.00321
<i>climate change: biogenic (global warming potential (GWP100)) [kg CO2-Eq]</i>	1.45E-03	3.39E-04	0.0001976	0.0001933	4.71E-08	3.40E-10	0.000724	2.78E-08
<i>climate change: fossil (global warming potential (GWP100)) [kg CO2-Eq]</i>	2.05E+00	0.9122	0.5313	0.5198	4.48E-05	1.20E-06	0.0851	0.00321
<i>climate change: land use and land use change (global warming potential (GWP100)) [kg CO2-Eq]</i>	1.00E-03	4.15E-04	0.0002418	0.0002365	3.64E-08	7.45E-10	0.000106	8.99E-08
<i>ecotoxicity: freshwater (comparative toxic unit for ecosystems (CTUe)) [CTUe]</i>	4.61E+00	1.952	1.137	1.112	0.0002442	1.87E-06	0.381	0.0299
<i>ecotoxicity: freshwater. inorganics (comparative toxic unit for ecosystems (CTUe)) [CTUe]</i>	4.54E+00	1.936	1.127	1.103	0.0002306	1.79E-06	0.346	0.0297
<i>ecotoxicity: freshwater. organics (comparative toxic unit for ecosystems (CTUe)) [CTUe]</i>	7.00E-02	0.0164	0.009553	0.009345	1.35E-05	8.29E-08	0.0345	0.000173

<i>energy resources: non-renewable (abiotic depletion potential (ADP): fossil fuels) [MJ. net calorific value]</i>	2.99E+01	13.18	7.679	7.513	0.001066	1.59E-05	1.53	0.000816
<i>eutrophication: freshwater (fraction of nutrients reaching freshwater end compartment (P)) [kg P-Eq]</i>	2.30E-03	1.03E-03	0.0006009	0.0005878	1.53E-08	1.22E-10	0.0000813	0.00000109
<i>eutrophication: marine (fraction of nutrients reaching marine end compartment (N)) [kg N-Eq]</i>	1.36E-03	5.99E-04	0.000349	0.0003414	3.23E-08	6.18E-09	0.0000696	2.55E-08
<i>eutrophication: terrestrial (accumulated exceedance (AE)) [mol N-Eq]</i>	9.93E-03	0.004271	0.002488	0.002434	3.17E-07	6.83E-08	0.000732	0.00000523
<i>human toxicity: carcinogenic (comparative toxic unit for human (CTUh)) [CTUh]</i>	5.00E-10	2.05E-10	1.19E-10	1.17E-10	7.82E-14	2.53E-16	5.61E-11	2.15E-12
<i>human toxicity: carcinogenic. inorganics (comparative toxic unit for human (CTUh)) [CTUh]</i>	3.58E-10	1.53E-10	8.93E-11	8.74E-11	5.83E-15	1.56E-16	2.76E-11	3.34E-13
<i>human toxicity: carcinogenic. organics (comparative toxic unit for human (CTUh)) [CTUh]</i>	1.42E-10	5.17E-11	3.01E-11	2.95E-11	7.24E-14	9.70E-17	2.85E-11	1.81E-12
<i>human toxicity: non-carcinogenic (comparative toxic unit for human (CTUh)) [CTUh]</i>	1.77E-08	7.58E-09	4.41E-09	4.32E-09	4.53E-13	6.43E-15	1.28E-09	6.53E-11
<i>human toxicity: non-carcinogenic. inorganics (comparative toxic unit for human (CTUh)) [CTUh]</i>	1.72E-08	7.39E-09	4.30E-09	4.21E-09	4.18E-13	6.04E-15	1.22E-09	6.47E-11
<i>human toxicity: non-carcinogenic. organics (comparative toxic unit for human (CTUh)) [CTUh]</i>	4.70E-10	1.89E-10	1.10E-10	1.08E-10	3.46E-14	3.93E-16	6.22E-11	5.7E-13

<i>ionising radiation: human health (human exposure efficiency relative to u235) [kBq U235-Eq]</i>	7.13E-02	0.02084	0.01214	0.01187	6.02E-06	4.52E-08	0.0264	0.00000156
<i>land use (soil quality index) [dimensionless]</i>	1.46E+00	0.549	0.3198	0.3128	0.0001264	6.95E-06	0.276	0.000788
<i>material resources: metals/minerals (abiotic depletion potential (ADP): elements (ultimate reserves)) [kg Sb-Eq]</i>	3.85E-06	1.34E-06	7.79E-07	7.62E-07	6.72E-10	2.17E-12	0.00000097	7.14E-11
<i>ozone depletion (ozone depletion potential (ODP)) [kg CFC-11-Eq]</i>	1.22E-07	4.18E-08	2.44E-08	2.38E-08	1.73E-11	1.95E-14	3.21E-08	5.02E-12
<i>particulate matter formation (impact on human health) [disease incidence]</i>	4.60E-08	1.98E-08	1.16E-08	1.13E-08	1.05E-12	6.94E-14	2.76E-09	5.19E-10
<i>photochemical oxidant formation: human health (tropospheric ozone concentration increase) [kg NMVOC-Eq]</i>	4.25E-03	1.86E-03	0.001083	0.001059	1.70E-07	1.91E-08	0.000246	0.00000184
<i>water use (user deprivation potential (deprivation-weighted water consumption)) [m³ world Eq deprived]</i>	3.76E-01	0.1595	0.09293	0.09091	2.58E-05	1.04E-07	0.0328	0.000066

Table 61: Normalised results for UC5 Alternative improvement scenario according to the Environmental Footprint method, version 3.1.

Normalised results UC5 baseline Scenario – ESDAK	Total impact category	Electricity 1st and 2nd stage	Electricity MF	Electricity pre-filtration	Pre-filtration membrane	Transport	Multifluidic system Cradle-to-gate	Multifluidic system EoL
acidification	1.66E-04	7.41E-05	4.32E-05	4.22E-05	2.74E-09	4.14E-10	6.87E-06	1.91E-08
climate change	2.72E-04	1.21E-04	7.04E-05	6.89E-05	5.94E-09	1.59E-10	1.14E-05	4.25E-07
ecotoxicity: freshwater	8.13E-05	3.44E-05	2.00E-05	1.96E-05	4.31E-09	3.30E-11	6.72E-06	5.27E-07
energy resources: non-renewable	4.60E-04	2.03E-04	1.18E-04	1.16E-04	1.64E-08	2.45E-10	2.35E-05	1.26E-08
eutrophication: freshwater	1.43E-03	6.42E-04	3.74E-04	3.66E-04	9.55E-09	7.60E-11	5.06E-05	6.78E-07
eutrophication: marine	6.95E-05	3.07E-05	1.79E-05	1.75E-05	1.65E-09	3.16E-10	3.56E-06	1.30E-09
eutrophication: terrestrial	5.62E-05	2.42E-05	1.41E-05	1.38E-05	1.79E-09	3.86E-10	4.14E-06	2.96E-08
human toxicity: carcinogenic	2.90E-05	1.19E-05	6.92E-06	6.77E-06	4.53E-09	1.47E-11	3.25E-06	1.25E-07
human toxicity: non-carcinogenic	1.37E-04	5.88E-05	3.43E-05	3.35E-05	3.52E-09	5.00E-11	9.94E-06	5.07E-07
ionising radiation: human health	1.69E-05	4.94E-06	2.88E-06	2.81E-06	1.43E-09	1.07E-11	6.26E-06	3.70E-10
land use	1.78E-06	6.70E-07	3.90E-07	3.82E-07	1.54E-10	8.49E-12	3.37E-07	9.62E-10
material resources: metals/minerals	6.05E-05	2.10E-05	1.22E-05	1.20E-05	1.06E-08	3.41E-11	1.52E-05	1.12E-09
ozone depletion	2.33E-06	7.99E-07	4.65E-07	4.55E-07	3.31E-10	3.72E-13	6.13E-07	9.59E-11
particulate matter formation	7.72E-05	3.33E-05	1.94E-05	1.90E-05	1.76E-09	1.17E-10	4.64E-06	8.72E-07



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<i>photochemical oxidant formation: human health</i>	<i>1.04E-04</i>	<i>4.55E-05</i>	<i>2.65E-05</i>	<i>2.59E-05</i>	<i>4.16E-09</i>	<i>4.68E-10</i>	<i>6.02E-06</i>	<i>4.50E-08</i>
<i>water use</i>	<i>3.28E-05</i>	<i>1.39E-05</i>	<i>8.10E-06</i>	<i>7.93E-06</i>	<i>2.25E-09</i>	<i>9.08E-12</i>	<i>2.86E-06</i>	<i>5.75E-09</i>

Table 62: Weighted results for UC5 Alternative improvement scenario according to the Environmental Footprint method, version 3.1.

Weighted results UC5 baseline Scenario – ESDAK	Total impact category	Electricity 1st and 2nd stage	Electricity MF	Electricity pre-filtration	Pre-filtration membrane	Transport	Multifluidic system Cradle-to-gate	Multifluidic system EoL
acidification	2.02E+01	1.03E+01	4.59E+00	2.68E+00	2.62E+00	1.70E-04	2.57E-11	4.26E-07
climate change	1.12E+02	5.73E+01	2.55E+01	1.48E+01	1.45E+01	1.25E-03	3.34E-11	2.40E-06
ecotoxicity: freshwater	2.98E+00	1.56E+00	6.61E-01	3.85E-01	3.76E-01	8.27E-05	6.34E-13	1.29E-07
energy resources: non-renewable	7.46E+01	3.83E+01	1.69E+01	9.83E+00	9.62E+00	1.36E-03	2.04E-11	1.96E-06
eutrophication: freshwater	7.88E+01	4.01E+01	1.80E+01	1.05E+01	1.02E+01	2.67E-04	2.13E-12	1.42E-06
eutrophication: marine	4.01E+00	2.06E+00	9.07E-01	5.29E-01	5.17E-01	4.90E-05	9.35E-12	1.05E-07
eutrophication: terrestrial	4.01E+00	2.08E+00	8.96E-01	5.22E-01	5.11E-01	6.66E-05	1.43E-11	1.54E-07
human toxicity: carcinogenic	1.16E+00	6.17E-01	2.53E-01	1.47E-01	1.44E-01	9.66E-05	3.12E-13	6.93E-08
human toxicity: non-carcinogenic	4.85E+00	2.52E+00	1.08E+00	6.31E-01	6.17E-01	6.47E-05	9.19E-13	1.83E-07
ionising radiation: human health	1.38E+00	8.46E-01	2.47E-01	1.44E-01	1.41E-01	7.14E-05	5.36E-13	3.13E-07
land use	2.56E-01	1.41E-01	5.32E-02	3.10E-02	3.03E-02	1.22E-05	6.74E-13	2.67E-08
material resources: metals/minerals	7.98E+00	4.57E+00	1.59E+00	9.25E-01	9.04E-01	7.97E-04	2.58E-12	1.15E-06
ozone depletion	2.56E-01	1.47E-01	5.04E-02	2.94E-02	2.87E-02	2.09E-05	2.34E-14	3.87E-08
particulate matter formation	1.33E+01	6.92E+00	2.99E+00	1.74E+00	1.70E+00	1.58E-04	1.04E-11	4.15E-07



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<i>photochemical oxidant formation: human health</i>	9.65E+00	4.97E+00	2.17E+00	1.27E+00	1.24E+00	1.99E-04	2.24E-11	2.88E-07
<i>water use</i>	5.34E+00	2.79E+00	1.18E+00	6.90E-01	6.75E-01	1.92E-04	7.72E-13	2.43E-07



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The Mediterranean Sea and its surrounding regions support a diverse variety of essential socioeconomic activities. It is one of the highly exploited water ways and the influence of anthropogenic activities on its marine habitats and ecosystems has grown significantly since the industrial revolution. Because of this, the Mediterranean Sea basin is very vulnerable to chemical contamination and build-up. To safeguard the Mediterranean Sea basin from contaminants for emerging concerns (CoEC), iMERMAID will integrate, coordinate, and synergize innovative preventive, monitoring, and remediation solutions. iMERMAID will build an evidence-based multidimensional framework that will guide policymaking and transform societal perceptions to reduce CoEC usage, emissions, and pollution. Furthermore, next generation sensor and remediation solutions will be developed within iMERMAID to monitor and remove prioritized chemicals from its source while reducing upstream pollution. iMERMAID builds an ideal interdisciplinary team by bringing together prominent SMEs, researchers, regulators, and innovation professionals who have been essential in improving the knowledge and awareness of CoEC. Beyond state-of-the-art techniques, iMERMAID will strive to strengthen regulations against CoEC, expand economic possibilities and competitiveness, improve the standard of living for EU residents, while preventing the accumulation of chemical pollution in the Mediterranean Sea basin. iMERMAID will empower the efforts to create a zero pollution, contaminant free waters by enabling the Chemical Strategy's goals to become a practical reality.



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