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SOS-ZEROPOL2030

D3.3 Peer Reviewed Publication that outlines the methodology

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Contents

Introduction to this report

This document reports the methodology that underpinned the Source to Sea - Zero Pollution 2030 (SOS-ZEROPOL2030) project which aims to deliver a stakeholder-led zero-pollution framework for achieving the European Union's long-term ambition of 'Zero Pollution' in European seas[1]. The project focuses on four priority marine pollutants: nutrient inputs, chemical contaminants, plastic litter, and underwater noise, alongside two specific case study pollutants: per- and polyfluoroalkyl substances (PFAS) and TWPs, representing examples of chemical contaminants and plastic litter, respectively. It addresses these issues in three European Regional Sea case studies: the Black Sea, the Mediterranean Sea, and the North-East Atlantic.

Task 3.1 focused on developing and operationalizing the participatory and iterative methodology through which the results of the (interdisciplinary) integrated assessment and scenarios developed in WP4 were assessed and complemented in regional Living Labs. To write the SOS-ZEROPOL2030 methodology as a scientific publication, the team had to integrate the following components:

- Source to Sea approach to marine pollution, recognising the pollutants' life cycle and the need to address sources of pollution.
- An EU zero-pollution agenda, which constitutes transformative change
- Involving a diversity of stakeholders in transdisciplinary research
- Co-creation through Living Labs
- Using multi-disciplinary and interdisciplinary research methods
- Iterative research process, in which initial research outcomes influence follow-up research steps
- Integrated/holistic analysis and complex systems thinking, which avoids searching for a single, neutral solution
- Research that strengthens the science-policy-society interface for environmental management

These aspects come together in the CO-ACT methodology, a co-creation methodology to support transformative action. CO-ACT is an acronym that refers to five phases: (1) identification and analysis of the **Challenges**; (2) setting of **Objectives**; (3) exploration of **Alternatives**; (4) assessment of the **Consequences**; and (5) understanding of **Trade-offs** between the different alternatives. The method was developed based on different activities and deliverables of SOS-ZEROPOL2030 carried out between September 2022 and August 2025, see Table 1.

Table 1. Overview of SOS-ZEROPOL2030 outputs feeding into CO-ACT methodology development.

Step	Period	Project outputs
Integrated case study assessment	Sept 2022 – August 2025	D2.1 (M8)
		D2.2 (M15)
		D2.3 (M21)
		D4.1 (M25)

[1] Project website: https://soszeropol2030.eu/

		D4.4 (M36)
Living Lab round 1	March 2024 – Dec 2024	D3.1 (M27)
Developing Exploratory Scenarios	Jan - August 2025	D4.3 (M36)
Living Lab round 2	Dec - August 2025	D3.2 (M36)
Article drafting	June - August 2025	D3.3 (M36)
Article submission	October 2025	Confirmation email from journal (M38)
Article publication	November – March 2026	Open access journal article online (M43)

The target journal for the publication of the open access article is the *Journal of Environmental Science & Policy*[2], which advances research in the intersections between environmental science, policy and society. Due to its interest in cutting edge developments in inter- and transdisciplinary work on co-production; the trade-offs and synergies between environmental issues and policies; and transitions and transformative change, the journal is a good fit for publishing the SOSZP co-creation methodology.

A draft manuscript is ready (see Annex) and over the course of September and October 2025, the authors will finalize the manuscript and submit it to the journal. We expect a review and revision process of approximately 5 months, before the final article is accepted and published online (see Table 1).

[2] https://www.sciencedirect.com/journal/environmental-science-and-policy

ANNEX – DRAFT MANUSCRIPT OUTLINING CO-ACT METHODOLOGY

CO-ACT: a co-creation methodology for transformative action – the case of the EU's zero marine pollution ambition

Target journal: Journal of Environmental Science & Policy

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Abstract

This paper introduces the CO-ACT methodology as a transdisciplinary co-creation approach for transformative action that helps define and address urgent and complex environmental problems. CO-ACT integrates the work of interdisciplinary science teams (social and natural sciences), multi-stakeholder platforms (e.g. Living Labs), and co-produced alternative futures (e.g. exploratory scenario development) to inform transformative action towards environmental sustainability. CO-ACT guides stakeholders through identifying *Challenges* and *Objectives*, evaluating *Alternatives*, while considering their *Consequences* and *Trade-offs*. By explicitly considering inter-relations and trade-offs, power dynamics and the wider context of co-creation and participation during and after implementing the CO-ACT methodology, we are able to present a theory of change which clarifies the preconditions under which transdisciplinary research can lead to transformative action. We conceptualise transformative action as contributing to transformative change.

We illustrate the application of CO-ACT through three empirical case studies on emerging marine pollutants in three EU regional seas: PFAS pollution in the Northeast Atlantic and the Black Sea regions, and microplastic pollution from tyre wear particles in the Mediterranean Sea region. We conclude with critical reflections on the strengths, limitations and broader relevance of the CO-ACT approach, drawing from recent literature and insights from the case studies.

1. Introduction

The urgency of the triple planetary crises - climate change, biodiversity loss and increasing pollution - has intensified calls for transformative change (van Leeuwen et al., 2025; Visseren-Hamakers et al., 2021). A significant reordering of society is needed; one that changes the drivers that create environmental problems (Díaz et al., 2019; Visseren-Hamakers et al., 2021) and challenges existing structures to enable innovative pathways for sustainability (Blythe et al., 2018). Achieving transformative change requires engaging a multi-perspective understanding of complex systems, as well as the ability to co-imagine and explore alternative pathways toward positive futures (Cork et al (2023). This can involve the transformation systems, or parts of systems, across temporal and geographical levels (Linnér & Wibeck, 2020, p. 223. Processes of transformation are inherently political, since the desired direction, scope and pace of transformation is often contested, and power relations and vested interests will need to transform too (Linnér & Wibeck, 2020; van Leeuwen et al., 2025; Visseren-Hamakers et al., 2021).

Thus, transformative change is neither guaranteed nor easily achieved, as it is about a deep, sustained and nonlinear change of a system (Linnér & Wibeck, 2020). It requires deliberation, contestation and the capacity to break through vested interest, discourses and power structures (van Leeuwen et al., 2025) and will not happen without the intensification of knowledge exchange between scientific, public, private and social actors (Shrivastava et al., 2020). Transformative change requires reflexivity and inclusive approaches to identify and capture the plurality of knowledge and values to enact transformative change (van Leeuwen et al., 2025; Visseren-Hamakers et al., 2021). New ways of producing, transferring, and utilizing knowledge are increasingly used to ensure the transformative effect of knowledge interactions. This is reflected in a wide variety of participatory approaches and spaces, including stakeholder workshops or focus groups (Kopke et al., 2025) and more recently living labs (Moallemi et al., 2022; Zavratnik et al., 2019). Such participatory spaces are created with the aim to engage relevant stakeholder groups around complex real-world problems (Kok et al., 2023).

Co-creating knowledge through participatory and transdisciplinary research entails a theory of change, one that is often not made very explicit. The literature highlights several underlying assumptions associated with participatory and transdisciplinary methodological approaches, including the potential to enhance understanding of diverse perspectives (Agnew et al., 2022), and improve understanding of the trade-offs and the costs of decisions (Darvill & Lindo, 2016), to build and strengthen communities of practice (Sellberg et al., 2021), and to foster the co-creation of shared meanings, values and solutions (Kelemen et al., 2023). In addition, it is argued that a better understanding of the problems and their potential solutions, combined with an inclusive and transparent process, can lead stakeholders to better accept the outcomes, even if they disagree with them (Kawa et al., 2021). This has led to the formulation of design principles for transdisciplinary research, such as being context-based, pluralistic, goal-oriented and interactive (Norström et al., 2020).

However, transdisciplinary design principles should also encompass the research work that feeds into the design of, and prepares for, the participatory process and defines how the outcomes of participatory engagement are processed. A focus is required on how the objective of transformative change informs choices and decisions that guide the participatory research methodology. Therefore, a more explicit link needs to be made between participatory and transdisciplinary methodological approaches (Chambers et al., 2021; Ligtermoet et al., 2025) and their theory of change to become a source of transformative action and change.

This paper presents an innovative and flexible co-creation methodology that enables a wide range of stakeholders to engage in a collaborative process of joint knowledge production. It reflects on the underlying objective of transformative change to examine how the use of participatory methods in transdisciplinary research enables transformative outcomes. The methodology was developed as part of the European Source to Seas-Zero Pollution 2030 project, which aims to co-design, co-produce and co-deliver a stakeholder-led European framework for zero pollution in regional seas (https://soszeropol2030.eu).

2. The CO-ACT methodology for transformative action

2.1. Co-creating transformative action for transformative change

While transformative change is the ambition put forward to address and solve the triple planetary crises, transformative action is - or should be - the aim of transdisciplinary participatory research approaches. The distinction between transformative change and action is important because transformative change is an overarching, and often longer-term goal, while transformative action is about specific actions that can be taken on the short term. *Transformative action* is defined here as specific initiatives or efforts (process, means) on the short-to medium term that contribute to wider processes of transformative change (outcome, goal) and transformative governance. Transformative action requires critically re-evaluating the current beliefs and values, as well as the associated institutions (Bosomworth, 2018).

What is still subject to debate is when actions or interventions can genuinely be considered supportive of transformative change. Visseren-Hamakers et al. (2021) argue that transformative change, or rather action, should be **integrative**, ensuring that local solutions have sustainable impacts across scales, places, issues and sectors; **inclusive**, empowering those whose interests are currently not being met and representing values embodying transformative change for sustainability; **adaptive**, enabling learning, experimentation, and reflexivity, to cope with the complexity of transformative change; and **pluralist**, recognizing different knowledge systems (Visseren-Hamakers et al., 2021).

While such guiding process principles are important, it is equally important to be able to identify whether transdisciplinary research translates into transformative action. Morrison et al. (2022) developed a typology of six interventions based on the extent to which they address the root causes and structural drivers of climate change. The six interventions range from leading to only limited, slow or maladaptive change, to some degree of deeper or faster change, or to fundamentally different power and economic structures (Morrison et al., 2022). Termeer et al. (2024), in turn, define three underlying dimensions of pathways to transformative change: **in-depth** (high level or order of change), **quick** (rapid pace) and **system wide** (large-scale scope). They argue that pursuing all three dimensions is unrealistic, which is why they propose three archetypical pathways for governing transformative change, each combining two dimensions: Small Wins (in-depth -and quick); Rule Changes (quick- and system-wide); and Big Plans (in-depth- and systemwide) (Termeer et al., 2024). Transformative action is, they argue, often only partial, requiring trade-offs between depth, speed and scale of change (Termeer et al., 2024).

Co-creation methodologies offer a basis for transformative actions that aim for deeper, wider and/or faster system change. A co-creation methodology is transformative when participants are able to take and learn from an interdisciplinary systems perspective and consider root causes that sustain sustainability issues to persist. Only with insights about the nature of transformative change required is it possible to consider what kind of actions would support processes of transformative change.

2.2. The CO-ACT methodology

Addressing complex environmental challenges requires methodologies that can navigate system complexity and uncertainty and foster inclusive, participatory decision-making. The CO-ACT methodology responds to this need by offering a structured, yet flexible, approach to collaborative problem solving. Building on earlier work, the CO-ACT methodology has been successfully applied across diverse environmental contexts (Hendriksen, 2019).

The CO-ACT acronym stems from its five core components: (1) identification and analysis of the **Challenge**; (2) setting of **Objectives**; (3) exploration of **Alternative futures** (4) assessment of **Consequences**; and (5) understanding **Trade-offs** between alternatives (see figure 1).

Figure 1. The five components and three steps of CO-ACT.

2.2.1. Step 1: Challenges and Objectives

The identification of challenges and the setting of objectives are iterative processes between interdisciplinary science and transdisciplinary platforms (see Figure 2). This is an explicit recognition of the multiplicity of forms of methodologies and knowledges that are necessary preconditions for CO-ACT to be conducive to transformative action. Firstly, this step has to go beyond (multi)disciplinary science, for example by formulating cross-disciplinary research question, working in interdisciplinary teams and facilitate continuous collaborative analysis and interpretation of data. Methods to achieve this include frequent meetings, peer-review, joint workshops, and synthesised/integrated reporting/presentation of the scientific knowledge base.

Secondly, this step has to go beyond science and facilitate co-creation of challenges and stakeholder objectives with all relevant stakeholders. We refer to 'transdisciplinary platforms' as collaborative spaces that transcend diverse areas of knowledge and interest, reshapes the science-policy interface, and encourages systems thinking, reflexivity and learning. The shape, duration, and frequency of co-creation at transdisciplinary platforms can vary depending on the type of transformative change and action pursued. This step will help stakeholders to shape and adjust their conceptualisation of the complex system of which they are part, including the variables, options and preconditions from stakeholders regarding the complex sustainability issue. Consensus is not the objective, but rather saturation in understanding of system drivers and dynamics based on different perspectives, power and interests. Transdisciplinary platforms to facilitate co-creation can be implemented in various shapes, including Living Labs, workshops, citizen science platforms, participation action research (PAR).

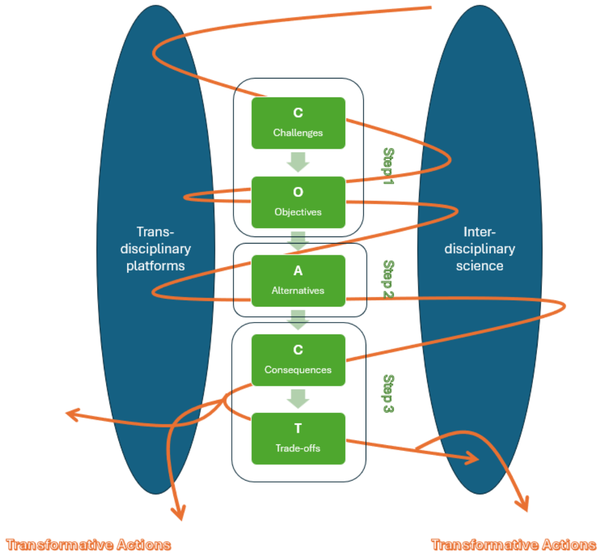

Figure 2. Iterative processes between interdisciplinary science and transdisciplinary stakeholder sessions moving through the CO-ACT steps.

2.2.2. Step 2: Alternative futures

In step 2, alternative pathways towards multiple possible futures are developed. These alternatives are validated internally, through cross-disciplinary design processes, and externally by all relevant stakeholder groups.

There is a wide range of established and emerging methods for imagining alternative futures. Alternative Futures-thinking draws on many disciplines and theories, creating 'definition confusion, dismal theory and methodological chaos (Cork et al., 2023). Dator (2019) argues that 'the future cannot be predicted because the future does not exist', 'but alternative futures can, and should be forecast', and 'preferred futures can and should be envisioned, invented, implemented, continuously evaluated, revised, and re-envisioned'. By exploring the frequently used concept of the Futures Cone (Voros, 2019), it is shown how different types of alternative futures thinking can identify alternative futures and deploy them strategically rather than attempting to predict the future.

Especially in the past decade, the focus of alternative futures studies has been on transformation in several ways, including research needs, creating opportunities for radical futures thinking across societies, exploring social and other mechanisms for transformations and considering possible pathways by which transformations might unfold (Cork et al., 2023). The methods employed have been diverse, such as visioning, back casting, horizon scanning or scenario-development. Visions aim at bringing people together in a shared perspective of a positive future and inspire, push, and impact behaviors. Back casting fills in the space between the future, today and the past and transforms abstract futures into actionable insights.

The latter can inform strategic planning processes and policymaking or build the basis for strategies and action plans. Horizon scanning is a foresight method to systematically detect early signs of potential future developments and their implications that can support policymakers and other decision-makers in anticipating future developments, managing risks and pursuing opportunities to help build resilience to future shocks and reduce uncertainty (Gall et al., 2022; van den Ende et al., 2021). Scenario-development is used to create awareness and prepare for an uncertain future, for exploring long-term developments (e.g., climate change scenarios), and help to test the robustness of different strategies against multiple possible futures (Cordova-Pozo & Rouwette, 2023).

2.2.3. Step 3: Consequences and Trade-offs

Due to the complexity and infinite interrelations among elements in dynamic social, technical, economic, environmental and political (STEEP) systems, it is impossible for a single stakeholder group, including research, to understand or predict the consequences of trade-offs of transformative action. CO-ACT therefore involves an iterative process between interdisciplinary science and transdisciplinary platforms. It engages stakeholders as experts to help draw out the range of consequences and trade-offs of each alternative future pathway. Based on different power positions, values, roles, knowledges and indeed ‘stakes’, stakeholders differ in their weighing of benefits and drawbacks of the various alternatives. In CO-ACT this step is done in co-creation at dynamic transdisciplinary platforms. Possible methods and tools for assessing consequences and trade-offs include Strength, Weaknesses, Opportunities and Treats (SWOT), Multi-Criteria (Decision) Analysis (MC(D)A) (Keseru et al., 2021), Life Cycle Assessments and participatory mapping in which the degree of co-production and participation can vary.

It contributes to transformative action not just through the outcomes of this process, through a set of recommendations to policy makers, but also through the learning, capacity building (including futures literacy (Mangnus et al., 2021), reflexivity and creativity of all stakeholders during the process.

Table 1 2. CO-ACT for transformative action: a Theory of Change.

CO-ACT components		Link with transformative action	Pre-conditions	Transformative outcome
Step	Challenges & Objectives	There is not 'one' challenge, or 'one' objective Invites systemic thinking (not just from own perspective) What are the bottlenecks (systemic drivers)?	Requires all relevant stakeholders Assumptions: same language, shared level of understanding, trust Requires input from natural and social science Facilitation capacity (methodological, financial, logistical) Valid framing/ pre-definition of problem. Room for minority voices	Identification of the challenge, based on natural/social science and broad societal stakeholder perspectives Variables, options and preconditions from stakeholders. Also overarching objectives Allows exploring divergence of objectives
Step	Alternative futures	There is not 'one' solution there are multiple pathways towards multiple futures	Team designing alternative futures needs to be part of transdisciplinary platform.	Validated set of realistic alternatives Complexity made concrete.
Step	Consequences & Trade-offs	Weighing of consequences and trade-offs differs Stakeholder interest determines which alternative is preferred	Participants have shared interpretation of alternatives	Understanding of challenges of other stakeholders Some kind of multi-criteria analyse / SWOT

Follow-up	Ensuring that results reach target audience to help translate outcomes into action Evaluate and reflect on process and outcome	Requires feeding forward of main outcomes Process should be in sync with decision-making processes Decision-making should be adaptive (not technocratic)	Visualisation of alternative pathways and their cost/benefits Revised or new regulation New research

2.2.4. Follow-up

In the theory of change of the CO-ACT methodology, transformative action is primarily encouraged through the transdisciplinary process itself. Reflecting on and (co-)evaluating the process ensures that lessons learned are documented. Transformative action is also encouraged through the substantive outcome of the CO-ACT process. The follow-up stage is important to ensure real-world impact is made, rather than tokenistic recommendations. Transformative change requires all stakeholders to change, so there is rarely a single target 'decision-maker'. Ideally, participants of the CO-ACT steps are mobilised for communicating the results back to their respective communities of practice. Scientific publications, policy briefs, social media etc. In some cases, monitoring & evaluation of agreed actions.

3. CO-ACT in practice: three empirical case studies on marine pollution]

This section describes three case studies which implemented the CO-ACT approach to help guide the EU in their ambition of zero marine pollution in the European seas. It first presents the case study context, before detailing how each CO-ACT step was implemented in the case studies and what outcomes were achieved.

3.1. Case study contexts: Transformative action towards zero marine pollution in the EU

As part of the European Green Deal, the EU formulated a zero pollution ambition in the Zero Pollution Action Plan, which "sets out an integrated vision for 2050: a world where pollution is reduced to levels that are no longer harmful to human health and natural ecosystems, as well as the steps to get there". CO-ACT was applied to two relatively novel chemical and plastic marine pollutants, Per- and polyfluoroalkyl substances (PFAS) and Tyre Wear Particles (TWPs), and across three European Regional Seas, the Black Sea (PFAS), the Mediterranean Sea (TWPs), and the North-East Atlantic (PFAS).

The 2030 Zero Pollution Action Plan target that relates to microplastics and TWPs is to improve water quality by reducing microplastics released into the environment (by 30%). In order to reduce microplastics from TWPs, the EU has developed different regulations and directives directly or indirectly addressing TWPs, including tyre production and wastewater treatment (Van Leeuwen et al., 2023). These regulations include setting thresholds for abrasion limits (Regulation (EU) 2024/1257), minimum requirements for eco-design for tyres (Regulation (EU) 2024/1781), and improve wastewater treatment to capture microplastics (Directive (EU) 2024/3019). Actions to address PFAS pollution stem from the EU Chemicals Strategy, which aims to phase out the most harmful chemicals. The main regulatory initiative to reduce PFAS pollution is the PFAS restriction proposal under REACH (Regulation (EC) No 1907/2006) that would restrict the use and placing on the EU market of all PFAS, with derogations for some applications (ECHA 2023).

For the first two case studies, in the **North-East Atlantic (NEA) region** and in the **Black Sea (BS) region** respectively (see figure x), the thematic focus was on reducing emissions from per- and polyfluoroalkyl substances (PFAS). These form a large group of persistent organic chemicals with very heterogeneous molecular structures (Evich et al., 2022) that have a multitude of industrial, and consumer uses (Glüge et al., 2020). Nearly all PFAS are persistent, many are also mobile, bioaccumulative, toxic, show high global warming potential, or bear a combination of these properties (Cousins et al., 2020). Current regulatory approaches have proven insufficient to protect humans and the natural environment from exposure beyond safe levels (Abunada et al., 2020; Ackerman Grunfeld et al., 2024; Cousins et al., 2022), which is why transformative action is needed. Due to alarming concentrations of PFAS close to several high-profile PFAS manufacturing sites in western Europe (Gebbink & van Leeuwen, 2020; Lasters et al., 2024) knowledge and awareness of PFAS is relatively high, and political and industrial action is emerging. In the Black Sea basin there is a more pronounced lack of reliable, systematically obtained and publicly available measurement data of PFAS concentrations in various matrices (Miladinova et al., 2024; Slobodnik et al., 2016) and lower overall awareness of PFAS compared to other parts of Europe ((Vaupotič et al., 2024). There is also very little information about the sources of these PFAS.

For the **Mediterranean Sea region** the thematic focus was on preventing and mitigating emissions of tyre wear particles (TWPs). TWPs are primarily produced through the friction and wear of tyres upon driving vehicles, meaning that urban, highway and rural roads are the main point sources of TWP emissions, with a direct link between increasing traffic volumes and higher TWP emissions. Heavier vehicles emit more particles by distance travelled, while braking, accelerating and turning cause increase emissions. Tyres are also the primary sources of many tyre-related chemicals (TWCs), with almost 800 additives and non-intentionally added substances (NIAS) are known to be used and/or present in tyres and TWPs. The risks of TWPs and TWCs to humans and the environment are largely unknown. Transformative action is needed throughout the tyre product chain, from the design and production of tyres, to driving behaviour and mitigation efforts at wastewater treatment plants.

3.2. CO-ACT step 1: Challenges and Objectives

Our operationalisation of CO-ACT in the three case studies is summarised in Table 2.

Table 2. 3 Operationalisation of CO-ACT methodology in three marine pollution case studies in the SOS-ZEROPOL2030 project.

CO-ACT component		**Operationalisation of CO-ACT in case studies**		
		Reduced PFAS emissions in the North-East Atlantic region	Reduced PFAS emissions in the Black Sea region	Reduced TWP emissions in the Mediterranean Sea region
Ste	Challenges & Objectives	Multi & interdisciplinary science Policy analysis, governance analysis, public perception analysis, mapping of pollutant sources, assessment of environmental risk, mapping of technological mitigation strategies, combined in integrated pollutant assessment. Based on expert interviews, surveys, literature and policy reviews, monitoring data analysis, environmental exposure modelling, toxicology review, risk assessment. Designing and facilitating Living Labs, identifying root causes of marine pollution, overview of systemic challenges, objectives and drivers of transformative change.		
		Transdisciplinary platform 2-day Living Lab in NLD (04-2024). 13 experts including product manufacturers, public authorities, NGOs and medical service providers from NLD, BEL, SWE	***Transdisciplinary platform*** 2-day Living Lab in BGR (05-2024) 16 experts including public authorities, water service providers, NGOs and researchers from UKR, BGR, TUR, ROU, GRC	***Transdisciplinary platform*** 2-day Living Lab in GRC (11-2024) 21 experts including researchers, NGOs, public authorities, WWT service providers and industry from GRC, FRA, HRV, MLT, CYP, ESP, SVN, ITA, BEL
Ste	Alternatives	Interdisciplinary science Methodology development for exploratory scenarios; analysis of CO-ACT Step 1; design of scenarios. Transdisciplinary platform Validation of scenarios at second round of Living Labs (see description below).		
Ste		Interdisciplinary science Design and facilitation of Living Labs, analysis of SWOT outcomes.		

	Consequences & Trade-offs	*Transdisciplinary platform* 2-day Living Lab in NLD (03-2025). 22 experts including product manufacturers, public authorities, NGOs, researchers and medical service providers from NLD, BEL, SWE.	*Transdisciplinary platform* 2-day Living Lab in NLD (04-2025). 16 experts including public authorities, water service providers, NGOs and researchers from UKR, BGR, TUR, ROU, GRC.	*Transdisciplinary platform* 2-day Living Lab in NLD (05-2025). 33 experts including industry, researchers, NGOs, public authorities, WWT service providers and industry from GRC, HRV, MLT, CYP, ESP, SVN, ITA, BEL.
Follow-up		EU-level Living Lab combining findings from 3 case studies into EU Zero pollution scenarios. Design of strategic zero pollution framework. Formulating new research priorities. Tracking scientific and social impact.		

3.2.1. Operationalisation

In step 1 of CO-ACT, the initial framing of the challenge was done in the proposal writing phase of SOS-ZEROPOL2030, which selected PFAS and TWPs as case study pollutants, and merged a life-cycle approach of understanding and addressing pollution from source to sea with systems thinking. Initial assessment of the case study pollutant involved disciplinary social science (relevant governance, public perceptions, stakeholder analysis, power) and natural science (emission sources, emission volumes, pollutant lifecycle, environmental risk).

To facilitate the transdisciplinary co-creation, Living Labs were organised. Living Labs are increasingly used as potentially effective tools that support the integration of knowledge and translate it into solutions for tangible economic, environmental, and social challenges in the real world (Heilmann & Pundt, 2021). Putting stakeholders at the heart of the innovation process at living labs can lead to more socially robust outcomes, provide legitimacy to interventions and create relevant action-oriented knowledge that could more effectively catalyse sustainable transformation, while facilitating social learning and reflection between participating actors (Waheed; 2017, Kok et al., 2023; Reed et al., 2010).

One Living Lab was organised per case study with between 13 and 22 participants who were selected based on their expertise and specialised knowledge in the governance of the pollutant and to ensure diversity in stakeholder type and nationality (see Table x). Through a range of dynamic, participatory methods different perspectives on the pollution issue were explored. Both individual responses and group responses contributed to joint system description across STEEP dimensions. The understanding of root-causes, challenges and objectives allows for the identification of drivers of change, or the leverage points from where systemic change might be achieved.

3.2.2. Results

Based on multi-disciplinary research, the interdisciplinary team process refined the thematic scope of the challenge and objectives. For the NEA the scope was reducing PFAS emissions from medical applications since the medical sector is associated with a significant share in the PFAS emissions but also has a strong argument that this use can be considered essential. We considered emissions along the product chain for three product categories that often contain PFAS: medical textiles; implants, meshes, tubes & catheters; and propellants. The scope of the BS case study was on governing PFAS emissions in the Black Sea basin and increase awareness and institutional capacity, since political- and industry action on PFAS were comparably low. For the MED the scope was on mitigating against TWPs by exploring the possibility of eco-design of cars and tyres as well as remediation of microplastic pollution through WWT. Living Lab participants received a factsheet for each case study containing the state-of-the-art knowledge on pollutant sources and concentrations and the relevant (emerging) EU policies.

The research findings coupled with co-creation of challenges and objectives at Living Labs were used by the interdisciplinary research team to list the most important drivers, those STEEP aspects shaping the ability to address the underlying causes of change. Identified drivers across three case studies, so applying both for PFAS and TWP pollution cases, were **responsibility** being taken for addressing pollution by all public and private actors including users, having a **coherent risk approach** with regards to known and unknown risks posed by chemicals, shaping an appropriate **regulatory landscape** that limits environmental damage without stifling the economy, **effective monitoring** strategy for independent actionable data, strategic **orientation of innovation** and technology efforts, appropriate level of **transparency in the supply chain** enabling public and private actors to make informed decisions, **balancing quality** and performance of goods and services **with their environmental costs** for example through true costing, appropriate level of **stakeholder and public inclusion** in decision making processes. For the BS also **awareness raising and agenda setting** was identified, applying across stakeholder groups, as well as **institutional capacity** for adaptive governance to be able to deal with emerging threats. For the MED focusing on TWPs, **mobility policy, incentives and communication** was included to refer to the wider mobility context in which TWP emissions take place, which includes aspects of driver behaviour and public transport.

3.3. CO-ACT Step 2: Alternatives

3.3.1. Operationalisation

In step 2 of CO-ACT, an interdisciplinary team of scientific experts designed alternative futures in the form of exploratory scenarios. Exploratory scenario design is increasingly being used to better inform decision-makers by creating multiple plausible futures (scenarios) based on drivers of uncertainties. The process of raising awareness and promoting creative and imaginative thinking about more distant futures can support robust and flexible policy measures dealing with change (Machiels et al., 2023). The aim of explorative scenarios is to analyze a range of possible consequences of strategic decisions and how these consequences can vary depending on which future development unfolds. Explorative scenarios respond to the question: What can happen if we act in a certain way (Cordova-Pozo & Rouwette, 2023)?

Based on scientific literature and previous experiences in other (EU)- projects, the SOS-ZEROPOL2030 interdisciplinary team first identified micro scenarios for each of the drivers of change identified in step 1. All drivers of change are divided into two extremes. The reason to opt for the most ‘extreme’ ends of the spectrum in scenario development, is to create clear, differentiated scenarios that demonstrate as many outcomes as possible. Prioritize the drivers by two criteria: the degree of importance of the driving forces to the issue at stake and most uncertain. These drivers will be the foundation of the scenario set. The two forces should not be too closely dependent on each other and must be able to go in contrasting directions in the future. Develop the scenarios by discussing the following questions ‘What happens in each scenario?’; ‘What policy options are available for each scenario?’; ‘Which interventions are needed to prepare for each scenario?’. Validation of scenarios.

3.3.2. Results

In the **North-East Atlantic region**, the scenarios for PFAS emission reduction from medical applications are presented in a matrix shaped by two axes: who takes responsibility for a zero-pollution economy (public sector versus private sector); and what is the approach towards pollution (reactive versus proactive), see Figure 3. The naming of the scenarios reflects that a transformation of the economy is required to address marine pollution from PFAS.

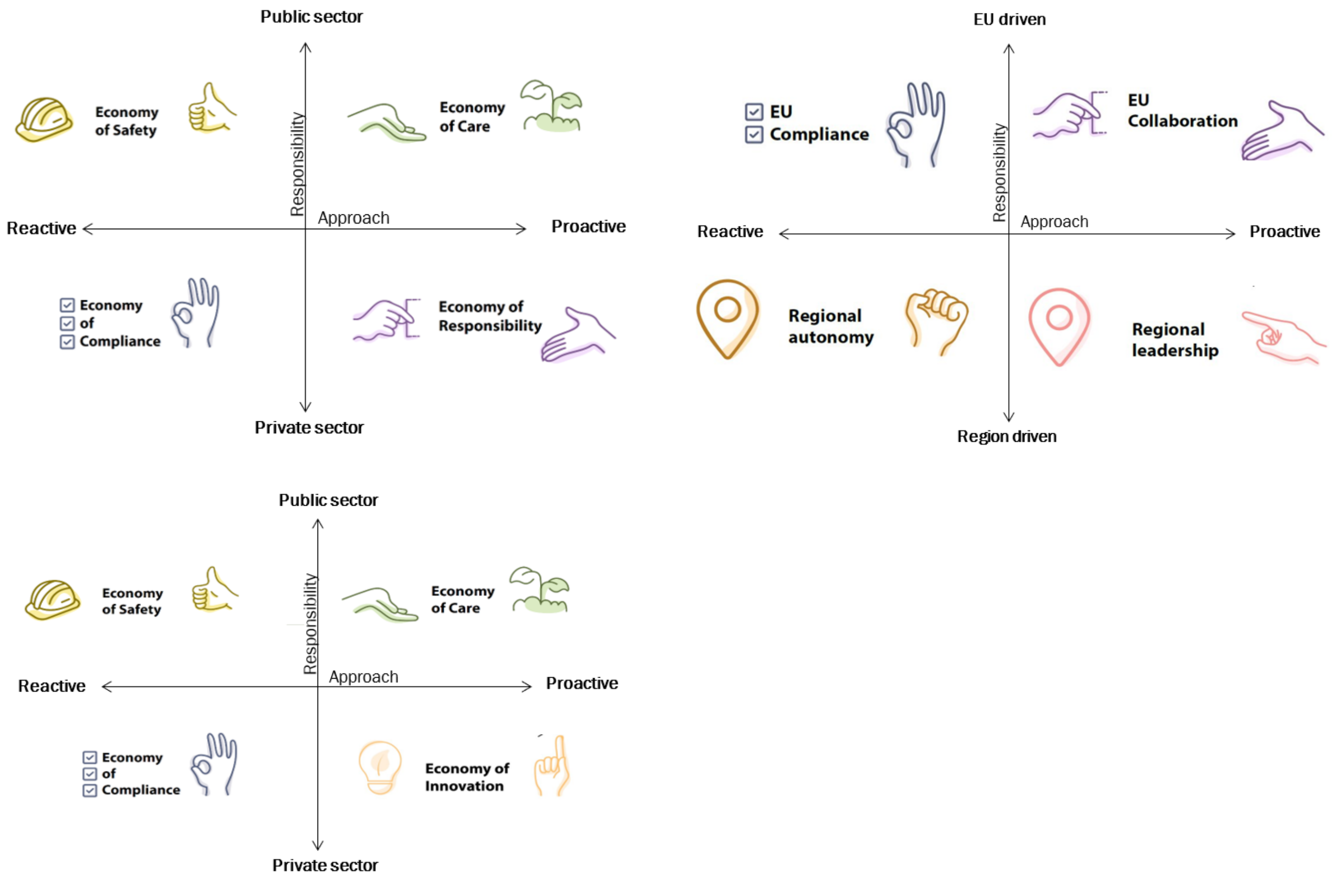

Figure 3. Scenario structure and titles for (i) reducing PFAS emissions from medical applications in the North East Atlantic region (top-left image); (ii) reducing PFAS emissions in the Black Sea basin (right image); and (iii) reducing TWP emission in the Mediterranean Sea (bottom-left image). For full scenario descriptions see (Hulst et al., 2025).

In the **Black Sea region**, the scenarios for PFAS emission reduction in the Black Sea basin are presented in a matrix that is shaped by two axes: who takes responsibility for a zero-pollution economy (EU-driven versus region-driven); and what is the approach towards pollution (reactive versus proactive), see Figure 3. The naming of the scenarios reflects the level of ambition regarding governance of pollution from PFAS coupled with alternative roles for the region vis-á-vis the EU.

In the **Mediterranean Sea region**, scenarios for reducing TWP emission through eco-design and improved wastewater treatment are presented in a matrix shaped by two axes: who takes responsibility for a zero-pollution economy (public sector versus private sector); and what is the approach towards pollution (reactive versus proactive), see Figure 3. The scenarios reflect the need for a transformation of the economy to effectively address marine pollution from TWPs.

3.4. CO-ACT Step 3: Consequences and Trade-offs

3.4.1. Operationalisation

In step 3 of CO-ACT, the scenarios were further explored at a second round of Living Labs in each case study. One of the defining characteristics of wicked problems is that no single solution exists. Each intervention pathway has advantages and disadvantages for different actors at different time scales. Consequences of all scenarios were assessed systematically by doing a SWOT analysis, a commonly used framework to perform analysis and evaluate decision situations. The combination of dynamic participatory tools for the mixed stakeholder groups ensured not only reflection and learning among participants but also highlighted trade-offs between values and interests held by different stakeholders.

3.4.2. Results

For the **North-East Atlantic region**, the SWOT analysis showed that the scenarios led by the public sector are associated with long-term health and environmental outcomes, while requiring significant expansion of public sector monitoring, reporting and enforcement capacity. The industry-led approaches are seen to require a more radical transformation in the economic workings of multiple sectors in terms of industry incentives and drivers. The proactive approaches towards chemicals governance were often highlighted as the preferred scenarios by stakeholders, but the effectiveness and environmental outcomes are seen as contingent on multiple preconditions and therefore more uncertain than remediation approaches.

For the **Black Sea region**, the SWOT analysis highlighted that across scenarios, stakeholders see advantages in any structured, integrated approach towards chemicals pollution. The EU-driven scenarios are seen as effective but requiring significant expansion of monitoring and policy enforcement. The regional-led scenarios are complicated by the current war in Ukraine and the associated lack of priority for environmental issues on the regional and national political agendas, increasing the disparity with the two EU Member States in the region. Overall, stakeholders express preferences for a more proactive approach and a strong role for the region to ensure a regional fit, while recognising the need to balance this with a realistic pace of regional political development and institutional capacity.

For the **Mediterranean Sea region**, the SWOT analysis showed high stakeholder appreciation of the proactive scenarios due to the associated health and environmental outcomes, while recognising the difficulty in fully transitioning to eco-design of tyres. The industry-led scenarios highlight the need for substantial transformation of the product chain required, especially regarding transparency, true costing, innovation orientation and shaping extended producer responsibility to include the costs of remediation action.

3.5. Follow-up

The interdisciplinary research and transdisciplinary Living Lab outcomes will be combined in the SOS-ZEROPOL2030 project in a series of zero-pollution scenarios at an EU-level

Living Lab. Regional stakeholders complemented with EU-level pollution experts will reflect on which future pathways best supports the transformative change required for a successful blue green transition towards clean European Seas. The outcomes will lead to a strategic zero pollution framework to pave the way for multi-stakeholder, multi-sectoral and multi-level actions that show what zero-pollution pathways exist. Project findings and results are also disseminated to a broader audience across the EU.

Formulating new research priorities. Tracking scientific and social impact

4. Discussion: CO-ACT for transformative action

This paper presents a co-creation methodology to support transformative action - and change – in complex urgent sustainability issues. The application of CO-ACT in three case studies of reducing marine pollution in European Seas shows that such transformative action can vary from supporting existing transformations to planting the first seeds for transformation. For example, in the North-East Atlantic case, CO-ACT actively engaged the medical procurement actors, i.e. hospitals, material and product developers, that seek to reduce PFAS in various medical applications, such as medical clothing and anaesthetics. In contrast, in the Black Sea, participants knew little about PFAS pollution of the Black Sea. CO-ACT brought actors together, such as environmental NGOs and the Regional Sea Convention's Secretariat that are known to be able to mobilize change by putting issues on the public and political agenda. In the Mediterranean Sea case, the network of actors that is already active on the issue of microplastic marine pollution gained a better understanding of the potential contribution of TWPs and TWCs, while also considering the dependency on land-based sources of TWP and TWC pollution and the complexity to address those.

The type of transformative actions that emerge during or shortly after the co-creation process relate to: improving the awareness and urgency of a sustainability issue, moving the issue up the agenda of various (influential) organizations, and building or strengthening networks around a sustainability issue (Agnew et al., 2023). In particular, CO-ACT formed a basis for transformative action through the development of a strong interdisciplinary scientific basis (despite limited data being available about these emergent pollutants), rooted in multiple social and natural disciplines. The interdisciplinary scientific work was inspired by a source-to-sea approach that enabled a system perspective that specifically addressed land-based sources of pollution and aquatic pathways of marine pollution. Even though methods such as surveys, interviews, and literature research were used to develop disciplinary insights, the development of various interdisciplinary products (e.g. a factsheet for living lab participants, strategic scenarios) allowed for interdisciplinary outcomes to feed into the co-creation process. As a result, systemic drivers and root causes of marine pollution were explored both as part of the interdisciplinary scientific work as well as during the Living Labs.

In addition, the transdisciplinary platform creations started with engaging experts as part of the scientific work, especially through interviews. This was combined with organizing a meeting (the living lab) of the transdisciplinary platform during step 1 of CO-ACT, allowing co-creation not just of alternatives, but also of the challenges and objectives that form the basis for these alternatives. This is in line with the insights that inclusion of stakeholders in co-creation in the problem analysis phase improves co-creation. In fact, CO-ACT also relies on engagement of the transdisciplinary platform more than once. Rather than a co-creation process in one place and time, CO-ACT, also in the way it was implemented, includes multiple engagement moments with the transdisciplinary platform. In addition, in inviting living lab participants a broad range of actors was targeted, e.g. from various industries, government, civil society and academia. The living labs were organized and led by facilitators that were regionally embedded, i.e. organizations that could either engage their own networks, but were also able to select and invite relevant actors beyond their networks.

Despite these strengths, in their implementation of CO-ACT (see Table 1), the case studies were not able to meet all preconditions. While not uncommon, a broader range of stakeholders were invited than engaged in reality. As acknowledged in previous studies, engaging incumbent and powerful actors, such as the tyre industry or PFAS producers, but also representatives of national governments, is difficult. As a result, in the implementation of CO-ACT convergence between stakeholders became a dominate focus, impeding a continuous exploration of different perspectives, both of power and less powerful and minority voices. In addition, transformative action in terms of changing regulations or industry practices turned out to be infeasible on the short term.

It is too early to tell whether these examples of transformative actions will lead to in-depth, quick and system-wide change. The follow-up of a co-creation methodology such as CO-ACT is therefore crucial. Yet, this follow-up is shaped by both the interdisciplinary science team and the transdisciplinary platform.

5. Conclusions

In line with Termeer et al (2024), we position CO-ACT as a flexible approach for transformative action which could be embedded in any of the three archetypical processes of transformative change ranging from Small Wins (combining in-depth- with quick change); Rule Changes (combining Quick- with System-wide change); and Big Plans (combining In-depth- with System-wide change). By making the theory of change explicit we set out preconditions for substantive transformative action that is rooted in system thinking, and interdisciplinary and transdisciplinary co-creation processes. CO-ACT goes beyond a call for 'more participation', rather, participation and transdisciplinary co-creation are essential for achieving transformative action.

By applying CO-ACT to three case studies, the paper explored how preconditions for co-creation support transformative action and change. The application showed that despite the flexibility that CO-ACT offers, implementing CO-ACT in such a way that all preconditions are met is challenging. As a result, the nature of co-created transformative action can vary in depth, pace and scope. The way in particular preconditions enable or constrain the depth, pace and scope of transformative action requires further research and implementation of CO-ACT among a wider range of issues. Moreover, since the co-created transformative action might not materialize on the short term, the way in which CO-ACT processes lead to transformative action and change on the longer term, warrants more (longitudinal) research.

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