European Commission

Emerging environmental and other issues impacting our ability to achieve a water-resilient Europe by 2050

FINAL REPORT OF 2022-23 ANNUAL CYCLE

FORENV

THE EU FORESIGHT SYSTEM FOR THE ENVIRONMENT

Environment

See Water Differently

#WaterWiseEU

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The European Environment Agency (EEA) Scientific Committee and the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER) contributed to this report by reviewing the emerging issue characterisations presented here.

The valuable contributions of the following EEA Scientific Committee and SCHEER members are kindly acknowledged:

EEA Scientific Committee (review of Issues 4, 5, 6, 9 and 10): Louis Meuleman, Jaroslav Mysiak and Susana Viegas

SCHEER (review of Issues 1, 2, 3, 7 and 8): Thomas Backhaus, Teresa Borges, Urbano Fra Paleo (external expert), Marian Scott (Rapporteur), Theodoros Samaras, Marco Vighi (Chair), Pim de Voogt.

To cite this publication: *The EU Environmental Foresight System (FORENV) Final report of 2022-2023 annual cycle Emerging environmental issues possibly impacting our ability to achieve a water-resilient Europe by 2050*, Publications Office of the European Union, Luxembourg, 2024 ISBN 978-92-68-10288-6, doi 10.2779/598202

February 2024, amended October 2024 and January 2025

EUROPEAN COMMISSION

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B-1049 Brussels

Luxembourg: Publications Office of the European Union, 2025

PDF	KH-05-23-518-EN-N	ISBN 978-92-68-10288-6	doi: 10.2779/598202

Contents

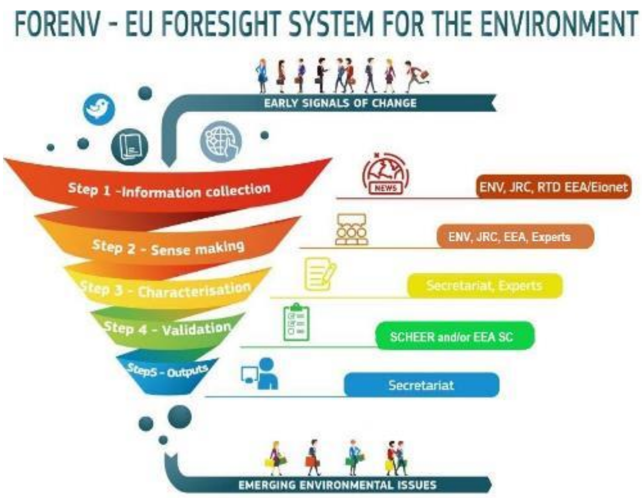
Appendices

EXECUTIVE SUMMARY

Action needed to improve the knowledge base for European Union environment policy set out in Priority Objective 5 of the 7th includes '*that (by 2020) the understanding of, and the ability to evaluate and manage, emerging environmental and climate risks are greatly improved'*. In 2017, the Environment Knowledge Community (EKC[1]), established the EU foresight system for the systematic identification of emerging environmental issues (FORENV), as a direct response to the need, identified in the 7th Environmental Action Programme[2] to secure *'that (by 2020) the understanding of, and the ability to evaluate and manage, emerging environmental and climate risks are greatly improved'*. FORENV is a collaborative process, implemented by members of the EKC, with the overall aim:

To identify, characterise and assess emerging issues that may represent risks or opportunities to Europe's environment, and to communicate these results to policy-makers and other stakeholders, encouraging appropriate and timely action to be taken. Ultimately the aim is to enable policy makers and other stakeholders to prevent or effectively manage emerging risks, and to ensure that opportunities are identified and exploited.

FORENV is based on a systematic, 5-step approach (see image) intended to provide regular and timely updates to EU policy-makers on issues which present potential risks and opportunities for the environment. The system was piloted in 2017 and four cycles were successfully completed in 2018 – 2019, 2019 – 2020, 2020 – 2021, and 2020 - 2021. This report is on the fifth annual cycle, which ran from September 2022 – December 2023, and focused on the topic of emerging environmental and other issues impacting our ability to achieve water resilience in the EU (see Box A).



In each annual cycle FORENV identifies 10 emerging issues which are characterised using expert knowledge and desk-based research into existing relevant literature and evidence.

In the first two cycles (between 2018 and 2020) the output of FORENV took the form of a detailed characterisation and visual 1-page summary of each emerging environmental issue (see Box B). The characterisations include information on: drivers of the issue's emergence[3]; potential

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[1] The EKC is a cross-institutional collaboration set up in 2015 between the European Commission's Directorates-General ENV, CLIMA, RTD, ESTAT, JRC and the European Environment Agency with the intention to improve the generation and sharing of EU environmental knowledge.

[2] Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet'

[3] Emergence is expressed as Short-term: 1 - 5 years; Medium-term: 5 - 10 years; Long-term: 10+ years

implications of the issue; associated risks and opportunities for Europe's environment and human health; key uncertainties and research needs; and, relevant EU policy. Since the third annual cycle (2021) additional, more policy-relevant outputs has been prepared: a Synthesis Report providing a cross-cutting analysis of the outcomes; and the preparation, in place of the individual issue characterisation visuals, of infographics presenting **five key clusters** of changes related to the priority emerging issues, together with key questions for policy arising from these. A short summary of each of these five key clusters is presented below.

Box A: Topic for FORENV 2022-23 –Emerging environmental and other issues impacting our ability to achieve a water-resilient Europe by 2050

Water management, particularly water quality, is a comprehensively regulated policy area in the EU. Increasing water scarcity and droughts call, however, for additional attention of policy makers to water quantity aspects of water management. While the Water Framework Directive (WFD) does not impose unambiguous requirements on water quantity, it does address water quantity in several ways. Water quantity is, for example, implicitly included in the definition of good ecological status for surface waters and explicitly in hydromorphological elements (i.e. flow regime). Furthermore, good quantitative status is required for groundwater, where Member States must ensure a balance between abstractions and recharge rates. The requirement of water pricing also aims to provide incentive signals for water users to use water resources efficiently. The recognition that water quality and quantity are closely related within the concept of 'good status' is fundamental in addressing water resources management challenges.

The EU has experienced extremely dry summers for 5 of the last 6 years, with significant damage throughout the economy (inland navigation, energy production, agriculture) and nature, with effects lasting well into the winter season and the next spring. A multitude of factors is behind the increased prevalence of water scarcity in Europe – droughts worsened by climate change, inefficient use of water (over-abstraction, over-use, over-allocation) combined with higher demand. Also, the modification of natural rivers to render them more directly useful for economic purposes and reduce flood risk, as well as draining agricultural land rather than retaining water inland play an important role. Climate projections suggest that water resource challenges will become much more widespread and severe across Europe in the coming decades. There will be increasing competition for scarce water resources, with potentially significant effects on economy, society and the environment.

In agricultural policy, quantity is a concern through a focus on availability and on more efficient water use. More recently the Water Reuse Regulation was adopted (implementation as of June 2023) which seeks to promote the uptake of reused water from waste water treatment facilities for irrigation in agriculture, where relevant. The Commission proposal for a revision of the Urban Wastewater Treatment Directive strengthens existing obligations, requiring Member States to systemically promote the reuse of treated wastewater from all treatment plants where appropriate, and for all appropriate purposes. The Recast of the Drinking Water Directive (application started in 2023) seeks to reduce leakages and the proposal for the Industrial Emissions Directive revision aims at stimulating water efficiency and water reuse across the lifecycle of processes. The 2021 EU Climate Adaptation Strategy is the first more comprehensive plan to address the role of water across a number of areas.

In terms of water use, agriculture and energy are the most important sectors in the EU; moreover, the land used for agriculture is 38% of the total EU land. Therefore, it is clear that addressing water scarcity and drought also implies designing new climate-resilient and sustainable sectors such as agriculture, energy, industry and households. A more comprehensive holistic approach on water scarcity and drought, moving beyond the perspective of environment alone, is therefore needed. From an EU policy perspective this would imply enhanced cooperation, use of current policies and potentially targeted revision of instruments. Nature-based solutions, making use of natural resources and landscape features should be part of this.

To respond to the increasing drought and water scarcity in Europe, the EU could work towards enhancing its "water-resilience" through the forthcoming European Water Resilience Strategy announced in the Political Guidelines of the President of the European Commission [4]: a more efficient and sustainable use of water resources across all seasons and sectors, to the point that the environmental, economic and social needs for water do not surpass water availability at any point in the year. To allow the development of pathways for such a water resilient EU by 2050 as well as testing plausible worst-case scenarios, it is important to identify opportunities and threats early on in current policies and in their future development, both at the EU and MS level.

Moreover, political, economic, technological and societal issues and trends will have an influence on water use, abstraction and valuation. But we don't necessarily know which trends have the most beneficial, which ones the most detrimental effect. Modelling (using JRC's capacities in that regard) is one tool that could be used to sketch out pathways.

As overall orientations for the elaboration of specific emerging issues, the following key research question is proposed: **Which emerging environmental, societal, economic and technological developments and other issues may impact (i.e. having benefits, opportunities and threats to) our ability to achieve a water-resilient Europe by 2050?**

Cluster 1: Need for sectoral adjustment

- A shift to sufficiency-based water governance in Europe, which aims to cap water usage at sustainable levels, may challenge water-intensive sectors like agriculture, manufacturing, and recreational services such as golf courses.

- If in future, meat consumption and production in the EU were to be reduced to meet climate goals, this might relieve pressure on local water resources in areas reliant on livestock farming. However, the cost of responding to environmental stresses, especially from climate change, may limit capital available for investment in sustainable agricultural practices. This would increase the vulnerability of the food production sector to water shocks, threatening future food security. At the same time, increased adoption of agroecological practices could improve soil health and drought resilience but could lower yields and struggle to meet food demands without changes to land use.

- Increasing societal pressure for responsible water stewardship could push businesses to adopt more sustainable practices or risk losing market share. However, the emergence of a 'hydrogen economy' to aid the low-carbon transition could substantially increase the water

[4] Von der Leyen, U., Europe´s Choice, Political Guidelines for the next European Commission 2024–2029, Strasbourg 2024.

footprint of energy systems, especially in water scarce regions where 60% of anticipated hydrogen projects are expected. This could undermine water resilience initiatives.

- In the long-term, water scarcity may drive transitions to less water-intensive practices in the agriculture sector, especially if enabled by supportive policies. However, such transitions may come with potential economic losses for affected farmers. Overall, water is likely to be the 'twin challenge' that companies across sectors face in working to achieve their carbon emissions goals, given the high-water consumption demands of some low-carbon solutions like hydropower, hydrogen production, and nuclear power.

Cluster 2: New technology, new risks?

- As water becomes scarcer in many EU regions, cities may turn to alternative water sources, like new desalination plants, to augment supplies and reduce pressure on surface and groundwater sources. Recent advances in portable desalination systems have potential in some areas to enhance decentralised water access. However, desalination requires brine disposal and has high energy usage, increasing carbon emissions unless paired with renewables. More extreme actions like iceberg towing or cloud seeding may be seen to be water supply solutions despite very uncertain efficacy and disruption to natural water cycles and ecosystems.

Box B: Emerging environmental issues

FORENV presents **emerging issues** or **changes to well-known issues** in Europe's environment. Emerging issues reflect observed changes or developments in the environment that occur as a result of new research or knowledge, a shift in geographical or temporal scales of impact, or due to heightened awareness or new response measures to issues. Emerging issues reflect current evidence of possible future change to the environment that is either positive or negative. These issues are assessed over 3 time horizons showing when an impact (either positive or negative) is likely to occur in Europe – short-term (1 - 5 years), medium term (5 - 10 years) and long-term (10+ years).

- The possible growth of controlled agriculture methods such as vertical farming and indoor farming, might lead to improved water efficiency and climate resilience. However, such methods have high energy demands for lighting and temperature control, limiting feasibility and investment potential.

- A new ecosystem of water-focused technologies like the Internet of Things (IoT), smart meters and pricing schemes may emerge leading to more efficient water demand management. However, digital systems have a range of environmental impacts, and their adoption can lead to new cybersecurity threats.

- Digital systems combined with data mining, artificial intelligence and modelling tools may enable a more integrated systems approach to water management, with better consideration of interconnections across sectors for shared benefit and cost distribution. The use of these technologies in urban water systems may also enhance efficiency. However, they may increase costs, and lead to risks related to cyber-attacks and privacy concerns that may limit implementation. Overall, the expanding digitalisation of water systems will require equivalent growth in cybersecurity measures and standards to mitigate threats to critical infrastructure.

Cluster 3: Hydropolitics – a driver of conflict or cooperation

- More climate-related population displacement and migration could enhance the profile of water resource governance in regional, national, and international security and migration policy frameworks. At the same time, growing sectoral and community demand for water may intensify competition (and potentially fuel conflict) over access, especially with more frequent and severe droughts requiring public authorities to mediate disputes. This dynamic could see water increasingly used as a geopolitical tool or leverage in regional conflicts, requiring robust legal and institutional governance mechanisms for (intra and extra-EU) transboundary water cooperation aimed at fostering peace and political stability.

- Unilateral large-scale abstraction and infrastructure projects taken by nations sharing river and lake basins may risk increasing tensions over water quantity and flows downstream. However, joint investments in resilience projects across borders may conversely promote cooperation through equitably distributing benefits, strengthening incentives for responsible sharing. Nonetheless, the accelerating transition to renewable energy systems could significantly increase national water demands for energy production. This may challenge existing transboundary allocation agreements developed under conditions of lower demand.

- Overall, there is uncertainty whether the pressures from growing climate impacts exhaust the capacity of cooperation mechanisms to equitably redistribute shared waters. But the likelihood of the latter depends on building confidence and trust between riparian states through basin-level governance that sustains engagement on benefit sharing as uncertainty increases. It also requires updating legal frameworks like transboundary agreements to enable cooperative management of climate impacts and sectoral transitions. Without these efforts, unilateral actions compromising flows are more likely to prevail, sparking grievances or security responses from affected states.

Cluster 4: Water inequalities and just transitions

- The accelerated impacts of climate change are expected to challenge to water resilience in the EU, exacerbating the risks of flooding, water scarcity and poor water quality. Specifically, the negative impacts of harmful algal blooms may be intensified, disrupting sectors dependent on affected water bodies (e.g. fishing, tourism) while posing a threat to public health. In addition, greater water scarcity and more extreme weather events could disrupt the predictable seasonality on which the agricultural sector depends.

- With more scarce and less reliable water supplies, food production could be challenged in many EU countries. Seasonal shortages and resulting food price spikes could impact food security, exacerbating health and economic inequalities. In addition, existing wealth inequalities may increasingly determine access to water if those on higher incomes are able to circumvent restrictions on consumption. At the same time, large-scale water diversion projects to urban areas may exacerbate rural-urban inequalities and have adverse impacts on ecosystems. Disputes over water access may take on an international dimension, which may see transboundary water agreements being challenged if Member States perceive them as a loss of sovereignty, resulting in more powerful countries using their economic advantages and water infrastructure to negotiate greater access.

- Increased circularity in water management and technological innovation to improve water efficiency may emerge as a response to reduced water availability as an economic input and help usher in a just transition. For example, the rise of 'aquapreneurs' and venture capital investment that accelerates the development of novel water technologies, although this also raises concerns about water privatisation and equitable access. In addition, technologies such as drip irrigation and remote sensing offer opportunities to optimise water use, although the associated up-front costs could raise equity issues among farmers. At the household and neighbourhood level, emerging circular water management practices could gain popularity, leading to the spread of new technical skills and changes in consumer behaviour, with wider economic spillovers.

Cluster 5: Water governance – centralised or decentralised system?

- Growing challenges to water resilience, including the continuation of polluting agricultural practices, could exacerbate water quality problems and reduce the availability of water supplies in Europe. In turn, we may see public and private investment to rapidly develop innovative water technologies and water sourcing emerge as part of the solution, such as an increased focus on water recycling and desalination, shifting traditional water supply models and enabling new sources of water altogether.

- At the same time, the normalisation of water reuse could catalyse the development of affordable, decentralised reuse technologies for residential and commercial buildings across Europe. This could lead to less reliance on centralised utilities, potentially changing traditional approaches to water management in several EU member states. The move towards decentralisation is also likely to address the risks associated with ageing water infrastructure, potentially strengthening water resilience at the community level.

- The emergence of decentralised and localised water systems, which can be supported by small-scale modular treatment technologies, may offer a compelling alternative to traditional centralised utility models in the EU. However, the economics of these new and decentralised water technologies remain uncertain. If they are very capital-intensive to purchase and maintain, communities may consider reverting to traditional water collection practices, which promotes decentralisation but also risks disrupting natural water cycles, particularly in southern European regions facing acute water scarcity challenges.

- The potential benefits of new and alternative water sources and the shift towards more decentralised water management models also come with their own regulatory challenges. This increased emphasis on decentralisation may also lead to a greater policy emphasis on diversifying how water is governed rather than relying solely on water infrastructure megaprojects. In addition, the wider use of rainwater harvesting would require careful coordination to avoid unintended impacts on environmental flows and groundwater recharge.

Key policy questions

The five clusters of disruptive development point to a range of potentially important changes that individually and collectively suggest the emergence or strengthening of drivers that can address water scarcity and enhance Europe’s water resilience, or conversely which may pose threats to the transition to water resilience. By considering these changes a series of potential implications for future water resilience are defined together with key uncertainties. These implications and uncertainties represent areas where it may be important to improve understanding and consider how policy could respond to mitigate possible risks and maximise opportunities.

By looking across these implications and uncertainties, some cross-cutting topics can be observed. By considering such themes, some key questions for EU policy related to water scarcity and resilience are identified. These are intended to help guide potential future policy discussions and identify opportunities but also where policy developments may need to reflect and respond to manage future risks.

1. Harnessing win-wins for a water resilient future

Water is fundamental to the viability of many economic sectors and is likely, along with addressing climate change, to represent a 'twin challenge' that many businesses will face in meeting their sustainability targets: reducing carbon emissions while also adapting to water scarcity (Cluster 1). Across the emerging issues characterised by this cycle of FORENV, and reflected in the clusters, is a theme of the potential for policy and action in one factor supporting or facilitating benefits in another, including in meeting wider transitions goals. For example, using nature-based solutions as part of an approach to more sustainable water management at neighbourhood or city scales (Cluster 4) will also help meet climate resilience, biodiversity and human health goals. Similarly, policy and action to support EU based innovation in novel water technologies (for supply, management, use) can help move towards a water resilient future while also providing economic opportunities and playing a role in the transformation of key sectors (Cluster 4). On a more strategic scale, regional and transboundary cooperation on water can enhance resilience while also addressing drivers and pressures that may exacerbate long-term drivers of geopolitical tensions (Cluster 3).

At the international scale the UN Water Conventions (the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention, and the Convention on the Law of the Non-Navigational Uses of International Watercourses (Watercourses Convention) provide the framework for such cooperation.

Whilst realising a water resilient future thus presents many challenges, there are also examples of potential win-wins where actions or policy changes can have direct or indirect benefits beyond their key focus. This could include using policy in one area (e.g. land-use planning) to achieve multiple social and environmental objectives, including enhanced water resilience; or may seem the use of economic and policy tools such as water pricing, coordinated with circular economy interventions to create 'virtuous cycles' of water use and reuse efficiency, the adoption of less water intensive processes and enhanced training and awareness of the value of water.

- How can EU and national policy-makers identify and harness win-wins for water resilience, to better integrate cross-sectoral perspectives by considering how actions in one area affect others, and align with broader sustainability objectives such as flood protection, biodiversity, circularity and climate adaptation?

- How can policymakers effectively harness innovation and 'aquapreneurship', while managing risks and avoiding unintended consequences?

2. Planned or 'enforced' change in sectoral use of water

The competing demands for access to water for citizens as well as economic sectors, together with the intrinsic needs of the natural environment, will necessitate the development of policies and regulations that foster cross-sectoral cooperation and holistic water management. The clusters identify a number of points of tension, for example in a more water scarce future water-intensive sectors may find their use is capped which can drive potentially costly adaptation at short notice (Cluster 1). Water availability may also mean farmers may find themselves forced to suddenly abandon water intensive traditional crops (Cluster 1) requiring support to transition gradually to more efficient water management practices or to less water intensive agriculture. Other clusters point to an increasing need for mediation between sectors as water scarcity deepens (Cluster 3), and that the costs of investment in water efficient technologies may favour larger and more commercially powerful businesses unless those less able to invest are supported in this transition (Cluster 4). This suggests the need for policies that support sectors to understand and plan in advance for necessary changes in their water use patterns.

- How can the EU proactively transition to water resilience and improve efficiency in key sectors such as food production and water-intensive industries before water scarcity forces disruptive changes?
- How can policies promote cross-sectoral cooperation on water resources, such as the agriculture and energy sectors?
- What mechanisms are needed to ensure that integrated water management policies consider the different needs and impacts of all relevant sectors, thereby mitigating risks to productivity and economic viability of their operations?

3. Understanding water's role in Europe's just green and digital transition

While water is explicitly recognised in Europe's ambitions for a green and digital transition, the need to address water scarcity and ensure resilience in Europe's transition has yet to be addressed in a systematic and holistic manner at EU level. The clusters defined in this report suggest that water's critical role in the green and digital transition will require a nuanced approach to ensure that its importance in energy (e.g. if a hydrogen economy emerges, Cluster 1), sectoral transitions (Cluster 1) and technological and digital advancements (Cluster 2 and Cluster 3) do not come at the expense of Europe's natural environment and biodiversity or other water uses. This will require policies that balance innovation with the intrinsic value of water in ecosystems. It is also essential to address water-related aspects of the clean and circular economy and low-carbon, low pollution energy solutions that are key to reaching the EU's Green Deal ambitions addressing the triple planetary crisis – climate change – biodiversity loss – pollution.

- How can policies ensure water resilience without hampering the technological progress assumed in enabling the EU's green and digital strategies?
- Will the future necessities of water management be a facilitator or an obstacle to these green and digital transitions?
- What policies can ensure that the digitalisation and greening of the economy does not exacerbate social and economic inequalities or harm the natural environment?

4. Navigating the complex challenges for water governance in the EU

Three of the clusters emphasise governance: Cluster 3 on hydro-politics; Cluster 4 on water inequalities and just transitions; and Cluster 5 on whether centralised or decentralised water governance systems will emerge. However, all of the clusters suggest that the governance of water at all scales and across sectors of the economy is likely to emerge as a critical issue especially as water becomes scarcer and the demands for water evolve in a changing climate. As water availability and potentially supply reliability declines (especially in some regions) authorities will face increasing pressure on water governance systems. Citizens, communities, economic sectors, cities, regions, and countries may increasingly compete for access to water. Imbalanced power and economic dynamics seem likely to raise concerns about equitable and inclusive governance and access to water. The future of water governance must address these challenges and evolve from a paradigm of abundance to one of sufficiency. It will be crucial to balance national interests with regional stability and claims made at the community level, especially in the context of transboundary disputes over access to water. Decentralised water governance could have a role in enabling a more equitable approach to the achievement of water resilience but may also create tensions where historically water management and governance has been centralised.

- In this context, can existing EU water management policies ensure equitable water governance at different scales (i.e. national, regional, local, personal) in a water-scarce future?
- What strategies are needed to maintain effective and peaceful transboundary water management?

ABSTRACT

Each year FORENV – the EU Foresight System for Emerging Environmental Issues – identifies and characterises 10 priority emerging issues of potential importance to the European environment and environmental policy. In its fifth cycle (2022-23) FORENV explored emerging environmental and other issues impacting our ability to achieve a water-resilient Europe by 2050. This focus of FORENV was to inform thinking and discussion for policies to support water resilience and associated uncertainties in particular the forthcoming European Water Resilience Strategy announced in the Political Guidelines of the President of the European Commission, Ursula von der Leyen[5]. The 10 priority emerging issues identified relate to social, economic and technological developments, including, among others, new and alternative sources of water, the circular economy as a driver for water resilience, water resilient cities, and the use of digital technologies to improve water management. To enhance policy relevance, a synthesis assessment was also completed, which identified five key clusters of change: need for sectoral adjustment; new technology, new risks?; hydropolitics – a driver of conflict or cooperation; water inequalities and just transitions; water governance – centralised or decentralised system? These clusters are presented together with associated implications for the environment and water resilience alongside uncertainties and key questions for policy.

[5] Von der Leyen, U., Europe´s Choice, Political Guidelines for the next European Commission 2024–2029, Strasbourg 2024.

1 FORENV RATIONALE AND METHOD

1.1 Background and rationale

Priority Objective 5 of the 7th Environmental Action Programme[6] established the need to improve the knowledge and evidence base for Union environment policy, to ensure, among other things, '*that (by 2020) the understanding of, and the ability to evaluate and manage, emerging environmental and climate risks are greatly improved'*. Responding to this, in 2015 the Environment Knowledge Community (EKC[7]), decided to jointly strengthen the Commission's capacity to consider emerging issues, including through foresight tools as well as to monitor and identify opportunities and complex risks and anticipate what their impact could be on environment and society.

Capitalising and bringing together existing knowledge, expertise and practices, in 2017 the EKC partners established FORENV, the EU foresight system for the systematic identification of emerging environmental issues, whose overall aim is:

> *To identify, characterise and assess emerging issues that may represent risks or opportunities to Europe's environment, and to communicate these results to policy-makers and other stakeholders, encouraging appropriate and timely action to be taken. Ultimately the aim is to enable policy makers and other stakeholders to prevent or effectively manage emerging risks, and to ensure that opportunities are identified and exploited.*

Policy context

The need for the systematic identification of emerging environmental issues has been identified in the 7th Environmental Action Programme (Priority Objective 5), and also aligns with the Better Regulation guidelines, which emphasise the importance of foresight and other forward-looking tools to combine quantitative modelling with systems thinking and a long-term approach.

"… (by 2020) the understanding of, and the ability to evaluate and manage, emerging environmental and climate risks are greatly improved."

7th EAP Priority Objective 5
http://ec.europa.eu/environment/action-programme

1.2 Objectives and process

1.2.1 Objectives

FORENV is a collaborative process for the early detection, characterisation and assessment of emerging environmental issues. The FORENV system is implemented by the members of the EKC and has the following specific objectives:

1. Bring together in a systematic framework existing knowledge and expertise in the European Union (EU) institutions and Member States to identify weak signals of change relevant for Europe's environment and environment policy.

[6] Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet'

[7] The EKC is a cross-institutional collaboration set up in 2015 between the European Commission's Directorates-General ENV, CLIMA, RTD, ESTAT, JRC and the European Environment Agency with the intention to improve the generation and sharing of EU environmental knowledge.

2. Identify 10 emerging environmental issues per year through EU internal and external expertise, based on their potential impact and policy relevance.

3. Characterise the detected issues on the basis of sound and up-to-date scientific literature and wider evidence, in order to highlight related risks and opportunities.

4. Communicate emerging issues to EU policy makers and stakeholders in a timely manner so that they are able to decide what action needs to be taken.

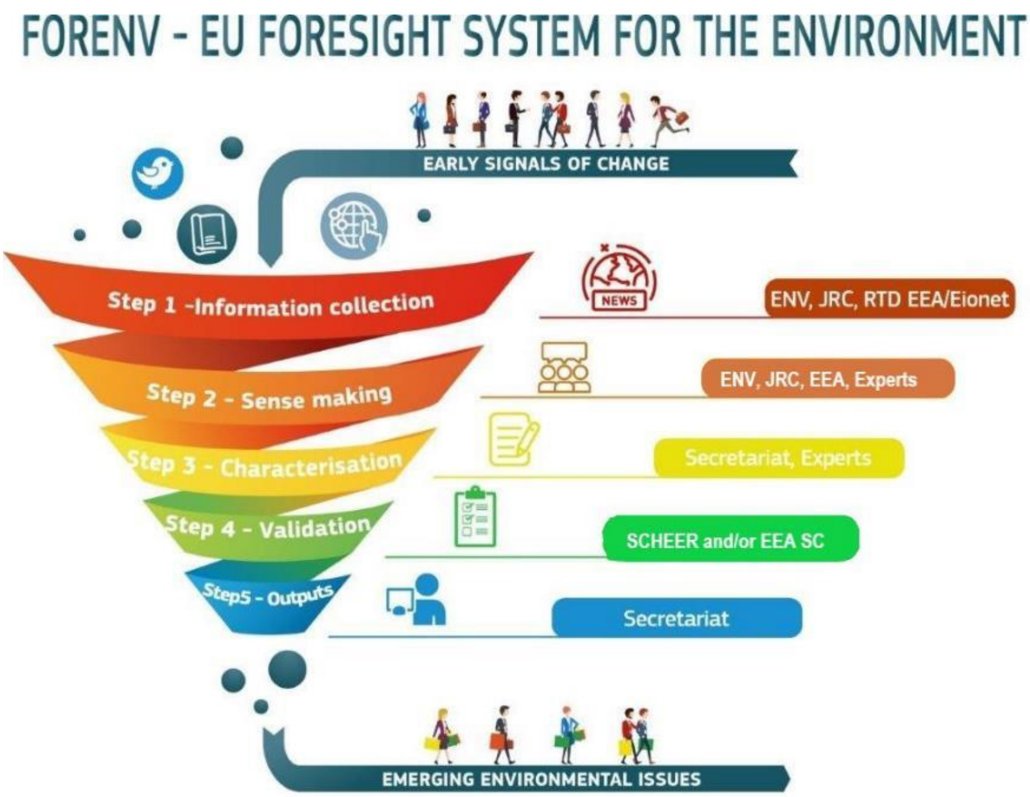
FORENV as an approach is based on horizon scanning and the results developed and presented in this report do not represent a comprehensive review of emerging trends. They are intended to raise some key questions and stimulate discussion on how emerging issues could change the societal, economic and environmental landscape over the coming decades.

Box 1: Horizon scanning as the basis of the EU Foresight System for the identification of emerging environmental issues and related opportunities and risks (FORENV)

The methodology used for FORENV is based on horizon scanning. Horizon scanning refers to the systematic identification and examination of potential future developments or drivers of change at the margins of current thinking and to explore the opportunities and threats to policy or society these may represent. As a process horizon scanning involves desk based and expert-led identification of weak signals of change that may challenge current assumptions or trends.

By making sense of such weak signals through its structured horizon scanning approach, FORENV identifies, characterises and communicates emerging issues to policy makers and risk managers so that they can decide what action needs to be taken. As FORENV is not embedded within a specific policy unit it is not intended to develop or assess policy options, however the outcomes are expected to be relevant for environmental policy.

More information on FORENV and the methodology used are available on the Commission website.



1.2.2 Fifth annual cycle:

In the fifth annual cycle of FORENV, which ran from September 2022 – December 2023, the focus was on emerging risks, opportunities and uncertainties for the achievement of a water resilient Europe by 2050 (see Box A).

Box A: Emerging environmental and other issues impacting water resilience

Water management, particularly water quality, is a comprehensively regulated policy area in the EU. Increasing water scarcity and droughts call, however, for additional attention of policy makers to water quantity aspects of water management. While the Water Framework Directive (WFD) does not impose unambiguous requirements on water quantity, it does address water quantity in several ways. Water quantity is, for example, implicitly included in the definition of good ecological status for surface waters and explicitly in hydromorphological elements (i.e. flow regime). Furthermore, good quantitative status is required for groundwater, where Member States must ensure a balance between abstractions and recharge rates. The requirement of water pricing also aims to provide incentive signals for water users to use water resources efficiently. The recognition that water quality and quantity are closely related within the concept of 'good status' is fundamental in addressing water resources management challenges.

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In agricultural policy, quantity is a concern through a focus on availability and on more efficient water use. More recently the Water Reuse Regulation was adopted (implementation as of June 2023) which seeks to promote the uptake of reused water from waste water treatment facilities for irrigation in agriculture, where relevant. The Commission proposal for a revision of the Urban Wastewater Treatment Directive strengthens existing obligations, requiring Member States to systemically promote the reuse of treated wastewater from all treatment plants where appropriate, and for all appropriate purposes. The Recast of the Drinking Water Directive (application started in 2023) seeks to reduce leakages and the proposal for the Industrial Emissions Directive revision aims at stimulating water efficiency and water reuse across the lifecycle of processes. The 2021 EU Climate Adaptation Strategy is the first more comprehensive plan to address the role of water across a number of areas.

In terms of water use, agriculture and energy are the most important sectors in the EU; moreover, the land used for agriculture is 38% of the total EU land. Therefore, it is clear that addressing water scarcity and drought also implies designing new climate-resilient and sustainable sectors such as agriculture, energy, industry and households. A more comprehensive holistic approach on water scarcity and drought, moving beyond the perspective of environment alone, is therefore needed. From an EU policy perspective this would imply enhanced cooperation, use of current policies and potentially targeted revision of instruments. Nature-based solutions, making use of natural resources and landscape features should be part of this.

To respond to the increasing drought and water scarcity in Europe, the EU could work towards enhancing its "water-resilience" through the forthcoming European Water Resilience Strategy announced in the Political Guidelines of the President of the European Commission [8]: a more efficient and sustainable use of water resources across all seasons and sectors, to the point that the environmental, economic and social needs for water do not surpass water availability at any point in the year. To allow the development of pathways for such a water resilient EU by 2050 as well as testing plausible worst-case scenarios, it is important to identify opportunities and threats early on in current policies and in their future development, both at the EU and MS level.

Moreover, political, economic, technological and societal issues and trends will have an influence on water use, abstraction and valuation. But we don't necessarily know which trends have the most beneficial, which ones the most detrimental effect. Modelling (using JRC's capacities in that regard) is one tool that could be used to sketch out pathways.

As overall orientations for the elaboration of specific emerging issues, the following key research question is proposed: **Which emerging environmental, societal, economic and technological developments and other issues may impact (i.e. having benefits, opportunities and threats to) our ability to achieve a water-resilient Europe by 2050?**

1.2.3 Summary of outputs and structure of this report

In the first two cycles of FORENV the outputs consisted of a main report (this report) containing the 10 priority issue characterisations and a summary infographic for each. Reflecting the process changes made in the third cycle to enhance policy relevance an additional assessment was completed to look across all 10 issues and identify key developments. A synthesis of these key developments identified five key clusters of drivers of potentially disruptive changes, with implications for policies to support water resilience and associated uncertainties. Key policy questions were then defined, which are intended to inform ongoing discussion about potential threats and opportunities to achieve a water resilient Europe. This cross-cutting assessment and related policy questions are also presented in a separate Synthesis Report.

In developing the synthesis report, infographics were prepared for each cluster and these are presented in **Section 3** of this report. **Section 4** then presents the key questions for policy arising from the risks, opportunities and uncertainties associated with the clusters.

Appendix A presents the full characterisation of each issue, on which the clustering presented in Section 2 was based. **Appendix B** summarises the validation and/or review feedback from the EEA Scientific Committee as well as the SCHEER on each of the issues.

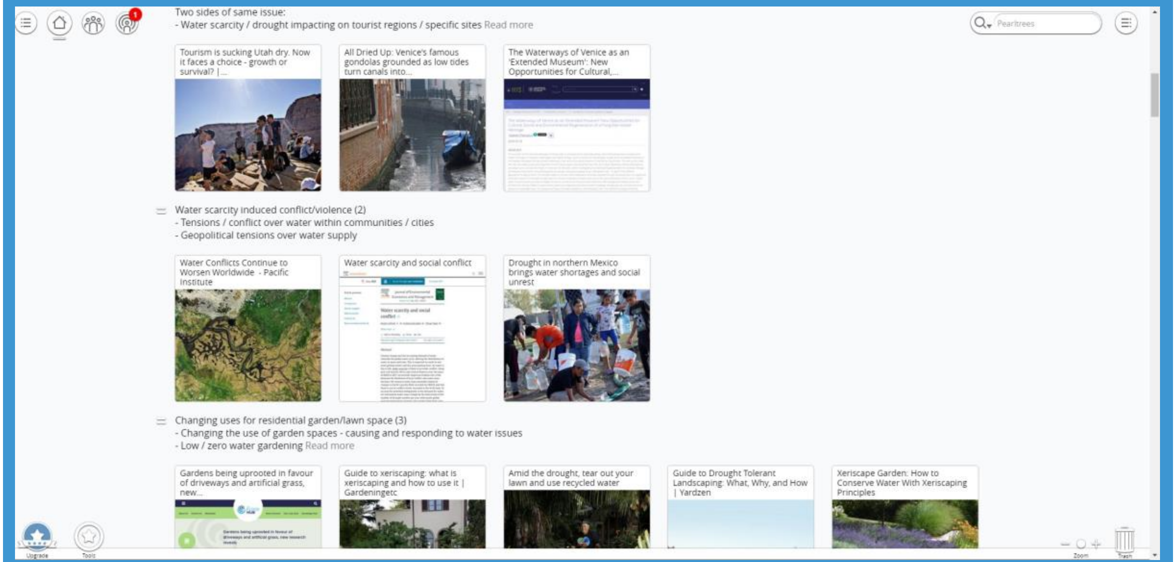
[8] Von der Leyen, U., Europe´s Choice, Political Guidelines for the next European Commission 2024–2029, Strasbourg 2024.

Table 1: FORENV Process 2021-22

Step 1: Information gathering

Around 150 weak signals of change were identified from existing horizon scanning activities in the Joint Research Centre (JRC), DG Research and Innovation (RTD), European Environment Agency (EEA) and its network of Member States, and the Science for Environment Policy News Alert managed by DG Environment. The weak signals were reviewed and collated to select 149 items that were then discussed in Step 2.

Picture 1 presents a screenshot from Pearltrees, an online software tool used to collate items found during Step 1, and cluster them using the STEEPL[9] framework.

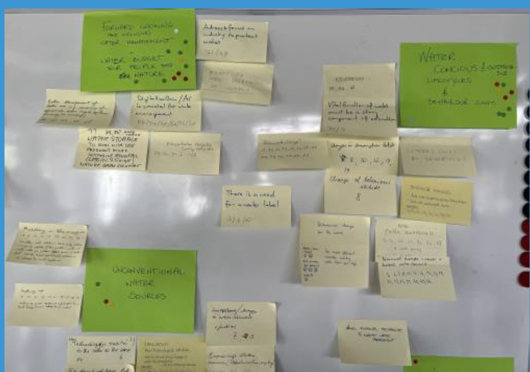


Picture 1: Example screenshot from items collation using Pearltrees software

Step 2: Sense-making and selection

Four sense-making workshops were convened, bringing together in total approximately 40 experts from the Commission and external organisations. Through these workshops, experts analysed the selected weak signals, discussed and assessed potential emerging issues. Using the workshop outcomes 10 emerging issues were prioritised by the EKC.

Picture 2 shows an example of the workshop process, illustrating the clustering of items to help identify potential emerging issues. The image also shows the results of expert voting prioritisation, to help identify those issues considered by the experts to be most important based on their likelihood and anticipated impact.



Picture 2: Example of results from FORENV workshop (27 April 2023)

[9] Social, Technological, Environmental, Economic, Political, Legal

Step 3: Characterisation

Preparation of characterisations of each of the 10 priority issues to highlight related risks and opportunities for the achievement of water-resilient Europe by 2050 (see **Appendix A**). The characterisation was based on a desk-based review of literature (including scientific journals), discussion and feedback from external experts and input from experts in a range of Commission DGs and the EEA.

Step 4: Validation by a scientific committee

The characterisations of the 10 issues were peer-reviewed in the fifth annual cycle by members of the EEA Scientific Committee and the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER). The Scientific Committee review of each issue is presented in **Appendix B**.

Step 5: Outputs and communication

The final findings are communicated, in the form of this report, to citizens, stakeholders and EU policy-makers for discussion and follow-up action. Reflecting the modifications to the FORENV process to enhance policy relevance, an additional Synthesis Report has been prepared which includes some key questions for policy (see section 1.2.3). The full and synthesis reports are accompanied by a slide presentation to communicate the outputs and questions for policy.

2 TOPIC CONTEXT AND SUMMARY OF THE TEN PRIORITY EMERGING ISSUES

2.1 Context: water resilience in Europe

Water resilience refers to the ability to adapt to, manage, and overcome various water-related challenges and their impacts on societies, economies and the environment. This includes but is not limited to, being able to cope with degraded water quality caused by harmful pollutants, with having too much water, as in the case of floods, and with too little water, which can lead to water scarcity. While each of these challenges is critical in its own right, they can also overlap and even interact with each other, such as a decline in water quality that decreases the quantity of water suitable for certain uses (this is explored in *Issue 1: Interrelated challenge of water scarcity and water quality*). This report explores the potential future water-and climate-related risks that may emerge and the opportunities that can be seized to achieve water resilience in Europe, as well as the linkages between them. Reflecting the topic for this annual cycle of FORENV, the emerging issues focus on water resilience and one of its main challenges, water scarcity, addressing the problem of not having enough water as the principal concern, in particular in light of a changing climate. Other water-related challenges, such as problems that can arise from having too much water (e.g. flooding) and poor water quality, while both important considerations in achieving water resilience, are not the intended focus of this cycle of FORENV.

Water scarcity is already being experienced by populations not only in Europe but around the world and is expected to increase in the coming years and decades, exacerbated when taking into account climate change predictions. UN-Water (2023) describes water scarcity as when 'demand for water may be exceeding supply, water infrastructure may be inadequate, or institutions may be failing to balance everyone's needs'. The European Environment Agency (EEA 2023, EEA 2024a) describes water scarcity as being 'determined primarily by (1) water demand and consumption, which largely depend on population and type of socio-economic activities; (2) climatic conditions, which control water availability and seasonality of supply; and (3) landscape and geological characteristics of the basins'. Socio-economic activities will themselves be determined by a range of factors including behaviours and attitudes of consumers and businesses. Taken together, these definitions illustrate the pervasive nature of water scarcity, its causes and its impacts on society, the economy, and the environment, and underscore the importance of developing water resilience strategies to ensure a water secure future.

This report includes in Appendix A the full characterisations of 10 different emerging issues (hereafter referred to as 'the characterisations') that provide a forward-looking examination of different dimensions of water resilience, considering how a range of water-related challenges can impact and shape strategies for resilience in the future. These characterisations are summarised below (see Section 2.2). The issues focus on the risks and opportunities to water resilience and how they may evolve over time, with an emphasis on water scarcity and its key drivers. In turn, they also suggest or point to potential strategies through which a water resilient Europe could be achieved. While each characterisation examines a pathway through which water resilience is being challenged (including by water scarcity) and may evolve in the future, they are not intended to be comprehensive literature or evidence reviews. Rather, the characterisations are forward-looking analyses, using recent developments and emerging trends related to water resilience and scarcity (including water governance and supply) as the starting point, to discuss how these trends may develop in future. The intention is that these selective and exploratory narratives can help identify and inform discussion of potential pathways through which water resilience may be attained.

Although water scarcity is an increasingly global phenomenon, the characterisations focus primarily on emerging issues in Europe, given the focus on risks and opportunities for a water resilient *Europe* to 2050. However, some characterisations also look transboundary concerns and regions outside Europe, mainly as points of comparison, to gain insight into the different ways in which water scarcity may develop in Europe in the future, as well as the wider environmental, economic, or societal impacts that may result.

In Europe, water scarcity events have increased in both frequency and magnitude in recent years. In 2019, for example, almost 30% of the EU territory[10] and approximately 20% of the European population experienced water scarcity at some point during the year, while river discharges across Europe were below average for nearly two-thirds of the same year, even though water abstraction has fallen over the preceding two decades (EEA 2023). Droughts have also become more frequent in southern Europe and most of central Europe, with up to 1.3 additional droughts per decade between 1950 and 2015 compared to years prior to 1950 (EEA 2021). Water scarcity is a particularly acute challenge in many parts of southern and south-western Europe, as indicated by the Water Exploitation index from the EEA (2023), which finds that Spain, Italy, Portugal, Greece, Malta, and Cyprus are already at the forefront of Europe's most intense water shortages. Most EU citizens that are already living in a state of water stress, a term that encompasses both water scarcity and drought conditions, live in southern Europe, including Spain, where 22 million people currently face water stress (50% of the population), Italy with 15 million people (26%), Greece with 5.4 million (49%), and Portugal with 3.9 million (41%) (Joint Research Centre 2020). Yet, water scarcity is not limited to southern European countries, but is a growing challenge for the entire continent, with water stress conditions extending to western and central European countries as well as affecting both rural and urban areas (EEA 2021). This is illustrated by the Danube River, which flows through nations such as Hungary, Slovakia, and Romania, where water levels have fallen considerably during the summer season (EEA 2021).

According to the EEA's (2024) recent European Climate Risk Assessment (EUCRA), duration, and severity of droughts, which together, are likely to exacerbate water scarcity in the coming years. The mechanisms by which climate change increases water scarcity are diverse. Rising temperatures are expected to enhance evapotranspiration, increasing overall water use and inducing more frequent episodes of extreme drought (EEA 2024b; WWF 2023). Based on the findings of the EUCRA, if global temperatures rise by 3°C, heatwaves that currently occur once every 50 years could become an almost annual occurrence in Spain and certain regions of Portugal. For the majority of other southern European locations, such extreme heatwaves may happen once every three years, while the rest of Europe could experience these events at least once every five years. Climate related temperature increases are also likely to increase the frequency of intense rainfall events, reduce the accumulation of snowpack, prompting earlier snow melt, and together these factors are likely to result in decreased water availability in most European regions (WWF 2023).

The EUCRA highlights that there are several other mechanisms through which the worsening impacts of climate change will be felt by populations and across sectors. For instance, the increasing frequency and intensity of heatwaves in Europe will result in heightened health risks, particularly for vulnerable populations and the capacity of health systems to provide the increasing level of support required, especially in southern and western-central Europe. Approximately 60,000 to 70,000 premature deaths in Europe were attributed to the excessive heat during the summer of 2022. In turn, as summers become hotter, winters milder, as well as longer droughts and more frequent floods, these conditions will create an environment that is conducive to the spread of infectious diseases, including water-borne infections.

It is expected that extreme precipitation events will continue across Europe, many of which have led to devastating floods in recent years. For example, extreme precipitation and large-scale floods in Germany and Belgium in 2021 resulted in EUR 44 billion in damages and more than 200 deaths, while in Slovenia in 2023, damages were equivalent to about 16% of national GDP (EEA 2024b). At the same time, sea level rise in Europe is accelerating, increasing the risk of coastal flooding and erosion, storm surges and the intrusion of saltwater into groundwater. Climate risks threaten critical European infrastructure, particularly in many coastal cities, regions and ecosystems, with the potential to result in significant negative impacts on their populations, infrastructure and economic activities. The worsening impacts of climate change also pose multiple challenges to European food production and security, with agricultural production already facing significant climate risks across Europe and critical levels of risk in southern Europe in particular. While reduced agricultural yields are already a critical risk during droughts and periods of extreme heat in southern European Member States, food production is also vulnerable to disruptions from severe meteorological events such as extreme rainfall and unseasonably late frosts, which are expected to become more frequent. While the link between climate change and

[10] excluding Italy

water scarcity, including water stress and drought, is well established, the environmental impacts of water scarcity itself are manifold, as is the potential for wider economic, cultural, legal or social knock-on effects.

Climate change is expected to alter regional water availability, intensifying not only water quantity but also water quality issues, as reduced water levels in rivers and lakes lead to higher concentrations of substances (WWF 2023), as demonstrated for instance in the recent Oder River disaster. The effects of climate change are also expected to result in the depletion of groundwater levels – the amount of water that is stored underground in saturated zones beneath the land surface – by impacting recharge rates and increasing reliance on groundwater due to reduced surface water availability, compounding the primary challenge of over-abstraction (Gelati et al., 2020). In view of the intrinsic water needs of natural ecosystems, an increase in water scarcity is expected to have a significant negative impact on biodiversity as well. Sufficient water availability, including groundwater, is critical for biodiversity protection in many areas where the survival aquatic species and their habitats depends on adequate groundwater flows (WWF 2023). In turn, prolonged periods of reduced water availability can lead to habitat loss, diminished species populations and disrupted ecological functions. Consequently, water scarcity has repercussions for the provision of vital ecosystem services, many of which are key to enabling water resilience and whose benefits are far reaching and essential to human welfare and economic stability.

Less understood, but no less important, is the link between increasing water scarcity and its wider social and economic impacts. In the face of inadequate water resilience strategies, greater water scarcity may introduce new challenges for the governance and equality of access and use of water at the local level (explored in *Issue 4: Emerging challenges for the governance and equality of access and use of water at the local and regional level*) and may impact how cities adapt to this changing reality (see Issue 6). Similarly, as periods of limited water availability become more common, it is not known whether societal change will drive water resilience, or if our collective ambition for water resilience will result in the transformation of society (explored in *Issue 5: Will societal change drive water resilience, or will our shared ambition for water change society?*). Water is also a critical input for a wide range of economic sectors and activities, such as agriculture, which may need to reassess and modify its operations to be more water resilient in the long term (explored in *Issue 7: Rethinking agriculture for a drought resilient EU*). Furthermore, amid the EU's long-term strategy of achieving carbon neutrality by the year 2050 (European Commission n.d.), the question arises as to whether the circular economy will drive water resilience (explored in *Issue 3: Circular economy as a driver for water resilience*), and to what extent there is a need for co-transitions to avoid the potential unintended consequences of water resilience (explored in *Issue 9: The need for co-transitions to avoid unintended consequences for water resilience*). These issues, among others, were explored in the ten emerging issue characterisations selected and described in this FORENV cycle, which include the wider environmental, economic, and social consequences of increasing water scarcity in the broader context of realising a water resilient Europe.

References for this section can be found in **Appendix D**.

2.2 Summary of the ten priority emerging issues

This section provides a short summary of the ten priority emerging issues identified and characterised by FORENV in the fifth cycle. The full characterisation of each issue can be found in Appendix A. An assessment of these priority issues, their implications for the environment and the green transition as well as related key policy questions are presented in **Sections 3 and 4**.

As part of the FORENV approach (see **Section 1**), each issue is reviewed and validated by members of the EEA Scientific Committee and the SCHEER (DG Santé). The Scientific Committee reviews are presented in **Appendix B**.

Interrelated challenge of water scarcity and water quality

Declining water quality and quantity threaten aquatic ecosystems, leading to biodiversity loss and diminished ecosystem services, while also exacerbating the frequency of harmful algal blooms that disrupt local economies and pose risks to public health.

- Deteriorating water quality, caused by pollutants, and reduced water quantity, could precipitate the collapse of aquatic ecosystems. As water bodies become more concentrated with harmful substances such as nutrients and industrial or agricultural chemicals, aquatic life is threatened, leading to a loss of biodiversity. The loss of aquatic biodiversity reduces the resilience of ecosystems to further environmental stressors, and limits the provision of essential ecosystem services such as water purification, carbon storage and flood mitigation, among others.
- The effects of climate change and water quality degradation may lead to more frequent and intense harmful algal blooms (HABs), which hamper recreational water use and related economies by preventing swimming, fishing and boating in affected waters. This could have far-reaching effects on tourism, local businesses and public health. The increasing frequency of these extreme water quality events could fracture the social and economic fabric of communities that previously relied on these waters for their livelihoods and recreational activities.
- Increased environmental stress from the accelerating effects of climate change, such as reduced rainfall and unpredictable weather patterns, and their associated economic pressures, may reduce the ability of the agricultural industry to invest in less polluting practices. This could make the industry even more vulnerable to water and climate-related shocks, with implications for food security. Moreover, the continued need to use fertilisers and pesticides and the resulting impact on water quality could increase tensions with between stakeholders and regulators.
- As poor water quality reduces the availability of freshwater sources, this could catalyse public and private sector investment in developing and scaling up technological advances to scale-up alternative water sources, such as water recycling and desalination. These innovations could in turn disrupt traditional water supply paradigms that have been dependent on the location of freshwater or groundwater sources, enabling communities and regions to tap into previously unusable seawater or recycled wastewater, particularly benefiting water-stressed communities in southern Europe.

New and alternative sources of water

There is growing interest and uptake of emerging and innovative approaches to expand the sources of freshwater to address increasing water scarcity, from new methods and advanced technologies to modifying traditional practices.

- The growth of "aquapreneurs" and venture capitalists investing in novel water sourcing technologies like desalination, atmospheric water collection, and biomimicry is accelerating technology development and commercialisation. This could lead to issues like privatisation, reduced public control, and inequitable access due to high costs.
- The growing speed of new innovations and approaches for water sourcing may pose significant regulatory challenges.
- Advances in desalination creating portable, efficient systems may make it a more viable option for households and industries. But expanded desalination may also lead to

environmental issues (e.g. brine disposal) and higher energy use if not coupled with renewables.

- Some regions may increase reliance on traditional small-scale water practices like rainwater harvesting if, there is increased water scarcity and novel technologies are unaffordable, leading to greater decentralisation. If scaled-up, this could have cumulative disruptive impacts on natural water cycles.
- Increasing impacts from climate change and droughts may create pressure to expand more extreme or peripheral practices like iceberg towing or cloud seeding despite uncertain efficacy and potential ecological consequences.

Circular economy as a driver for water resilience

The transition to a circular economy in Europe over the coming decades is disrupting how water is used and managed across sectors, with a shift towards reusing, recycling, and recovering resources from wastewater.

- Decentralised and localised water systems, enabled by small-scale modular treatment technologies, may emerge as alternatives to traditional centralised utility models.
- Integrating nature-based solutions like constructed wetlands and retention ponds into urban water systems has the potential to align circularity goals with wider sustainability objectives like flood protection, biodiversity, and climate adaptation.
- Recovering resources like nutrients, energy, and chemicals from wastewater in line with circularity principles may increase. However, economic viability of bringing these resource recovery processes to scale may be an issue given the current high capital costs of specialised extraction infrastructure and marginal value of recovered resources.
- The wastewater reuse market in Europe may see significant growth mainly due to reuse opportunities for agricultural irrigation.
- Resurging interest in rainwater harvesting at household and community levels across Europe may reduce pressure on water resources during periods of scarcity. However, it may also disrupt natural water cycles if implemented at scale without management of cumulative impacts on environmental flows and groundwater recharge.
- The growth of lithium-ion battery recycling in Europe and the increasing requirements to use recycled materials in battery production may reduce water consumption in the production process.
- Water pricing pressures caused by scarcity combined with circular economy policies may increase water reuse and recycling in water-intensive industries like textiles and agriculture. However, realising the benefits may require updated standards, training, and implementation of comprehensive circular economy strategies.

Emerging challenges for the governance and equality of access and use of water at the local and regional level

Competition for increasingly scarce water resources between different stakeholders challenges the ability of local and regional governance to ensure equality of access. The need to balance the provision of water with environmental and societal considerations may jeopardise the economic viability of water-intensive industries and sectors, especially those considered non-essential.

- Wealth inequalities may become an increasingly prevalent determinant of access to water as water scarcity in the EU increases. The wealthy may be able to circumvent restrictions by paying higher costs for water use, undermining the intended effect of instruments such as water tariffs, while the economically disadvantaged are effectively bound by imposed restrictions on consumption. This divide could exacerbate social tensions along socio-economic lines and challenge equitable water governance.

- Competition over water access may sharpen the divide between different stakeholders. Businesses, particularly in sectors such as agriculture, energy and manufacturing, will see water as an indispensable resource for their operations to justify their access, putting them at odds with local communities and environmental interests. Conflicts over access to water will increasingly take on a stakeholder or group-centric character, further elevating the role of governing authorities in arbitrating access between them.
- The shift from demand-based to sufficiency-based water governance, driven by the need to ensure that scarce water resources can first meet essential needs of the environment and society, may significantly challenge water-intensive industries, including agriculture, certain manufacturing processes and luxury activities (e.g. golf courses). This may make some of their operations economically unviable, particularly those considered non-essentials.

Will societal change drive water resilience or will our shared ambition for water change society?

Growing adoption of water-saving behaviours, such as water reuse, could lead to a wider change of societal values and consumer preferences, putting pressure on businesses to adopt sustainable water practices. Legal personhood for water bodies and the transformation of water use standards in urban development could further promote water conservation.

- The normalisation of water reuse and conservation behaviours on a mass scale could drive a powerful social movement, leading to a profound shift in societal values and consumer behaviour regarding water usage. As individuals increasingly adopt water-saving measures and technologies, they would likely begin to scrutinise the water footprint of the products and services they consume.
- If water stewardship becomes a widely shared societal value, businesses could be pressured into demonstrating sustainable and efficient water use in their operations. This could influence consumer preferences, as companies that do not align with these values may suffer a loss of market share as consumers favour competitors with better water conservation practices, or boycott their products and services altogether.
- We may see wider adoption of legal personhood being granted to bodies of water as a means of strengthening water resilience. Their legal status would allow for lawsuits that protect their health and ecological integrity over economic interests. This could have wider implications, affecting traditional water governance, curbing industrial and agricultural run-off, and influencing land-use change that would limit urban sprawl.
- Land use planning approaches such as water neutrality could disrupt urban development practices. Such approaches would require all new developments to be designed so that they do not increase net water demand. This could lead to a proliferation of new building standards, water reuse systems and innovative building designs that promote water conservation.
- The consumption of treated wastewater could become normalised, leading to the emergence of affordable, decentralised water reuse technologies for individual households or buildings. This would reduce individual consumers' reliance on centralised water utility systems and change the traditional dynamics of water management.

Water resilient cities - new challenges and solutions

European cities are adopting a range of technological, infrastructure, and governance shifts to build resilience against escalating water scarcity driven by climate change, pollution, and population growth.

- The mainstreaming of smart technologies like metering, sensors, and IoT connectivity into urban water systems may optimise distribution, and integrated data-driven management contributing to more efficient water use. However, cybersecurity threats, high costs of implementation, and potential privacy issues could impede mainstream adoption of smart water systems.
- Water rationing and restrictions for water use may become a more permanent form of water management in urban areas. As water scarcity worsens, cities may implement measures like water rationing, banning certain high-consumption activities leading to significant changes in resident and business behaviours.
- Cities may increasingly turn to alternative water sources like desalination plants to augment supplies and reduce pressure to conventional surface and groundwater sources.
- Nature-based solutions may become a core element of resilient urban water infrastructure for their ability to recharge aquifers, filter stormwater runoff, and restore ecosystems. This could lead to increased cost for cities to maintain green infrastructure.
- Decentralised, circular management systems that reuse, reclaim, and recycle water at the household or neighbourhood level may become common practice but will require new technical skills alongside changes in consumer perceptions and behaviour.
- Large water diversion projects that transport water from distant regions into cities with significant economic influence could be increasingly pursued but may disrupt ecosystems and deepen inequities between urban and rural communities.

Rethinking Agriculture for a Drought Resilient EU

Climate change driven increases in drought frequency and severity across Europe are necessitating transformations in agricultural practices and technologies to build resilience to water scarcity.

- Seasonal shortages and price increases for water-intensive foods like fruits, vegetables, and beef could disrupt current dietary patterns and exacerbate health and economic inequalities. However, reduced beef consumption may benefit carbon emissions and public health. Over the longer-term, shortages may spur transitions to less water-intensive crops and practices, enabled by supportive policies, though with potential losses for farmers.
- Declining meat production in EU could also accelerate depopulation of some rural areas where livestock farming has been the main source of income resulting in reduced pressure on local water resources.
- The growth of controlled environment agriculture (e.g., vertical farming, indoor farming) and associated technologies in Europe improves (water) efficiency and climate resilience but is constrained by high energy demands, limiting feasibility and investment potential.
- Expanded adoption of agroecological practices may enhance soil health and moisture retention to support drought resilience but may be limited by lower yields and ability to meet food production demands without land use change.

- Tensions between the supply of water for agriculture and demands from industry, household use, power generation and biodiversity needs may escalate with more frequent droughts, stirring conflicts between farmers and environmental campaigners.
- Improved technologies like drip irrigation and remote sensing will offer opportunities for a more optimised water use but may lead to equity issues due to associated upfront investment costs for farmers.

Use of digital technologies to improve water management

Increases in water demand due to climate change, urbanisation and population growth and challenges inherent in maintaining ageing water assets and infrastructure are driving the adoption of digital technologies to foster more efficient monitoring, control and optimisation of water management systems.

- A 'new digital ecosystem' is being created by integrating smart and IoT-enabled home appliances, smart utility meters and predictive analytics, based on historical price data from utilities, to accelerate problem-solving in critical areas related to water demand, such as quantity, resource management, resilience, and adaptation and innovate for the benefit of both utilities and customers. Tension arises with the need to manage environmental impacts of digital technologies and cybersecurity threats to digital infrastructure, data and individual privacy.
- Smart irrigation control (e.g. sensors that monitor soil, plant and weather conditions) and the use of digital tools to integrate water management services is bridging operational siloes and providing more dynamic and real-time monitoring of water consumption patterns and quality issues to enable more informed and possibly timely decision-making and more optimal water management practices.
- The integration of data mining, machine learning/AI can integrate perspectives and support the development of integrated basin/aquifer plans, based on both analytical and stakeholder input, thus taking a systems approach that recognises the interconnectedness of water across sectors and the benefit of more integrated decisions that acknowledges differences in stakeholder interest/priorities and the need for benefit sharing.
- Decentralising water management could reduce risks associated with failure of old infrastructure and may ultimately improve water resilience in communities.

The need for co-transitions to avoid unintended consequences for water resilience

Co-transitions (e.g. energy, digitalisation and the green economy) have the potential to enhance water resilience but will require a whole systems approach to avoid unintended pressures on water and other natural resources.

- As industry gears up for decarbonisation, water supply is likely to be the 'twin challenge' that companies face in achieving their carbon goals given water is critical for some key decarbonisation solutions (e.g. micro chip production, carbon capture and storage (CCS), hydrogen production, nuclear power, hydropower).
- The energy transition, particularly the emergence of a 'hydrogen economy', could potentially increase the water footprint of energy systems and undermine the water resilience agenda in water scarce regions where a large share of hydrogen energy projects (cf. 60%) is expected to be implemented.
- The green and digital transitions potentially reinforce each other, where for example, we could see the adoption of digital technologies to improve the environmental impacts

of the water sector. Each transition, however, will have implications for water resources requiring a coordinated approach to measure and manage cumulative impacts.

- Digital twin modelling will enable smarter water management and efficiency across sectors but could also expand cyberattack risks against critical infrastructure, necessitating security measures.

Future water-related disputes and geopolitical conflicts drive transboundary cooperation on water

Political, technological, and environmental disruptions—including weaponisation of water infrastructure, unilateral projects straining transboundary agreements, climate impacts displacing populations, and advances easing resource pressures—are increasing the urgency of strengthening governance of shared waters.

- The increased use of water as a geopolitical tool or weapon during conflicts could drive more urgent efforts to establish stronger governance mechanisms and institutions for transboundary water cooperation and "water diplomacy" that could foster peace and political stability overall. There is increased momentum behind and interest in United Nations global water conventions: the Water Convention and the Watercourses Convention.
- However, greater cooperation on transboundary waters may be perceived by some countries as a loss of sovereignty over national resources. More influential countries with greater economic wealth could increasingly leverage their advantages in water infrastructure and investments as bargaining chips in negotiations with less affluent nations.
- The growing energy demands combined with shifts to non-fossil fuel sources could massively increase national water demands for energy production. This may strain transboundary allocation agreements developed under different demand conditions.
- Severe droughts and heatwaves resulting from climate change could cause large-scale population displacement and migration from especially vulnerable regions. This may elevate water resource governance as an important issue within regional, national and international policy frameworks on security/migration.
- Major upstream infrastructure projects unilaterally taken by nations sharing basins risk increasing tensions over water flows. However, joint investments in resilience projects may conversely promote cooperation.

3 CLUSTERS OF DISRUPTIVE CHANGES FROM THE PRIORITY EMERGING ISSUES

As noted in Section 1, the FORENV scanning exercise identified 149 weak signals of change relevant to the topic of water scarcity and resilience. These were collated and discussed in four workshops bringing together Commission officials and external experts which led to the identification of ten priority emerging issues, as summarised in Section 2. These issues were then characterised via desk research, including defining their key drivers and expected future development. Drivers and future changes include those that are societal (e.g. the potential for normalisation of water reuse and conservation behaviours, or increasingly prevalent water inequalities), economic and technological (e.g. the growth of a water-reuse market in the EU, or the growth of 'aquapreneurs' and investment in novel water sourcing technologies), and environmental (e.g. deterioration of water quality due to multiple pressures). The characterisations of these ten priority issues are included in **Appendix A**.

The ten priority issues were reviewed, and five clusters of potentially disruptive changes associated with the emerging issues were developed. These clusters were then discussed by the Secretariat and DG Environment to identify potentially important implications for policies to support the green transition and associated uncertainties. Key policy questions were then defined (as presented in **Section 4**), which are intended to stimulate discussion around how emerging environmental, social, and economic issues could influence water resilience in Europe, and what policy responses may be required.

These results will, it is hoped, help inform reflections on future policy and action, as well as potentially guide the direction of related research in the Commission. It is also intended that these findings will be of value to policymakers in national or regional government. As a detailed horizon scanning exercise, the outcomes of FORENV are well suited to inform potential wider foresight, such as strategic foresight within the Commission or elsewhere.

The clusters presented in this Section are:

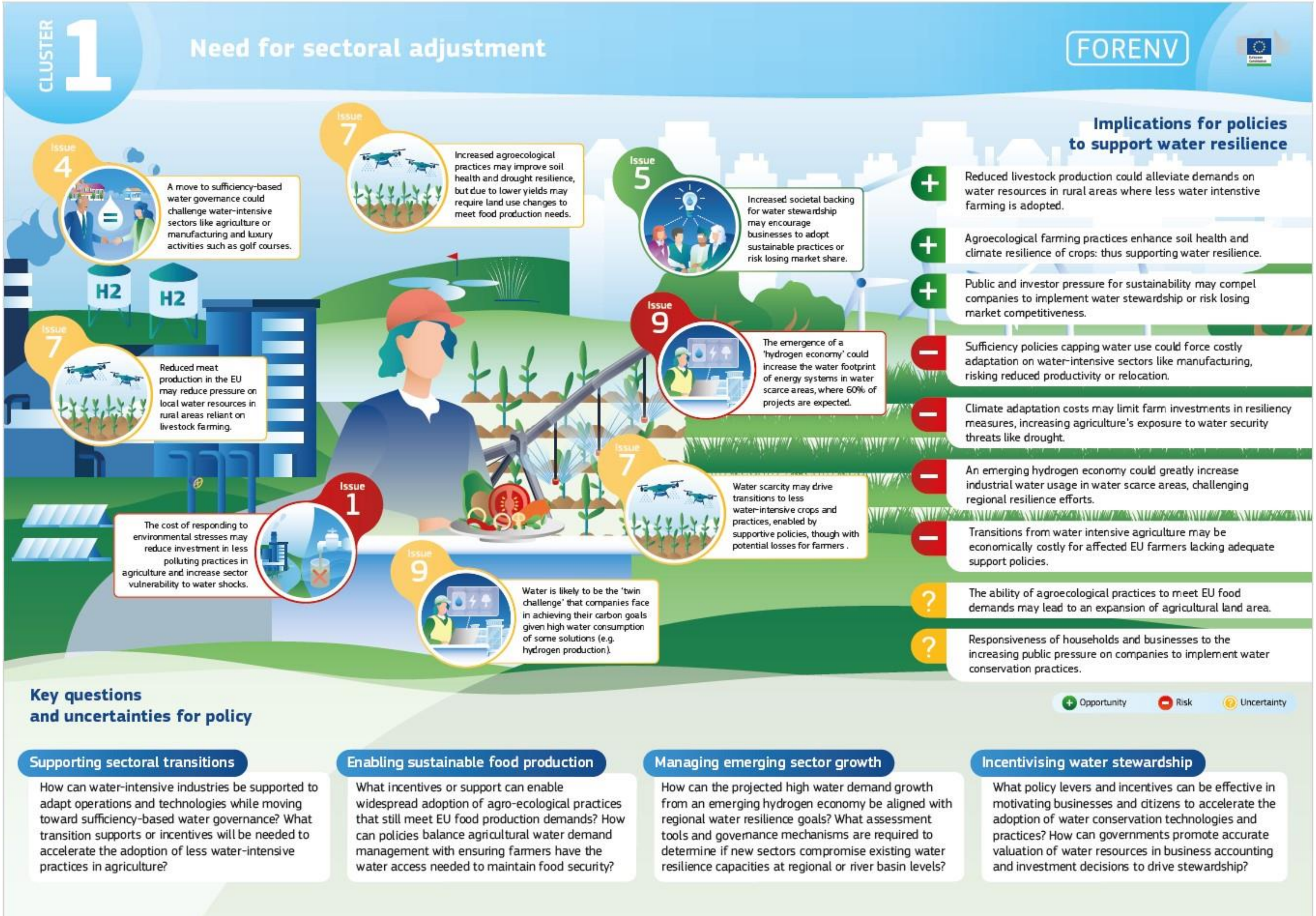
1. Cluster 1: Need for sectoral adjustment
2. Cluster 2: New technology, new risks?
3. Cluster 3: Hydro-politics, a driver of conflict or cooperation
4. Cluster 4: Water inequalities and just transitions
5. Cluster 5: Water governance – centralised or decentralised system?

Each icon used in the cluster infographics corresponds to one of the ten priority emerging issues, as presented in Section 2. A key to the icons used is also included in **Appendix C.**

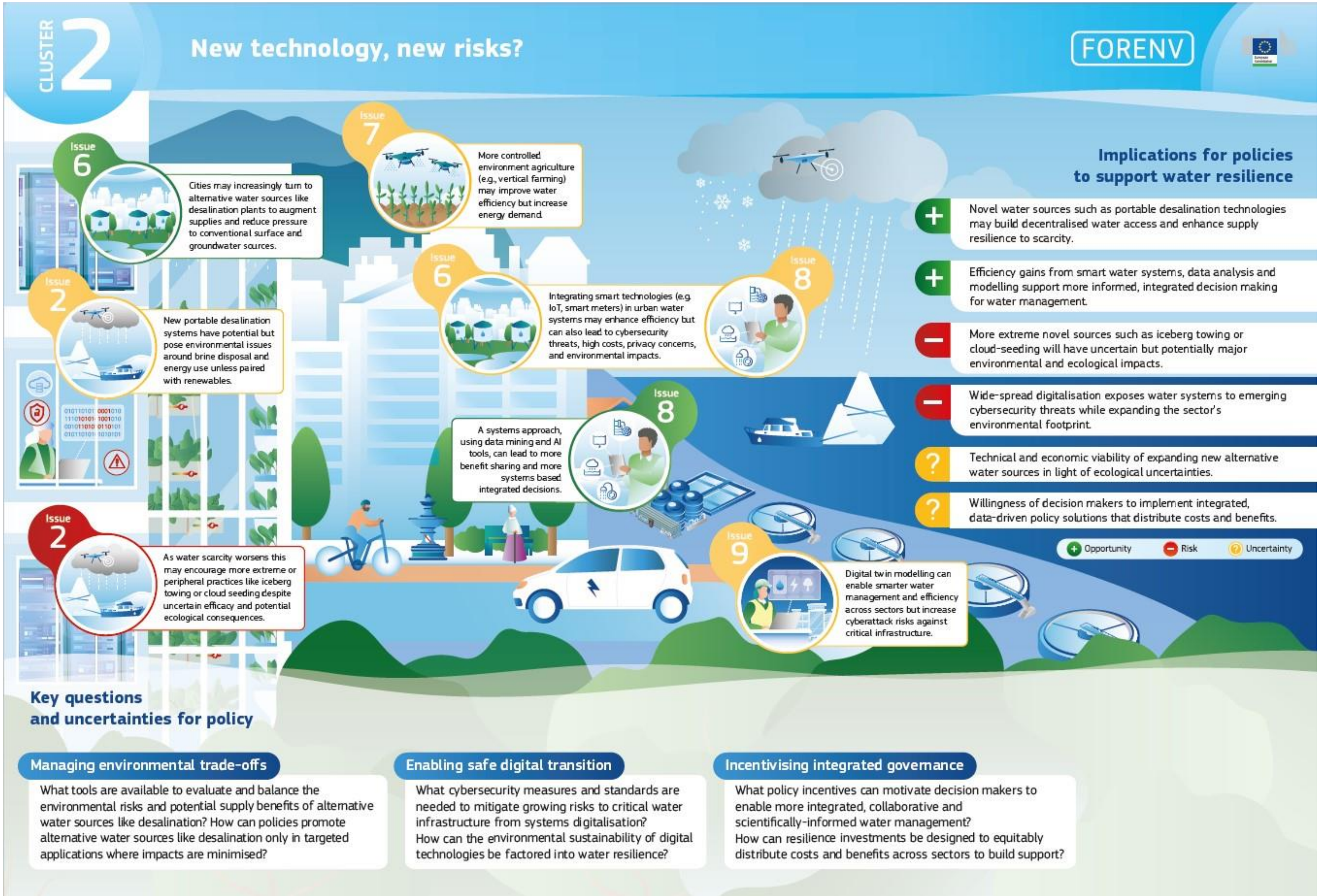
Emerging environmental issues

This report presents **emerging issues** or **changes to well-known issues** in Europe's environment. Emerging issues reflect observed changes or developments in the environment that occur as a result of new research or knowledge, a shift in geographical or temporal scales of impact, or due to heightened awareness or new response measures to issues. Emerging issues reflect current evidence of possible future change to the environment that is either positive or negative. These issues are assessed over 3 time horizons showing when an impact (either positive or negative) is likely to occur in Europe – short-term (1 - 5 years), medium term (5 - 10 years) and long-term (10+ years).

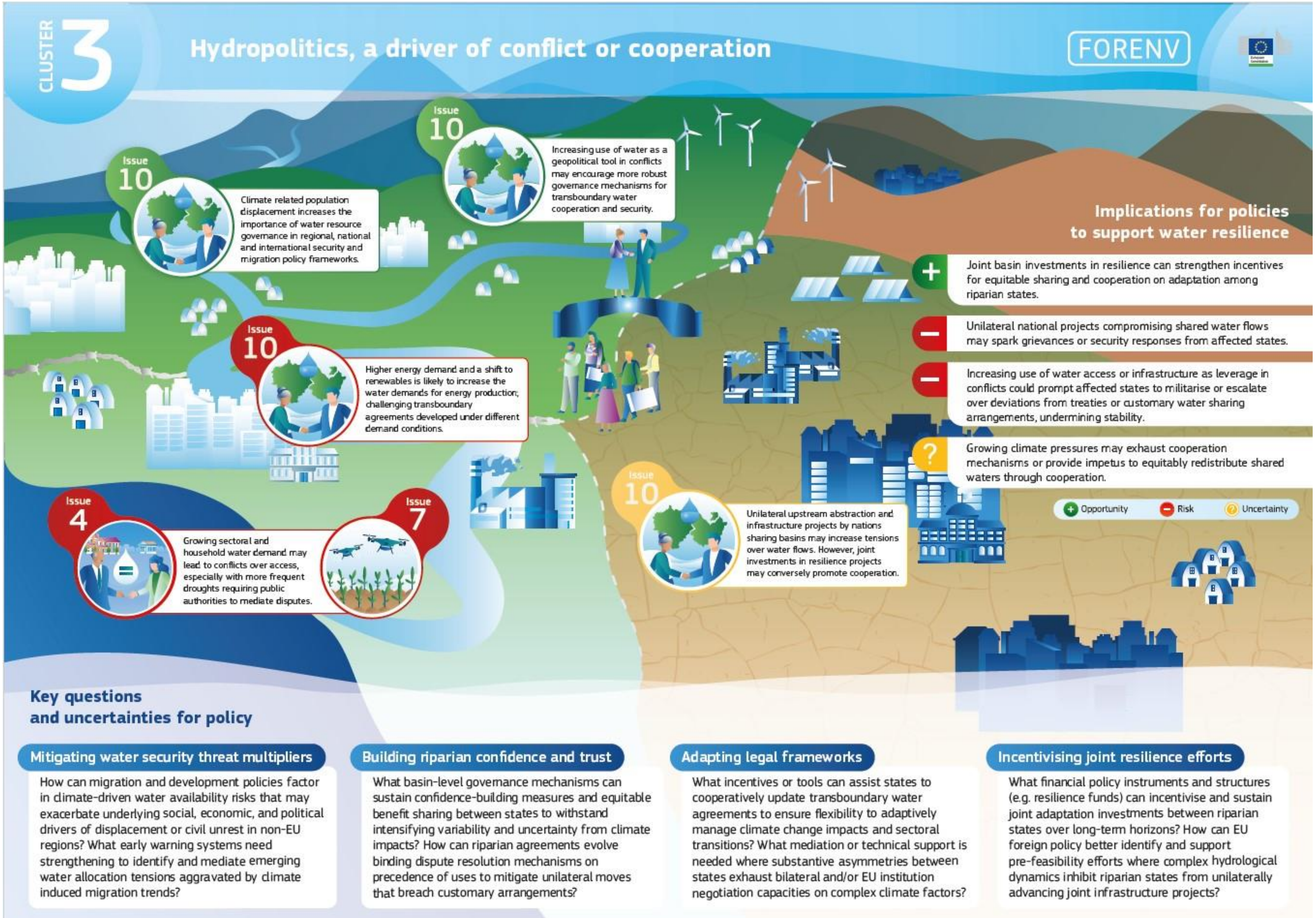
3.1 Cluster 1: Need for sectoral adjustment



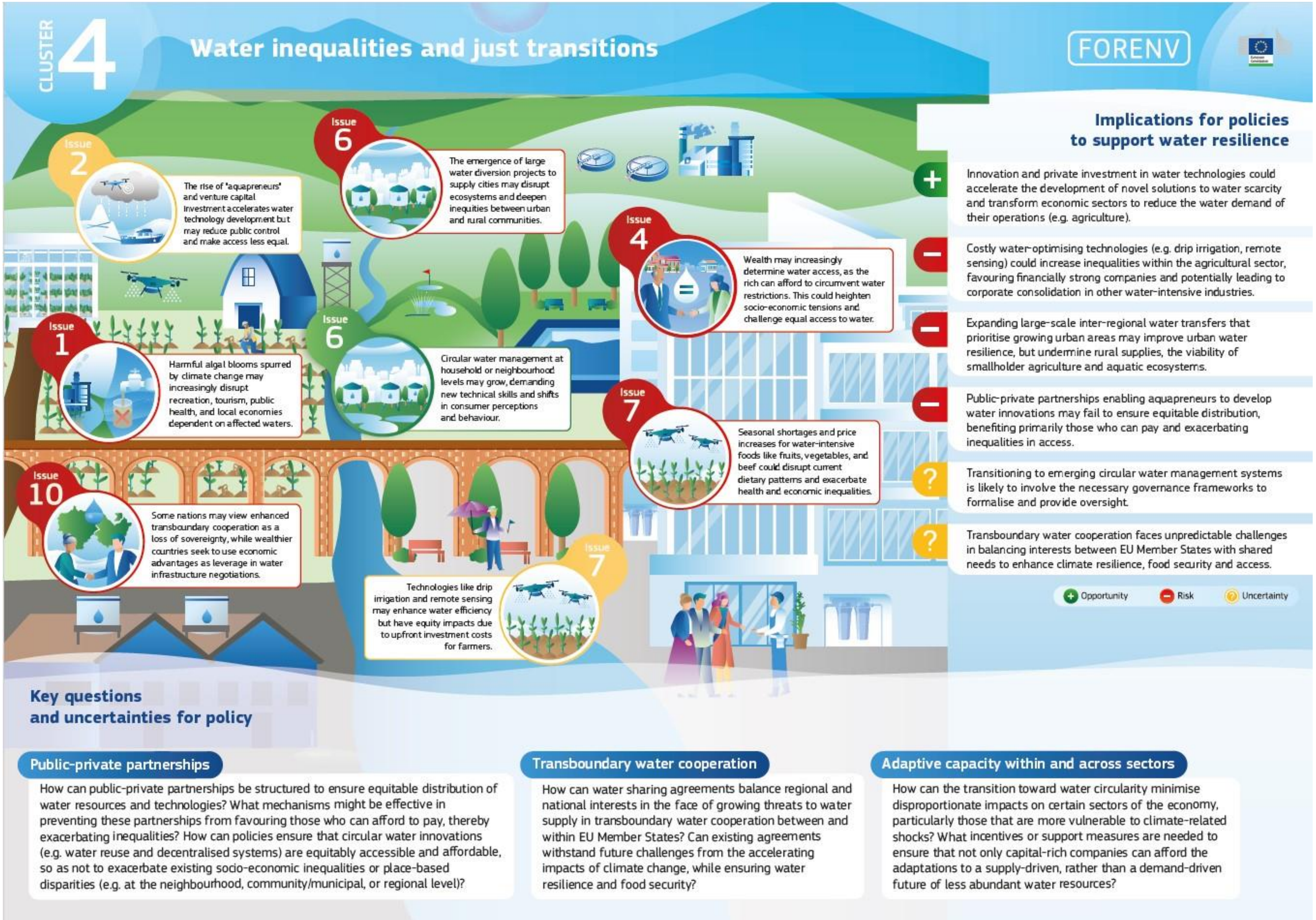
3.2 Cluster 2: New technology, new risks?



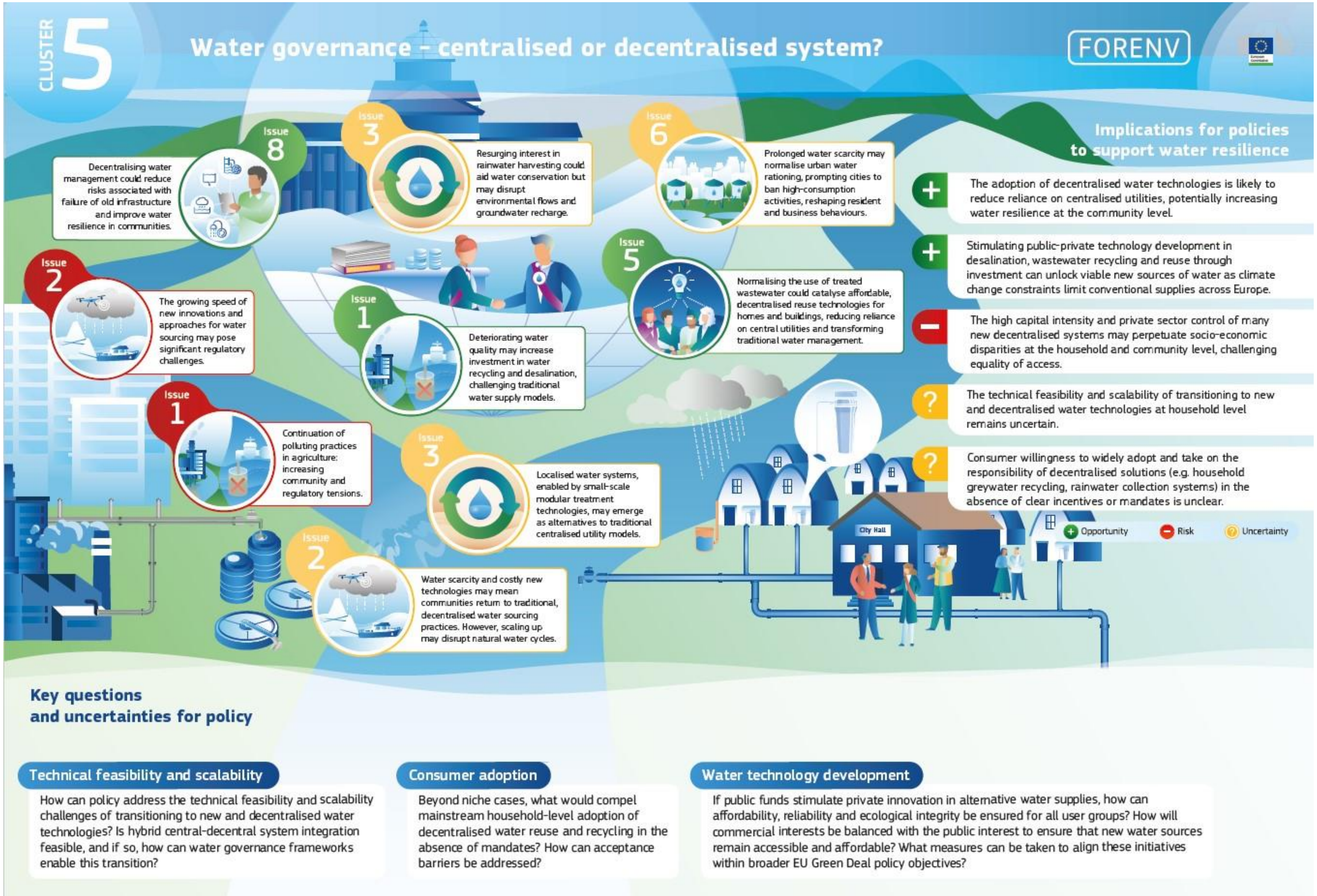
3.3 Cluster 3: Hydropolitics – a driver of conflict or cooperation



3.4 Cluster 4: Water inequalities and just transitions



3.5 Cluster 5: Water governance – centralised or decentralised system?



4 POLICY QUESTIONS AND CONCLUDING REFLECTIONS

The five clusters of disruptive development presented in Section 3 point to a range of potentially important changes that individually and collectively suggest the emergence or strengthening of drivers that can address water scarcity and enhance Europe's water resilience, or conversely which may pose threats to the transition to water resilience. By considering these changes a series of potential implications for future water resilience are defined together with key uncertainties. These implications and uncertainties represent areas where it may be important to improve understanding and consider how policy could respond to mitigate possible risks and maximise opportunities.

By looking across these implications and uncertainties, some cross-cutting topics can be observed. For example, across the clusters there are drivers which suggest that actions taken in one sector can have benefits in others, leading to win-wins for water resilience, e.g. integrating nature-based solutions in urban water systems can enhance water resilience while meeting wider sustainability objectives related to flood protection, biodiversity and climate adaptation. Technologies and their application in water supply, management and use also feature across most clusters, something that reflects the outcomes of previous FORENV cycles: harnessing technological progress while managing the associated risks will be key to Europe's transition. The intrinsic importance and value of water to the environment, society and the economy is also reflected across the clusters. The need to plan and manage the evolving needs and demands of communities and economic sectors, and the vital role of and need for transparent and collaborative governance of water, are also highlighted.

By considering such themes, some key questions for EU policy related to water scarcity and resilience are identified. These are intended to help guide potential future policy discussions and identify opportunities but also where policy developments may need to reflect and respond to manage future risks.

4.1 Harnessing win-wins for a water resilient future

Water is fundamental to the viability of many economic sectors and is likely, along with addressing climate change, to represent a 'twin challenge' that many businesses will face in meeting their sustainability targets: reducing carbon emissions while also adapting to water scarcity (Cluster 1). Across the emerging issues characterised by this cycle of FORENV, and reflected in the clusters, is a theme of the potential for policy and action in one factor supporting or facilitating benefits in another, including in meeting wider transitions goals. For example, using nature-based solutions as part of an approach to more sustainable water management at neighbourhood or city scales (Cluster 4) will also help meet climate resilience, biodiversity and human health goals. Similarly, policy and action to support EU based innovation in novel water technologies (for supply, management, use) can help move towards a water resilient future while also providing economic opportunities and playing a role in the transformation of key sectors (Cluster 4). On a more strategic scale, regional and transboundary cooperation on water can enhance resilience while also addressing drivers and pressures that may exacerbate long-term drivers of geopolitical tensions (Cluster 3).

At the international scale the UN Water Conventions (the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention, and the Convention on the Law of the Non-Navigational Uses of International Watercourses (Watercourses Convention) provide the framework for such cooperation.

Whilst realising a water resilient future thus presents many challenges, there are also examples of potential win-wins where actions or policy changes can have direct or indirect benefits beyond their key focus. This could include using policy in one area (e.g. land-use planning) to achieve multiple social and environmental objectives, including enhanced water resilience; or may seem the use of economic and policy tools such as water pricing, coordinated with circular economy interventions to create 'virtuous cycles' of water use and reuse efficiency, the adoption of less water intensive processes and enhanced training and awareness of the value of water.

- How can EU and national policy-makers identify and harness win-wins for water resilience, to better integrate cross-sectoral perspectives by considering how actions in one area affect others, and align with broader sustainability objectives such as flood protection, biodiversity, circularity and climate adaptation?
- How can policymakers effectively harness innovation and 'aquapreneurship', while managing risks and avoiding unintended consequences?

4.2 Planned or 'enforced' change in sectoral use of water

The competing demands for access to water for citizens as well as economic sectors, together with the intrinsic needs of the natural environment, will necessitate the development of policies and regulations that foster cross-sectoral cooperation and holistic water management. The clusters identify a number of points of tension, for example in a more water scarce future water-intensive sectors may find their use is capped which can drive potentially costly adaptation at short notice (Cluster 1). Water availability may also mean farmers may find themselves forced to suddenly abandon water intensive traditional crops (Cluster 1) requiring support to transition gradually to more efficient water management practices or to less water intensive agriculture. Other clusters point to an increasing need for mediation between sectors as water scarcity deepens (Cluster 3), and that the costs of investment in water efficient technologies may favour larger and more commercially powerful businesses unless those less able to invest are supported in this transition (Cluster 4). This suggests the need for policies that support sectors to understand and plan in advance for necessary changes in their water use patterns.

- How can the EU proactively transition to water resilience and improve efficiency in key sectors such as food production and water-intensive industries before water scarcity forces disruptive changes?
- How can policies promote cross-sectoral cooperation on water resources, such as the agriculture and energy sectors?
- What mechanisms are needed to ensure that integrated water management policies consider the different needs and impacts of all relevant sectors, thereby mitigating risks to productivity and economic viability of their operations?

4.3 Understanding water's role in Europe's just green and digital transition

While water is explicitly recognised in Europe's ambitions for a green and digital transition, the need to address water scarcity and ensure resilience in Europe's transition has yet to be addressed in a systematic and holistic manner at EU level. The clusters defined in this report suggest that water's critical role in the green and digital transition will require a nuanced approach to ensure that its importance in energy (e.g. if a hydrogen economy emerges, Cluster 1), sectoral transitions (Cluster 1) and technological and digital advancements (Cluster 2 and Cluster 3) do not come at the expense of Europe's natural environment and biodiversity or other water uses. This will require policies that balance innovation with the intrinsic value of water in ecosystems. It is also essential to address water-related aspects of the clean and circular economy and low-carbon, low pollution energy solutions that are key to reaching the EU's Green Deal ambitions addressing the triple planetary crisis – climate change – biodiversity loss – pollution.

- How can policies ensure water resilience without hampering the technological progress assumed in enabling the EU's green and digital strategies?
- Will the future necessities of water management be a facilitator or an obstacle to these green and digital transitions?
- What policies can ensure that the digitalisation and greening of the economy does not exacerbate social and economic inequalities or harm the natural environment?

4.4 Navigating the complex challenges for water governance in the EU

Three of the clusters emphasise governance: Cluster 3 on hydro-politics; Cluster 4 on water inequalities and just transitions; and Cluster 5 on whether centralised or decentralised water governance systems will emerge. However, all of the clusters suggest that the governance of water at all scales and across sectors of the economy is likely to emerge as a critical issue especially as water becomes scarcer and the demands for water evolve in a changing climate. As water availability and potentially supply reliability declines (especially in some regions) authorities will face increasing pressure on water governance systems. Citizens, communities, economic sectors, cities, regions, and countries may increasingly compete for access to water. Imbalanced power and economic dynamics seem likely to raise concerns about equitable and inclusive governance and access to water. The future of water governance must address these challenges and evolve from a paradigm of abundance to one of sufficiency. It will be crucial to balance national interests with regional stability and claims made at the community level, especially in the context of transboundary disputes over access to water. Decentralised water governance could have a role in enabling a more equitable approach to the achievement of water resilience but may also create tensions where historically water management and governance has been centralised.

- In this context, can existing EU water management policies ensure equitable water governance at different scales (i.e. national, regional, local, personal) in a water-scarce future?
- What strategies are needed to maintain effective and peaceful transboundary water management?

4.5 Concluding reflections

This FORENV cycle, focussing on emerging issues, risks and opportunities for a water resilient Europe in 2050, highlights the crucial role that water already plays in many economic sectors, and especially in water intensive sectors like agriculture, energy and industry. The findings emphasise the need for water availability, use and efficiency to be a core consideration in sectoral transitions, and that there are multiple opportunities, but also risks for policy. There is a clear need to seek solutions with multiple, systemic benefits (win-wins), while recognising that there will be sometimes complex trade-offs. Examples include the wide-spread adoption of renewable energy, which is often water intensive, and a circular economy, which is expected to have uncertain impacts on water use in many sectors, for example where material reuse or recycling processes may reduce water use in resource extraction and processing, but can require large volumes or water, or create pollution risks.

FORENV has highlighted risks related to equality of access and potential inter-sectoral tensions in a water scarce future. However, water has until recently been lacking clear visibility in

Europe's ambitions for a green transition. Tt is also fundamental to a just transition. The increased political attention at EU and Member State level to the water resilience agenda demonstrates that the time may be right for further action at EU level. The European Council[11], European Parliament[12] and European Economic and Social Committee[13] have all voiced their concern and called for a more strategic approach to water at EU level. And at the global level, the UN Water Conference 2023[14] framed water as 'the biggest deal breaker' in the achievement of international sustainability goals.

As well as being vital to human health and the functioning of our economy, water is also crucial for our ecosystems and natural environment and has deep cultural and heritage significance. The value of water, in economic, but also intrinsic terms is perhaps beyond measure. Yet water remains often undervalued in economic decision-making and is, perhaps, somewhat taken for granted by some. The risks, opportunities and uncertainties identified in the FORENV emerging issues all point to the need for a meaningful way of considering the economic value and role of water in Europe. This finding is echoed in, for example, the work of the Global Commission on the Economics of Water, which in 2023 published a seven-point call for collective action[15], including (among others) for the management of water as a global common good, an end to the under-pricing of water, the phasing-out of water use subsidies and requirement for organisations to disclose water footprints.

The transition to a water resilient EU will have sectoral impacts and effects on equality, either directly through supply management or indirectly through costs. Navigating how EU policy can support this transition in a fair and equal manner will be key to acceptance and support, and ultimately success.

In this context, the outcomes of FORENV will also be used in ongoing research activities by the EU Policy Lab (JRC) as an input to their research and planned publication of their outputs on the avenues for a cross-cutting, holistic and systemic EU water policy for the next mandate.

[11] European Council Conclusion of 23 March 2023 - EUCO 4/23.

[12] EP Resolution of 15 September 2022 on the consequences of drought, fire, and other extreme weather phenomena: increasing the EU's efforts to fight climate change (2022/2829(RSP)) and subsequent EP Plenary debates.

[13] The EESC Umbrella Opinion "A call for an EU Blue Deal" CCMI/209 of 25 October 2023.

[14] https://sdgs.un.org/conferences/water2023

[15] https://turningthetide.watercommission.org/

APPENDIX A FULL CHARACTERISATION OF EMERGING ISSUES

Issue 1: Interrelated challenge of water scarcity and water quality	
Emerging issue description	According to the Water Framework Directive (WFD), the status of a water body is determined by its chemical, ecological, and hydro-morphological characteristics, encompassing both the quality and quantity of water (Scientific Committee on Health, Environmental and Emerging Risks (SCHEER, 2023; European Commission, n.d.). While most people in the European Union have access to high-quality water for drinking and bathing, our water resources are subject to competing uses and increasing demand in many places. This poses a significant risk, as more frequent droughts and poor water quality in certain regions threaten water availability in Europe, which in turn exacerbates water scarcity. In this context, the concept of water security, which revolves around ensuring reliable access to sufficient and clean water resources, becomes increasingly critical. Furthermore, the impacts of climate change, including changing and unpredictable precipitation patterns and rising temperatures, threaten to escalate the extent and severity of water scarcity to new extremes, potentially shifting the baseline in many locations from what we currently understand as ‘water shortage’ to ‘severe water scarcity’ in the future. Despite the paucity of research on the interconnectedness of these different factors, this issue explores the link between water quality and freshwater scarcity, and how a decline in the former may exacerbate the latter (Ma et al., 2020; Jones and van Vliet, 2018). A better understanding of these phenomena is crucial, particularly for many parts of southern Europe that are already prone to extended periods of drought and elevated water scarcity, and where climate change is expected to accelerate these challenges even further; however, these issues are seen to varying degrees across Europe as well. For instance, while approximately 20% of the European territory and an average of 30% of the European population experience water stress each year (EEA, 2021b), the majority of EU citizens currently facing water stress – a term that includes both drought and water scarcity – live in southern European countries, including Spain (22 million; 50% of the national population), Italy (15 million; 26%), Greece (5.4 million; 49%), and Portugal (3.9 million; 41%) (JRC, 2020c). Yet the impacts of current and expected water scarcity are not limited to southern Europe but are in fact an increasingly Europe-wide challenge (EEA, 2021b). For example, in 2018, central and northern Europe experienced a severe drought during the spring and summer months, and the EEA's (2021b) updated assessment of water stress notes that it is increasingly spreading from southern to western and central Europe. Assessments of future trends in water scarcity also show that under a 3°C warming scenario, western and central Europe will experience similar impacts on river discharge and aquifer recharge as southern Europe (EEA, 2021b). In recent years, the Danube River, flowing through countries like Romania, Slovakia, Hungary, and Poland, has shown significant reductions in water levels during the summer months (EEA, 2021b). Looking ahead to 2050, simulated projections by the International Commission for the Protection of the Danube River (ICPDR 2019) forecast that the southern and eastern parts of the Danube River Basin will face intensified droughts, while rising temperatures will exacerbate water quality problems, stress ecosystems, and compound the effects of frequent droughts. Water scarcity describes the situation where the demand for water from human activities exceeds the available supply of freshwater systems (EEA, 2018b). Water scarcity is partly driven by human activities, but also influenced by the various impacts of climate change such as changing precipitation patterns, which can push more regions into a state of seasonal or constant water scarcity. Moreover, the reduction in water flows, a direct result of heightened water scarcity, can lead to a shrinking of aquatic habitats, thereby affecting the overall health of aquatic ecosystems (Rytwinski et al., 2017).

	Among the variety of drivers affecting water scarcity, poor water quality plays a contributory role (Ma et al., 2020; Jones and van Vliet, 2018). Poor water quality, driven by pollutants such as industrial discharge, agricultural runoff, and inadequate wastewater treatment, pose threats to existing supplies of both surface water and groundwater in Europe (United Nations, 2022). These sources of pollution impact the natural water cycle, harm ecosystems, and extend their impacts beyond biodiversity and habitats, influencing the overall quality of water and soil (Mosley, 2015). Amidst these challenges, the European Environment Agency (EEA, 2023a) highlights that the escalating demands for water not only contribute to heightened pollution but also lead to resource over-exploitation, with serious implications for human health. Specific contaminants, such as bacteria, viruses, metals, or pesticides, pose direct health risks. At the same time, water is a key input in the food production process, and its declining quality would further jeopardise the maintenance of food safety (FAO and WHO, 2019). Despite the prevalent access to high-quality drinking and bathing water in Europe, emerging threats encompass chemical pollution and water scarcity (EEA, 2023a). Additionally, concerns are mounting over plastic pollution, including microplastics that originate from textiles, and pervasive chemical pollutants like PFAS, which are now ubiquitous in soil and water across Europe. Droughts, which are temporary periods of natural water shortage due to an abnormally large precipitation deficit, further exacerbate the challenges associated with water scarcity. However, these are no longer considered sporadic events, as evidenced by the recurrent droughts of 2018, 2019, 2020, and 2022 as well as 2023. Between 2000 and 2020, Cyprus and Malta were among the Member States experiencing high average shares of land area affected by drought (JRC, 2022c). Looking forward, projections under a 3°C warming scenario for 2050 and 2100 show that the most significant economic losses from more severe droughts will occur in southern and western Europe, where absolute drought losses could increase by a factor of eight in the Atlantic sub-region and by a factor of five in the Mediterranean (JRC, 2022c). Droughts also weaken the ability of water bodies to dilute pollutants and affect variables such as water temperature, due to the effect of returned abstraction water used for industrial cooling, and contribute to the intrusion of saline substances (EEA, 2021b). Additionally, the reduction of freshwater bodies such as lakes, rivers, and wetlands due to more frequent and prolonged droughts, combined with persistent levels of pollutants (SCHEER, 2023), could further degrade water quality and contribute to increased water scarcity. In turn, the cycle of poor water quality contributing to water scarcity may be intensified as the impacts of droughts increase over time. The potential interactions between reduced water quality, water quantity, and increased frequency of droughts would together present a significant, compounding environmental challenge and would heighten water scarcity. These challenges will be explored in more detail in this issue.
Key drivers: what is driving the emergence of this issue?	**Key contributors to the slow improvement of Europe's freshwater quality** The current state of Europe's freshwater quality, and the slow and limited progress in improving it, are matters of concern, primarily due to a range of complex issues such as pollution, habitat degradation, and overexploitation. For instance, the assessment of the third River Basin Management Plans (RBMPs) reveals that the status of Europe's surface waters remains a concern. For example, in 2021 only 37% of lakes, rivers, estuaries, and coastal areas achieved a minimum 'good' or 'high' ecological status, and only 29% achieved good chemical status. Groundwater bodies, such as aquifers, have shown better overall results, with 77% rated as having good chemical status. While there

are observable improvements in the quality of individual pollutants and other elements of water quality, the overall status may not improve. As a result, the third RBMPs demonstrate minimal changes in status compared to the previous cycles (EEA, 2024). (It should be noted that comparisons are affected by changing standards, as thresholds for some chemical parameters are becoming more demanding, and in future, a greater number of substances will be used in chemical status assessment.)

Another challenge stemming from poor water quality in Europe is the concerning decline of biodiversity. According to the World Wildlife Fund's Living Planet Report 2022, one in three freshwater fish species in Europe is currently at risk of extinction, and populations of freshwater species have declined by 83% since the 1970s (WWF, 2022). Of particular concern is the collapse of migratory freshwater fish populations, which surpasses the severity observed on any other continent (WWF, WFMF, ZSL, IUCN, TNC, 2022). To remedy these challenges, an EU guidance document called on Member States to ensure that "ecological flows" are always maintained in surface waters to achieve good ecological status while protecting habitats and species that depend on water (EC, 2015). While implementation of this concept has advanced in southern Europe, further work is needed (Leone et al., 2023).

The factors impacting water quality are largely due to various human activities (United Nations, 2022; Zeleňáková et al., 2018). In Europe, where groundwater plays a particularly important role in supplying clean drinking water, nitrates and pesticides are the most frequent contributors to water with poor chemical status (EEA, 2018c). The main economic sectors from which these pollutants originate include agriculture, chemicals used in various industrial processes, and effluent from mining, all of which contribute to the degradation of groundwater in river basins. Further research is needed to better understand such emerging contaminants (United Nations, 2022).

The interactions between water quality and water scarcity

While research in this area is limited, studies have suggested there is an interaction between low water quality and increased water scarcity. Water scarcity can be defined as a lack of sufficient amounts of water of sufficient quality for the intended purposes. Thus, while the total amount of water can be sufficient, there can be an insufficient amount of sufficient quality for a specific purpose at the same time. The more water quality is compromised (e.g. by pollution) the higher the risk of this happening. For example, a comprehensive study of water scarcity in China found that certain regions in the north of the country with poor water quality experienced markedly worse water scarcity than other regions where water quality was acceptable, even though water quantity was otherwise considered sufficient (Ma et al., 2020). In addition, research on the key drivers of drought in Texas in the United States found that, while the causes of drought in 15 different river basins were diverse, instances of poor water quality compounded conditions of drought, which in turn reduced water availability (Jones and van Vliet, 2018). In Europe, there is a trend in some locations towards increasing water abstraction from groundwater sources and a simultaneous decrease in surface water abstraction; this can be attributed to factors such as deteriorating surface water quality and seasonal variations in surface water availability (Zal, 2023).

Interestingly, both the studies mentioned above point to a general lack of focus in the current state of research on water scarcity, citing poor water quality as a key driver of water scarcity alongside other important considerations, such as the prevalence of drought (Ma et al., 2020; Jones and van Vliet, 2018). These findings demonstrate the interplay of issues contributing to water scarcity in Europe. The additional pressures posed by climate change are compounding the challenge and threatening to jeopardize the resilience of these already vulnerable freshwater ecosystems.

Increasing human water demand remains high in areas facing water stress

Demand for water in Europe has risen steadily over the past five decades, mainly as a result of population growth. Southern Europe has experienced the highest population growth, with a 17% increase between 1990 and 2017, while the rest of the EU (in addition to the UK) has seen an 11% increase (EEA, 2018b). As a result, there has been a significant decline in renewable water resources per capita, with a 24% reduction observed across Europe (EEA, 2018b). However, it is not just population growth spurring this demand; the nature of urban expansion plays a substantial role, especially given recent projections that suggest the EU's total population will peak as early as 2026, at 453 million inhabitants, steadily declining thereafter (Eurostat, 2023). It is therefore not merely population growth, but the movement of populations from rural to urban environments that will lead to a higher concentration of water demand in certain areas than in others, and in turn, to more acute water quantity and quality challenges (Hommes et al., 2019). Urban sprawl, characterised by the spread of development and impervious surfaces (like concrete), may further exacerbate this scenario. The proportion of the population living in urban areas in Europe has surged from approximately 55% to around 70% over the past 70 years (EEA, 2023f). Projections indicate that by around 2050, European urban areas will account for 80% of the total population (EEA, 2023f). This sprawling urban growth is changing land use, encroaching on natural landscapes and agricultural land to make way for residential and industrial development and expanding areas that cannot absorb water (EEA, 2022a). These patterns of urbanisation not only increase the demand for water, but also put pressure on water resources and infrastructure. The shift from permeable to impermeable surfaces impedes the natural absorption of water into the soil, altering hydrological patterns and reducing the replenishment of groundwater reserves (Hanh Nguyen et al., 2023). As a result, during heavy rainfall events, instead of being absorbed into reservoirs or the soil, excess water often ends up in sewers, contributing to overflows and water pollution and further eroding water quality (Hanh Nguyen et al., 2023).

While long-term population trends are shifting, with many Member States seeing stable or declining populations, demand has not decreased. The tourism industry plays a substantial role in water consumption, as millions of people visit destinations throughout Europe each year, accounting for approximately 9% of total annual water usage (EEA, 2018b). In the Mediterranean, addressing 'overtourism' is emerging as a critical challenge, as a limited number of destinations bear the brunt of a large tourist influx (Plan Bleu, 2022); this is especially true during specific periods of the year when water availability is already compromised, such as the summer season along the coast or the winter season in ski resorts.

Excessive water consumption poses a significant challenge to water availability in southern Europe, with agriculture, public water supply, and tourism being the primary contributors (Jager et al., 2022). These sectors experience a notable surge in water usage, particularly during the summer season. Agriculture stands as the largest consumer of freshwater in southern Europe, accounting for 80% of freshwater consumption compared to the EU average of 58% (EEA, 2021b). Intensified water usage during the summer, coupled with the increased frequency of droughts, puts a significant strain on water resources. In many parts of Europe, the cooling demands of power generation also exert substantial pressure on water resources. In northern Europe, the manufacturing industry emerges as the largest consumer of water (EEA, 2021b). These water-intensive sectors can be both major 'users and abusers' of water resources (EEA, 2018b).

The largest water stress hotspots identified by the EEA include agricultural regions that heavily rely on intensive irrigation, popular tourist islands in southern Europe, and densely populated urban agglomerations (EEA, 2021b). Events in the Po Valley, one of these agricultural regions, serve as a vivid example of this trend. In July 2022, severe water scarcity reached critical levels, leading authorities to implement water rationing measures in 125 municipalities and halt irrigation activities. This historic drought persisted for 100 days without any rainfall (Climate-KIC, 2022).

Rising frequency and intensity of droughts and water scarcity due to climate change

Climate change is expected to exacerbate the significant economic and human costs of water scarcity by further reducing water availability as well as water quality. The JRC considers climate change – specifically the associated higher temperatures as well as changing and more variable and extreme precipitation patterns – as the main driver for water stress on populations (JRC, 2020a). Inhabitants of southern Europe are particularly vulnerable to these changes.

For instance, Spain and Italy have already experienced dramatic fluctuations between extended periods of drought to sudden and intense flooding within a short period of time. This pattern was evident in the spring of 2023, when the Emilia-Romagna region in Italy endured destructive floods after a prolonged period of drought (Petrini, 2023). By 2030, an elevated risk of droughts is expected across Europe, driven by an increase in the frequency and intensity of heatwaves that trigger higher evaporation rates (Climate-ADAPT, 2023).

These conditions induced by climate change are expected to not only impact water availability but also damage its quality, posing even greater risks. For example, a 2022 study in Spain highlighted a dual loss of not only water quantity but also water quality in aquifers due to agricultural water use, as well as contamination from agricultural nitrates and pesticides (Schmidt et al., 2022). As a result, small and medium-sized municipalities that depend on groundwater for their drinking water face risks to their water supplies.

Moreover, when it comes to coastal groundwater, excessive extraction can result in seawater intrusion, rendering the groundwater unusable for an extended period and increasing treatment costs. The karstic aquifers along the Mediterranean coast, found in countries such as Croatia, Greece, France, Italy, Malta, and Spain, are particularly vulnerable to this issue. Heavy demand from agriculture, drinking water needs, and tourism puts these aquifers at a higher risk of saline intrusion (EEA, 2022b).

The 2022 drought in Italy also led to higher concentrations of pollutants in wastewater and in the wastewater treatment plants from which treated wastewater is discharged (Giorgi, 2022). Compounding the problem, low water levels in rivers and lakes meant there was less opportunity for dilution, making it more difficult to reduce the levels of pollutants. Furthermore, after a drought, the initial heavy rainfall is usually even more polluted and can flush accumulated pollutants into sensitive ecosystems.

Looking forward, EEA (2021b) forecasts under a scenario of 3°C of warming show that, compared to 1981-2010, 2041-2070 will see far more common weather-related droughts across Europe, with the exception of some central-eastern and north-eastern areas. The PESETA IV Study projects a twofold increase in drought frequency by 2100 under the same 3°C warming scenario across approximately 25% of the Mediterranean region (e.g. Italy and Spain) and 15% of the Atlantic region (e.g. Belgium and the Netherlands) (JRC, 2020b). An analysis of the impact of three consecutive dry years (2018, 2019, and 2020) in the Netherlands found that soil moisture and groundwater levels did not fully recover during the intervening winters, potentially leading to prolonged or multi-year periods of drought (Sjoukje et al., 2020).

Taken together, these studies demonstrate how the diverse impacts of climate change, including more frequent droughts, reduced water quality and, in turn, heightened water scarcity, are expected to

	accelerate over the coming years.
How might the issue develop in future?	**Increase in extreme water quality events, such as harmful algal blooms, affect recreational uses of water** As the impacts of climate change continue to intensify over time, they may exacerbate extreme water quality events, affecting the availability and quality of water for different use cases. One significant consequence is the disruption of aquatic ecosystems caused by rising water temperatures. In recent years, there has been a notable increase in algal blooms triggered by cyanobacteria in freshwater due to warmer temperatures (JRC, 2018). The more frequent occurrence of harmful algal blooms (HABs) renders rivers, lakes, and beaches unsuitable for swimming, boating, and drinking, as they lead to uncontrolled algal growth, disrupting aquatic organisms and depleting oxygen from the water. Some species of algae also release toxins, further exacerbating the water quality problem. The increased frequency and severity of droughts, coupled with warming temperatures, will likely accelerate the occurrence of these events. For instance, in California, which has experienced more frequent and extreme droughts over the past five years, the number of HAB events rose by more than 450%, from 56 in 2016 to 316 in 2020 (NRDC, 2021). Similarly, in 2019 Europe witnessed a record-setting algal bloom in Hungary's Lake Balaton, a popular tourist destination, especially for bathing. Moreover, research suggests that climate warming directly impacts lakes by altering their thermal structure and mixing, leading to an increased likelihood of stratification events lasting two or more days in Balaton, potentially rising five-fold by 2100 (Istvánovics et al., 2022). HABs also occur in coastal areas, as illustrated by the recent proliferation of the microalgae *Ostreopsis* in the Basque Country, which developed in June 2023 under warming water conditions (Franceinfo, 2023). First found in the Mediterranean 20 years ago, it has now spread to the Bay of Biscay, also degrading the quality of bathing water in a major tourist destination. Furthermore, droughts have been found to reduce bathing water quality across Europe, especially in freshwater areas, such as small lakes and rivers with low water flow (EEA, 2023e). Looking forward, the accelerating impacts of climate change, namely temperature increases and more frequent droughts, are expected to increase the frequency and severity of extreme water quality events. This is likely to affect water availability and quality, affecting not only recreational water use but also other water-dependent economic sectors, with potentially significant social and economic consequences. **Increased stress on aquatic life due to declining water quality** As climate conditions become more severe over time, increased frequency, intensity, and duration of droughts are expected to reduce river flows, which in turn will lead to a higher concentration of pollutants and nutrients, amplifying the stress experienced by freshwater wildlife. (Greater demands from human activities for groundwater abstraction during drought episodes might further affect freshwater availability.) The increased temperature alone will pose a challenge to freshwater ecosystems, creating an imbalance where certain species suffer more while others are better adapted to the higher temperatures. Furthermore, increasingly frequent algal blooms, driven by heightened nutrient pollution and higher water temperatures, may outcompete submerged aquatic plants, causing their loss during droughts and warm spells. Algal blooms can also occur in non-drought conditions, but droughts can lead to algal blooms of greater proportions, as they are not drained away. The subsequent aquatic plant losses have a significant impact on freshwater ecosystems, biodiversity, and dependent terrestrial birds and mammals (UK Centre for Hydrology and Ecology, 2022). An indication of how these interconnected climate impacts may play

out over the future was recently demonstrated in 2022, when an algal bloom led to the death of hundreds of thousands of fish in the river Oder, located between Germany and Poland. Fragile river ecosystems such as this – already subject to multiple pressures, such as pollution from excess nutrients and wastewater discharges – can reach an ecological tipping point. In this case, drought conditions, including high water temperatures and reduced water flow, together with large discharges of polluting salts, created a tipping point that facilitated the proliferation of harmful toxin-producing algae, resulting in widespread damage to the river's ecosystem.

The combined effects of these changes, such as rising temperatures, lower water flows in rivers and lakes due to more frequent and severe droughts, and increased nutrient pollution, may culminate in more ecological tipping points like those in Germany and Poland. Scientists are already warning that a repeat of this algal bloom is possiblein the near future(JRC, 2023).

Ecosystem services essential to water quality in decline, impacting quantity

The EU boasts highly biodiverse wetlands and floodplains, which provide vital ecosystem services such as water filtration, flood control, and carbon storage. They also act as natural buffers against droughts, helping to regulate water flows and maintain stable water levels. However, as droughts are expected to become more frequent and severe due to the escalating impacts of climate change, the ability of wetlands to provide these essential ecosystem services may be increasingly compromised. For instance, droughts hinder carbon sequestration in forests and release carbon stored in grasslands and wetlands due to insufficient soil moisture (EEA, 2023b). In addition, studies predict a significant increase in soil moisture droughts across Europe as global temperatures continue to rise (Berg and Sheffield, 2018; Samaniego et al., 2018). For instance, research by Samaniego et al. (2018) suggests that a 3°C rise in global mean temperature, which aligns with current projections to 2100, could expand drought-affected areas by 40%, impacting up to 42% more of the population. This scenario would also double the frequency of severe drought events by the end of the century, normalising what are currently considered extreme conditions.

As of 2023, droughts affect approximately 2% of EU wetlands, and trends are on the rise (EEA, 2023b). Among EU ecosystems, wetlands have experienced the largest increase in areas affected by droughts, leading to more CO2 emissions being released as a result (EEA, 2023b). In addition, the trend of wetlands being increasingly impacted by droughts, as seen in recent years, may accelerate, disrupting the natural water cycles and flow levels and subsequently reducing water quantity. Furthermore, the Convention on Wetlands (2021) highlights that Mediterranean wetlands, in particular, are under severe stress and are 20% more vulnerable to climate change than the global average. The region's large agricultural sector, which uses two-thirds of available freshwater resources, is demanding greater access to freshwater, exacerbating the situation. As a result, there has been an alarming decline in biodiversity since 1992, with freshwater species declining by nearly 30% and marine species by more than 50% (Convention on Wetlands, 2021).

In addition, marine ecosystems, particularly seagrasses, play an important role in maintaining marine water quality. The Mediterranean Sea is currently experiencing a decline in *Posidonia oceanica*, an endemic seagrass species that is essential for maintaining the quality of bathing waters. *Posidonia oceanica* enriches waters and the atmosphere by releasing oxygen, absorbing carbon, and storing it in the seabed; it also acts as a natural water filtration system, effectively trapping particles and pathogenic micro-organisms. However, the survival of this species is jeopardized by climate change, with projections suggesting that by 2050, *Posidonia oceanica* may lose 70%

	of its habitat, with a potential risk of functional extinction by 2100 (Pörtner, 2019). (Seagrasses are also harmed by poor quality freshwater from rivers.) If these trends materialise or accelerate at a higher rate than currently anticipated, the loss of these critical ecosystem services would lead to poorer water quality, which would further exacerbate water scarcity, as studies by Ma et al. (2020) and Jones and van Vliet (2018) have shown. **Increase in conflicts over water use** Frequent droughts and declining water quality are likely to lead to more recurrent conflicts over water use. As water scarcity worsens, this may accelerate the existing trend of increasing competition for limited water resources between sectors such as agriculture, industry, energy production, and households, exacerbating existing tensions between these different stakeholders with their own vested interests (see Issue 4 – Emerging challenges for the governance and equality of access and use of water at the local and regional level). To mitigate these challenges, some countries (e.g. Germany, France, the Netherlands) have addressed this through water strategies that establish prioritisation systems. In the Netherlands this is called *verdringingsreeks* (the 'displacement sequence'). This system prioritises flood protection and the prevention of irreversible damage to nature and landscapes over utility services (drinking water and energy production to guarantee the security of supply), small-scale high-quality use (irrigation of capital-intensive crops and processing industrial process water), and other types of use. Similar prioritisation systems exist in several other EU Member States, although the specific categorisations and sequences of use may vary. In most cases, drinking water production is considered the highest priority, unlike in the Netherlands, where geographic location plays a major role in the prioritisation (Utrecht University, 2022). However, with more frequent droughts, water conflicts may challenge the use of these prioritisation systems if they are increasingly seen as unfair by affected stakeholders. This may lead to a loss of legitimacy of these systems, in turn requiring new water management solutions (see Issue 4).

Potential implications for water resilience, the wider environment and human health	**Opportunities**	**Risks**
Vicious circle of increasing water stress and declining water quality leading to elevated and more persistent risks to human health	• There is a rising awareness among citizens, fuelling stronger political will among elected officials and policymakers. This leads to smarter and more efficient use of natural resources, namely water, enhancing the sustainability of its usage. • Growing calls to improve water quality may catalyse public sector investment into advanced and innovative water treatment technologies and infrastructure. Part of this new investment can be targeted at reducing	• Health issues resulting from poor and diminishing water quality contribute to rising costs in the healthcare sector. • Declining water quality has a negative impact on the quality of bathing waters, with adverse effects on public health, and poses risks where sites are increasingly contaminated with sewage and faecal bacteria (EEA, 2023g). For example, the presence of antimicrobial resistant bacteria in bathing waters is a growing threat, potentially causing hard-to-treat infections (Farrell et al., 2021). • Vulnerable populations, including less affluent

	losses in existing engineered and managed water systems, including fixing leaks and making better use of water-saving technologies.	households, may face disproportionate impacts from water-related health issues (linked to Issue 4 – Emerging challenges for the governance and equality of access and use of water at the local level and also constitutionally). • Water-related health issues could lead to reduced productivity, which could have a negative impact on a wide range of economic sectors.
Lower water quality and greater scarcity leads to increased conflicts over water usage, e.g., the reservoir conflict in France in 2023 (link to Issue 4 – Emerging challenges for the governance and equality of access and use of water at the local level). These conflicts extend to disputes over the direct access to water sources, adding to strain on groundwater resources.	• Conflicts over usage of limited water supplies could prompt the development of more equitable and participatory approaches to water governance and allocation, as already demonstrated by the use of participatory river contracts in Italy (Venturini and Visentin, 2022), for example (see Issue 4). • In response to increasing local and regional conflicts over lack of access to diminishing water supplies, the national governments of Member States may choose to invest in the expansion and construction of reservoirs and advanced water distribution systems. By harnessing excess rainwater resulting from more extreme weather events where there is too much water in some regions and not enough in others, these strategies could alleviate water scarcity in drought-prone areas by transporting it from areas with too much water.	• As a result of declining water quality, which will in turn contribute to reducing overall water availability, conflicts between groups over access to an increasingly limited supply of water may emerge amid the absence of sufficient water governance systems (linked to Issue 4). • Heightened conflicts may result from competing water users, such as agriculture and industry, who face significant economic setbacks if they are unable to secure access to an increasingly limited supply of water (linked to Issue 4).
Technological innovation for improving water quality (links to Issue 3 – Will the circular economy drive water resilience? and Issue 7 –	• If greater attention is paid to the link between declining water quality and reduced water quantity, this may spur investment in the development of	• Technological solutions are seen as a panacea for declining water quality and scarcity, thereby discouraging necessary behavioural and policy changes. In the absence of a

Rethinking agriculture for a water resilient EU)	innovative technologies that mitigate the release of pollutants, toxins, and other harmful byproducts from agricultural and industrial processes into water ways. The agricultural industry may not only lower its impact on water quality but increase its resilience to water scarcity by developing new technologies, such as drought resistance crops (see Issue 7). Improving the efficiency of water use through technological innovation or greater use of digital technologies to further advance water management (see Issue 8) would also reduce water consumption and, consequently, the discharge of polluted water into rivers, lakes, and coastal waters. • Accelerated development of technologies and practices to minimise contamination from industrial and agricultural processes (e.g. precision agriculture, clean energy production, improved management and circularity of wastewater treatment) (linked to Issues 3 and 7). • Technological innovation could lead to the development of new and alternative water sources (see Issue 2), such as desalinated seawater (Goergen, 2022), particularly for coastal communities, providing additional water resources in water-scarce areas. • Acceptance of reused water might increase, driven by the implementation of the Water Reuse Regulation and advancements in	society-wide effort, water quality or scarcity will continue to deteriorate (linked to Issue 5 – Will societal change drive water resilience or will our shared ambition for water change society?). • Industries that are acutely affected by water scarcity, such as many industrial, energy, manufacturing, and agricultural processes, do not have the capital to invest in the technological innovations needed to transform their operations in recognition of the impact of their by-products on water quality. • The benefits of innovative water treatment technologies – such as new wastewater treatment facilities (Bhaskar, 2022), desalination (Goergen, 2022), and improving cooling technologies – are costly and therefore limited to higher income communities and urban centres. This, in turn, may lead to increased inequalities over access to water between and within regions (linked to Issue 4).

	more efficient and effective technologies. As the regulation sets clear quality standards for reused water, it is likely to boost public confidence in its safety. • More frequent and extreme rainfall events, a consequence of climate change, present an opportunity to be harnessed for water conservation. This can drive the development of technologies to capture and store large volumes of water more cheaply and on a larger scale. Turning extreme weather events such as excessive rainfall into an advantage, coupled with sufficient water storage systems, can improve water security in times of scarcity.	
Ecosystem services that are essential to water quality (e.g. those provided by wetlands, floodplains, and certain species) and water quantity (e.g. flow regulation, groundwater recharge, and river levels) are negatively impacted	• The observed decline of wetlands and other freshwater ecosystems contributes to a changing societal perspective towards greater environmental stewardship. This leads to increased recognition of wetlands and the important ecosystem services they provide, motivating further conservation and restoration efforts by the public (linked to Issue 5 – Will societal change drive water resilience or will our shared ambition for water change society?).	• While it is important to recognise that droughts are not the sole driver of wetland degradation, the increasing duration and frequency of droughts across Europe pose significant challenges to wetlands' capacity to deliver critical ecosystem services. These services, notably water filtration and water flow regulation (United Nations, n.d.; Delle Grazie and Gill, 2022) will continue to decline, leading to deteriorating water quality and more frequent flooding. • The rise in wildfires, intensified by droughts and a diminished capacity for containment due to limited water resources (Bracewell, et al., 2023; Vale, 2023), initiates a chain of cascading hazards. Following wildfires, heavy rains can wash away nutrient-rich soil and ash, causing soil loss, clogging reservoirs with sediment, and smothering estuarine and coastal ecosystems. This chain reaction disrupts essential ecosystem services, such as those provided by wetlands and floodplains,

		crucial for maintaining water quality. • The risk of water pollution spikes due to sudden influxes of polluted urban runoff after droughts is significant, severely impacting water quality in rivers, lakes, and coastal waters. In some cases, water flow in rivers downstream of large cities can consist predominantly of wastewater. For example, the Manzanares River downstream of Madrid is about 90% wastewater for several months each year due to discharge from several wastewater treatment plants, leading to a complete change in the structure and function of the ecosystem and rendering it uninhabitable for aquatic species (Paredes et al., 2010). This decline in water quality and the erosion of ecosystem services can have a knock-on effect on human health, contributing to the spread of waterborne diseases. • The decline of ecosystem services due to deteriorating ecosystem conditions is leading to greater changes and reductions in river flows and groundwater recharge, contributing to increased water scarcity.
Increased stress on aquatic life and disruption of freshwater ecosystems as water quality declines	• Increased stress on aquatic life due to declining water quality may also contribute to a greater societal shift towards conservation. This may lead to changes in public behaviour in the form of reduced use of products containing harmful chemicals or increased participation in conservation efforts (linked to Issue 5). • Economic actors in the aquaculture sector innovate to minimise the impact of their business practices on the environment.	• If declining water quality continues unabated, it may further contribute to biodiversity loss in aquatic ecosystems (UK Centre for Hydrology and Ecology, 2022). • Amid worsening water quality and scarcity, there are more frequent zero-flow days, particularly in southern Europe, signalling escalating water stress in intermittent rivers (Tramblay et al., 2021). This development threatens the survival of local biota and disrupts the rivers' natural biochemical process. • The earlier onset of zero-flow periods, becoming permanent in certain instances, has a significant

		cascading impact on freshwater and aquatic ecosystems (Tramblay et al., 2021). • Deteriorating water quality leads to declining fish populations, threatening the food security of communities and regions that depend on them. • The twin challenge of decreased water quantity and quality results in significant economic impacts to industries that rely on aquatic life, such as the aquaculture and tourism sectors (Karlson et al., 2021).
Extreme events associated with declining water quality, such as algal blooms, become more common, driving down water quantity in certain cases	• No specific opportunities identified	• The growing prevalence of algal blooms pose an increasingly disruptive economic impact to sectors that depend on access to clean freshwater bodies, including the tourism and fishery sectors as well as coastal communities, as a growing number of water bodies are rendered unsuitable for recreational activities (National Institute of Environmental Health Sciences, 2023; Karlson et al., 2021). • The increasing prevalence of harmful algal blooms poses a growing threat to the safety of drinking water sources, while also compounding the issue of reduced water quantity (Karlson et al., 2021). • Harmful algal blooms cause adverse human health effects in communities in close contact with them, in both the short and long term (West et al., 2021). Their long-term effects on wildlife, livestock, domestic animals, and human health (e.g. repeated ingestion of toxins through the consumption of fish that have been in contact with algal blooms) are not well understood (National Institute of Environmental Health Sciences, 2023).

Timeframe of emergence	Events demonstrating the interaction between water scarcity and water quality, as already demonstrated by the 2022 Oder River crisis, are likely to become more frequent in the short term, i.e. within the next 1

	to 5 years. The main areas affected in this timeframe are likely to be parts of southern Europe that are already vulnerable to water scarcity, such as the Mediterranean islands (Climate-ADAPT, 2023). The Mediterranean is predicted to be a hotspot of climate change, warming 20% faster than the rest of the world (MedECC, 2020). Here, rising temperatures could lead to more frequent and severe droughts, which in turn could exacerbate water quality challenges such as eutrophication, affecting both human water uses, such as tourism activities, and local ecosystems. In the medium term, from 5 to 15 years, the interrelated effects of water scarcity and water quality are projected to extend to the Atlantic regions of Europe as well (JRC, 2020b), demonstrating that a change in water stress is not only a threat for southern Europe.
Uncertainties	While uncertainties surrounding the impacts of climate change are generally well recognised (Tollefson, 2022), the interaction between the different drivers of water scarcity that climate change accelerates, namely water quality, has received little research attention and is therefore less well understood, adding another layer of complexity to the issue. For instance, there has been a significant shift in the geographical distribution of drought patterns over the last decade. Countries in the Atlantic region, such as the Benelux Member States, as well as the Baltic region and Scandinavia, are now facing a substantial increase in the severity and extent of drought impacts, which are affecting progressively larger areas (EEA, 2023b). However, the increasing prevalence of water scarcity induced by these droughts is only one aspect of this complex challenge. As studies have shown, the presence of poor water quality can have a compounding effect on water scarcity (Ma et al., 2020; Jones and van Vliet, 2018). As such, the interplay of these factors presents a challenge in predicting the frequency and depth of water scarcity events, leading to increased risk and uncertainty, especially as to how the relationship between water quality and scarcity will evolve in the long term, to 2050 and beyond. Estimating the losses and costs associated with droughts is another element of uncertainty. The potential impacts are wide-ranging and affect different sectors of the economy, potentially leading to major crop losses, disruptions in electricity and drinking water supplies, and even disruptions to shipping. In addition, the lens through which the challenges posed by drought are viewed is important. It is crucial to distinguish drought as a hazard rather than a risk to ensure that vulnerability to this hazard is properly addressed. Accurately assessing losses and costs becomes increasingly complex when considering the long-term structural impacts of droughts on these different sectors. Crop losses are, for instance, not limited to isolated incidents directly caused by single droughts; they also encompass a structural decline in yield resulting from the degradation of soil health, which can be attributed to processes like erosion caused by the combined effects of droughts and floods. Projections of the future economic importance of various sectors add to the uncertainty, particularly for drought-sensitive sectors such as agriculture. While agriculture remains crucial for the EU's food security, it is anticipated to have diminished economic prominence in future EU economies (JRC, 2020b). Simultaneously, there could be a shift in the food system, with reduced reliance on animal products in the diet and a greater emphasis on drought-tolerant crops. This transformative trend would add complexity to the outlook for these sectors. This uncertainty hampers the ability of policymakers to make informed decisions on drought mitigation and adaptation measures (EEA, 2018b). A further uncertainty is the extent to which European societies can adapt their water systems to the interrelated challenge of reduced water quality and more frequent droughts. This would require addressing issues across multiple systems and sectors which are

	affected by other emerging issues, such as governance (Issues 4 and 5), urban areas (Issue 6), and agriculture (Issue 7).
Additional research or evidence that may be needed	**Further research needed on the relationship between water quality and quantity** The interaction between water quality, drought, and water scarcity (quantity) is a highly under-researched phenomenon, particularly in an EU-specific context. To the extent that studies in other geographical contexts have explored this issue, they have also noted the lack of focus on water quality in the context of water scarcity (Ma et al., 2020; Jones and van Vliet, 2018). Accordingly, it is recommended that future studies continue to explore the interconnections of these different issues in greater depth. To support these studies, prioritising data collection efforts is essential, as current large-scale data collection may not fully meet the requirements for studying water supply and demand aspects. Data gaps remain concerning the quantity and quality of water available at specific locations and times, as well as the exact location and timing of water demand. **Droughts and water scarcity damage ecosystems to an extent that is not yet known** While current research tends to prioritize the examination of short-term implications associated with extreme events like droughts, there is a notable lack of attention given to the long-term ecological consequences of these events. By focusing primarily on short-term implications, we may overlook the gradual and cumulative effects that droughts have on ecosystems over extended periods. Droughts can lead to shifts in species composition, changes in habitat structures, and alterations in ecosystem functioning that may persist long after the drought event has ended. **Quantification of the costs of droughts for ecosystem services** The economic value of these services in relation to drought impacts is not adequately quantified. It is crucial to conduct research that accurately estimates the economic losses associated with the disruption or degradation of ecosystem services during drought events (though it can be argued that it is difficult or perhaps even not possible to value some ecosystem services). This information can guide decision-making processes and facilitate the inclusion of ecosystem values in policy frameworks. **More research needed on tipping points and ecological droughts** Tipping points refer to critical thresholds in ecosystem functioning, beyond which abrupt and irreversible changes occur. Identifying these tipping points and assessing their vulnerability to drought conditions are crucial for predicting ecosystem responses and preventing catastrophic shifts. Moreover, ecological droughts, which are characterised by prolonged and severe water deficits, require further investigation to comprehend their ecological implications and develop effective management strategies.
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Issue 2: New and alternative sources of water	
Emerging issue description	The increasing impacts of water scarcity and droughts in Europe and globally have attracted significant research and media attention, with the need for new water sources increasingly emphasised (Goergen, 2022; Moloney, 2023; Weise and Zimmermann, 2023). As a result, the search for innovative technologies and approaches to secure water sources is becoming of growing interest for entrepreneurs and investors alike (EIT Food, 2022; Kothapalli, 2023). This could lead to the resurgence or wider adoption of existing (mainstream and niche) methods like desalination, including from the sea, cloud seeding, or collecting water from icebergs. Additionally, there is potential for the development and commercialisation of innovative technologies such as biomimicry, which imitates how insects or plants extract water in arid environments, and other technologies that extract moisture from the air to create a viable water source (Irving, 2022; Jiang et al., 2023). This issue focuses on novel and emerging potential sources of water; it will not cover water and wastewater reuse, which are addressed in Issue 3: Will the circular economy drive water resilience? While these approaches may currently be niche and small-scale in application, and their effectiveness is in many cases unproven, they may provide or be perceived as a lifeline for dry and water-scarce European regions and communities. For example, the Mediterranean EU countries account for 82% of EU desalinated water capacity (Fourneris, 2023). However, the EU only accounts for 10% of all desalinated water globally and only 1% of global freshwater comes from desalination (Climate ADAPT, 2023; Fourneris, 2023). A recent projection indicates that in southern European regions, water availability is expected to decrease by up to 40% by 2050 in the face of increasing demand and climate change impacts (Weise and Zimmermann, 2023). National and EU policies are increasingly supporting the use of new and alternative sources of water (Weise and Zimmermann, 2023). However, the risks associated with the introduction of unproven technologies and the large-scale implementation and commercialisation of novel approaches for water sourcing are as yet unclear. Potential drawbacks may include high energy requirements, unintended ecological consequences (e.g. of cloud seeding), or logistical challenges and wider environmental impacts (e.g. of approaches such as collecting water from icebergs) (Condron, 2023; Danfoss, 2021; Kuhl, 2022). Comprehensive research, rigorous testing, and thorough evaluation will be required to mitigate potential risks and ensure the long-term sustainability and viability of these emerging approaches.
Key drivers: what is driving the emergence of this issue?	**Multiple pressures leading communities and industry to seek alternative water sources** Europe faces rising water scarcity risks (approximately 30% of southern Europe's population is living in areas with permanent water stress), with 17% of its population and 13% of its GDP likely to be affected by high or extreme water scarcity by 2050 (EEA, 2023; WWF, 2022). In light of this, communities and industry in the EU (as elsewhere) are increasingly recognising the need for alternative sources of water to ensure their survival in the face of mounting challenges (Enyedi, 2022). Population growth and climate change are worsening water scarcity, driving industries to seek innovative solutions beyond traditional water sources. Moreover, EU industry is increasingly acknowledging the economic, social, and environmental advantages of utilising alternative water sources to ensure long-term sustainability in water availability for both people and ecosystem survival. This trend is prevalent across all EU regions, though it is particularly prominent in southern Europe, where the agricultural and tourism sectors play a vital role in the regional economy and are significant water consumers. **Water technology innovation and economic incentives** In 2022, the European Institute of Innovation and Technology (EIT) launched the EIT Community Water Scarcity initiative as a response to the pressing issue of water scarcity in southern Europe. As part of this

initiative, 40 small and medium-sized enterprises (SMEs) and start-ups across Europe have been invited to develop and present innovative solutions to tackle water scarcity challenges in the region. The technologies developed by the chosen companies to source water fall into three different categories (EIT Food, 2022):

- technologies that extract water from atmospheric humidity
- water vending machine technology designed for small communities or islands
- nature-based treatment technologies that either utilise or imitate natural processes to treat water for its reuse.

There are also new start-ups emerging (commonly referred to as 'aquapreneurs') who have recognised that water will be an increasingly precious resource and could become increasingly profitable (EIT Food, 2022; Harper, 2023). Consequently, they are actively exploring and embracing novel technologies that enhance water resilience. These include wider adoption of existing water sourcing methods and the introduction of new technologies to increase water supply. They are increasingly supported by banks and investment funds who have recognised the economic profitability of investing in novel and alternative water sourcing, viewing it as the 'blue gold' of the 21st century (Kothapalli, 2023; Usborne, 2021). Goldman Sachs, HSBC, UBS, Allianz, Deutsche Bank, European Investment Bank, and BNP have all made investments in this emerging market for water sourcing (Aljazeera, 2022; Deutsche Bank, 2021; EIB, 2023; Goldman Sachs, 2019). Furthermore, these start-ups are also supported by innovation hubs. For example, the World Economic Forum's open innovation platform, UpLink, is establishing an ecosystem for innovation that aims to discover and expand water solutions worldwide. Through an extensive selection process, 227 submissions from 45 countries were received and 10 top innovators (including 2 from Europe) were chosen to join the UpLink Innovation Network (UpLink, 2023; World Economic Forum, 2023).

The increasing presence of 'aquapreneurs' and venture capitalists, driven by the economic potential of the water crisis, has led to the development of new water sourcing methods and technologies, as well as advancements in existing approaches. Some notable examples include:

- Advances and new methods in desalination – for example, advances in membrane technology leading to improved efficiency in reverse osmosis desalination (Goergen, 2022; University of Tokyo, 2022), and innovative seawater desalination methods (e.g. combined Reverse Osmosis and Forward Osmosis method; use of CO_2 for desalination method) (Cantrell, 2021; State of Green, 2020)
- Biomimicry for water collection (Jiang et al., 2023)
- Hydrogen fuel cells (Marsh, 2022)
- New methods for fog catching (Burgen, 2022)
- Water transfer megaprojects (Shumilova et al., 2018; Stanway, 2023)
- Water from air technologies (Irving, 2022; Riva Ras, 2019; Rogers, 2021; Watergen, 2023)
- Emerging water purification technologies (Newton, 2023; Water Technology, 2021):
  - Solar-Powered Water Filtration (SolarDew, n.d.)
  - Nanotechnology (Ajith et al., 2021)
  - Acoustic Nanotube Tech (Kosowatz, 2022)
  - Photocatalytic water purification technology (Kosowatz, 2022)
  - Biomimicry for water purification (McVicar, 2021)
  - A portable drinking straw for water filtering (Riva Ras, 2019)

National and EU policies stimulating the use of new and alternative sources of water

EU Member States are increasingly becoming aware of the looming threat of water scarcity. In response to the detrimental impacts witnessed in sectors such as agriculture, energy, and industry during the recent droughts in Europe, governments are now formulating policies that embrace new and alternative sources of water to address the existing and anticipated water shortages (Weise and Zimmermann, 2023). For example,

	Italy has recently implemented a drought decree to streamline administrative processes for water infrastructure projects, such as desalination plants. Similarly, Spain's updated water management plans until 2027 comprise over 6,500 measures with a €22.84 billion investment. These plans include enhancing water supplies by promoting the increased utilisation of desalinated and reclaimed water sources (Council of Ministers, 2023; Symons, 2023). Specifically in the case of desalination, outlooks suggest that the European desalination industry holds substantial growth opportunities in both arid and non-arid regions. The potential increase in desalination activities could relate to the advantages of utilising desalted water for agricultural purposes (MacErlean, 2022). Research and innovation (R&I) policies and initiatives at the EU level play a crucial role in enabling the development of innovative technologies and approaches for water sourcing. The European Commission has been and remains actively involved in providing support for R&I initiatives that focus on tackling water scarcity by employing innovative methods for water access. This support is facilitated through various R&I programs such as Horizon Europe (and previously Horizon 2020), as well as funding mechanisms like the LIFE program (e.g. LIFE Nieblas project) (LIFE Nieblas, 2023; Water JPI, 2020). This commitment to R&I was reinforced in the lead-up to the UN Water Conference in March 2023, where the EU outlined a series of voluntary commitments for the Water Action Agenda. Among these, the EU also pledged to provide support for water-related R&I, including international research and innovation cooperation, with the goal of addressing water supply challenges by 2030.
How might the issue develop in future?	Amidst the anticipation of water scarcity in EU countries in the coming decades, there is an ongoing shift towards a more proactive approach by communities and EU industry to effectively adapt to the evolving water accessibility landscape; this is likely to lead to greater demand for alternative sources of water (alongside efficiency in use). Two main directions are emerging for the development and utilisation of existing methods, as well as new technologies and approaches, in water sourcing. To upscale these innovative technologies for sourcing freshwater, it will be crucial to ensure adherence to national and EU regulatory frameworks related to health and environmental safety. While novel water supply solutions may hold promise, they will need to be thoroughly vetted before widespread implementation. Regulators will have an important role to play in analysing potential human and ecosystem impacts and setting evidence-based guidelines. Beyond technical feasibility, social acceptability and long-term sustainability are key additional considerations. Community perceptions and ethics around alternatives will need to be addressed. Lifecycle costs, energy demands, and infrastructure requirements will also need to be evaluated for a full understanding of economic and environmental viability. A solution that appears promising in limited trials may prove unsustainable when scaled up. ***Expansion of new and existing methods and technologies for collecting water*** The practice of collecting water has a rich and extensive history. However, due to a wide array of technological interventions and innovations, collecting water is anticipated to emerge as a potentially key area for water sourcing in the foreseeable future. A variety of established methods are evolving, alongside novel methods and technologies that are being tested for wider adoption. *<u>Extracting vapor from the atmosphere</u>* An emerging technique that some researchers consider promising is the extraction of water vapor from oceans through the process of water vapor collection. A recent study by Rahman et al. (2022) suggest that extracting water vapor from the atmosphere above oceans could be an abundant and renewable water source. Using specialised structures that imitate the natural water cycle, the process involves transporting moist air from the

	ocean surface to nearby shores (through pipes), where cooling systems condense the vapor into drinkable water (Irving, 2022). While treatment of this extracted water may not be strictly necessary, many such systems still opt for treatment. This is done to ensure the water's potability for extended storage periods and to enhance taste by adding minerals (Notman, 2020). It is estimated that a single installation of this technology (a vertical 'capture surface' 210 m wide and 100 m tall) has the potential to meet the daily drinking water needs of approximately 500,000 people (Nield, 2022). This approach could complement existing desalination plants (Nield, 2022). Both technologies require abundant energy, and thus they will require new (or use of existing) renewable energy sources to be considered sustainable, which in turn could have water use implications. The emergence of and demand for portable atmospheric water extraction systems, with the potential to be powered by clean energy sources, may increase in the future. Their emergence will depend on a range of factors, including cost and economic viability. Where economically viable, such systems may become increasingly popular due to the ability to relocate them in response to changing climate and decreasing relative humidity (Rogers, 2021). *Biomimicry* There is a growing focus on biomimicry to collect rainwater. Researchers and aquapreneurs are studying the strategies employed by plants and species that efficiently utilise limited water resources to develop sustainable methods for rainwater collection (Jiang et al., 2023). The building sector, particularly in architecture, has significant potential to incorporate biomimicry principles into future constructions (Aslan and Selçuk, n.d.). For example, architects are exploring building designs that emulate the mechanism observed in leaves in a forest that effectively slow down the speed of rainfall (The Spaces, 2022). *Cloud seeding* Rain enhancement through cloud seeding to increase the volume of water extracted from air has been around since the late 1960s. However, the promise of generating 'artificial' rain (more accurately, catalysing precipitation using artificial means) may become an increasingly attractive prospect. Ongoing research and development are exploring alternative technologies for more efficient cloud seeding, potentially replacing the use of existing techniques and particularly silver iodide, which holds risks for the environment (Ossola, 2022). The use of nanotechnology and nanoscience could be increasingly important to develop and customise cloud-seeding materials that possess ideal properties for efficient water vapor condensation, aiming to maximise rainfall (MIT Technology Review, 2022); however these may have uncertain environmental and health risks. Collaborative efforts between scientists and engineers are expected to drive significant advancements in this area in the coming years (Ossola, 2022). *Extracting water from fog* There appears to be renewed interest in extracting water from fog among communities in remote and rural areas as well as in large cities around the world. Instead of fog nets that require a lot of space, architects are looking at ways to design structures that create a large surface area for collecting water throughout fog patches (including the highest point) (Trevino, 2020). In Europe, Portugal and the Canary Islands are particularly well suited due to the relative prevalence of wind and mist/fog. This water extraction method could expand in the future, with ongoing studies on innovative methods of fog catching for reforestation in Spain, Italy, and Greece (Burgen, 2022). *Iceberg appropriation* Although not a new concept, as the water scarcity crisis intensifies, more and more scientists, scholars, and politicians are considering the collection of water from icebergs as a possible freshwater source for the future. Countries such as the United Arab Emirates and South Africa are understood to be exploring the possibility of iceberg towing to address

water supply challenges (Qadir and Smakhtin, 2021). There is no evidence that European countries have yet seriously considered this approach. If successful in other regions, iceberg towing from the Arctic may gain traction (and public and media attention) as a potential easy – although only temporary – solution for Europe's water scarcity issues.

Water ATMs (incorporating rainwater collection or other water abstraction technology)

Water ATMs (automated teller machines), also known as automated water dispensing units or water kiosks, are being increasingly deployed as a mechanism for managing limited clean water availability. Utilising solar energy for power and incorporating rainwater collection and solar-powered osmosis, water ATMs can operate autonomously or connect to the grid. Accessible through water cards/tags sold by vendors and small shops, users can top them up with credit and use them to obtain water from machines (Root, 2019; The Unilever Foundry, n.d.). For now, these technologies are emerging in arid and developing regions around the world (e.g. Africa). However, in the long term, if Europe faces dire water scarcity crises, such technologies may emerge as governments and water companies are forced to reconsider the way communities buy clean (drinking) water.

Expansion of desalination

While it is not a new technology, there is evidence that desalination may increasingly emerge as a key source of water. Over the past decade, there has been a consistent increase in global desalination capacity, particularly in Europe and Africa, where the adoption of this technology has experienced a surge that is expected to continue in the near future (Ayaz et al., 2022). For example, in June 2023, Spain's national government announced plans to allocate €220 million for the expansion of a desalination plant near Barcelona and €200 million for a plant on the country's southern coast, as part of a €2.2-billion drought response package. Other countries in water-scarce regions, such as Israel, have prioritised desalination as a key solution to declining freshwater supplies. However, Israel is now facing emerging health and environmental challenges resulting from its heavy reliance on desalination. For example, desalination removes magnesium and increases salt content, leading to higher incidence of heart disease where desalinated water is the sole drinking source. Saltwater intrusion into aquifers and farmland has also occurred due to irrigation with reclaimed water. Furthermore, damming the Sea of Galilee has disrupted flow to the Dead Sea and contributed to declining sea levels (UNESCO, 2021).

The concept of desalination is undergoing a paradigm shift away from the traditional approach of extracting fresh water from saltwater. Instead, new technologies are increasingly focused on directly eliminating salt and solids from the water source. There are estimated to be over 50 diverse desalination technologies currently in development, encompassing various natural science disciplines. For example, the technology known as capacitive deionisation removes salt ions from water by using an electrostatically charged surface. An emerging technology that could offer a stand-alone desalination in future is temperature swing solvent extraction (TSSE). This technique utilises a solvent that functions like a sponge, selectively absorbing only the water and leaving behind the dissolved salt (Goergen, 2022).

Another recent innovation is the portable desalination unit, weighing under 10 kilograms and capable of producing clean drinking water (reported to meet WHO standards). The suitcase-sized device operates on low power and can be powered by a small, affordable solar panel (Zewe, 2022). This raises the potential for individual households living close to a source of saltwater (e.g. coastal communities) to have their own domestic desalination devices in the future.

It is expected that some of these technologies (i.e. capacitive deionisation, TSSE etc.) will replace reverse osmosis; however, according to experts, it will be a lengthy process (i.e. decades) before new plants utilising these technologies become operational (Goergen, 2022).

As desalination capacity expands, managing and disposing of the resulting byproducts (e.g. brine water and/or sludge) will become an increasingly pressing issue (Zolghadr-Asli et al., 2023). The environmental and economic burdens of disposal via landfills, discharge to water bodies, or diversion to evaporation ponds will grow substantially with greater sludge volumes (Hanley, 2018). Developing alternative disposal and reuse pathways will be critical. Ultimately, a combination of solutions tailored to local contexts may be needed to sustainably handle growing quantities of brine water and/or sludges. If not addressed proactively, sludge disposal could pose a significant bottleneck for the expansion of global desalination capacity.

The expansion of desalination in Europe could also exacerbate climate change should it occur without the integration of renewable energy sources. Research indicates that the expected growth of desalination could increase carbon emissions from the sector by 180% by 2040 if not coupled with renewable energy (Pistocchi et al., 2020). However, as desalination technology becomes more energy efficient, governments and organisations are increasingly using renewable energy to enhance clean desalination. For example, the Global Clean Water Desalination Alliance is investigating and promoting renewable energy sources for desalination. The organisation has established a series of global targets to be achieved by 2036, aiming to progressively increase the share of clean energy utilised to power desalination plants to 80% by 2036 (Acwa Power, 2019; Padmanathan, 2022).

Desalination may increasingly emerge as a cost-effective alternative to traditional water sources as the long-term results of increased EU investment in new, sustainable energy sources become clear, combined with advancements in seawater desalination methods (SCHEER, 2023). Conventional sources are likely to face rising costs due to pollution and climate-related challenges, whereas the cost of desalination technology is expected to continue decreasing as advancements are made and new technologies mature (Voutchkov, 2020). This, in turn, holds the potential to enhance water availability in arid and semi-arid regions (notwithstanding the environmental and health risks and challenges discussed previously).

Return to traditional small-scale practices within communities?

The implementation of novel water sourcing technologies could present challenges in terms of equitable access to water. While these technologies offer promising solutions for water scarcity, their costly implementation and the higher cost per litre of water produced compared to tap water may create disparities in access, particularly for marginalised communities (Hristov et al., 2021; Limón, 2022). As a result, these communities may increasingly return to local and traditional water sourcing practices (low technology solutions) that have proven to be effective over time. These practices often involve collecting rainwater, groundwater recharge, and certain traditional irrigation techniques. For instance, in the mountainous regions of southern Spain, the application of an ancestral integrated water resources management system known as 'acequias de careo'[16] are being revived to help overcome water scarcity. This traditional solution catches the meltwater from mountain streams and rivers, channelling it into a network of unlined canals (acequias de careo) that are dug into the ground at high elevations. This allows the water to infiltrate the upper valleys (Martos-Rosillo et al., 2019).

Additionally, traditional rainwater collection techniques, such as the use of cisterns and restoring natural water retention spaces (e.g. ponds, lakes), are being rediscovered and implemented in several EU countries to capture and store rainfall for later use (Balzan, 2023; Plester, 2022; Thompson, 2023). For example, there is growing demand for the expansion of infrastructure for water retention ponds in Italy. These would enable the capturing and storing of winter rain and meltwater in villages, towns, and regions near the Italian Alps, allowing it to be utilised during the spring

[16] "acequia" – meaning "water conduit" or "water bearer" are centuries old community operated water ditches or channels (National Geographic, 2019)

	season (Schauenberg, 2023). Although reservoirs serve the critical function of securing water supplies for various purposes, their expansion raises several social and environmental concerns. One primary risk is the alteration of natural ecosystems and landscapes due to the inundation of land, impacting local habitats and potentially leading to the displacement of communities. Moreover, the formation of reservoirs can impede the natural flow of rivers, affecting downstream ecosystems and disrupting sediment transport, altering water quality and aquatic biodiversity. Reservoirs may also face issues such as sedimentation and the accumulation of pollutants, impacting the long-term sustainability and functionality of these water storage systems (CIWEM, 2018). Furthermore, there is a growing interest among households in adopting traditional rainwater collection methods, such as using barrels for irrigating allotments. Social media platform Pinterest reported an increase of 155% in searches for 'rainwater harvesting architecture' and a surge of 100% in searches for 'rain barrel ideas' in 2023 (Joyner, 2023). By returning to these traditional water sourcing practices, the arid regions of Europe may improve water resilience and preserve local water resources for future generations. However, increased reliance on and cumulative impacts of the large-scale adoption of such traditional practices could lead to significant levels of water extraction and diversion. These could in turn disrupt the natural water cycle, causing ecological imbalances and potential harm to ecosystems.

Potential implications for water resilience, the wider environment and human health	**Opportunities**	**Risks**
Diversification of freshwater sources from increased application of novel water sourcing technologies	• Enable users to apply these additional supply options during periods of water scarcity or drought. • There may be opportunities from innovative approaches to create job opportunities. • Introduce new financing models / attracting more investors and public sector to take on the risk of funding water technologies in their later stages (Huber, 2023). • Encourage participation and collaboration among diverse investors, policymakers, and companies from both within and outside the water sector.	• A rapid adoption of new technologies will have uncertain impacts on the environment and human health and cause challenges in policy development and regulation to keep up with the pace of technological advancements.
Increase in production of salty brine, waste, and toxic chemicals from desalination plants	• Implement stringent environmental regulations and monitoring systems. • Adopting the principles of the circular economy, recognise brine as a valuable resource with potential for reuse and recovery instead of treating it as waste (Voutchkov, 2020).	• The increased presence of salty brine could harm seagrass beds and negatively impact the survival of fish larvae. It could also cause depletion of oxygen in specific ocean layers, thus posing a threat to larger marine animals (Goergen, 2022).
Growing energy consumption by desalination plants to process increasing amounts of seawater	• Accelerate the transition of the EU's energy system towards renewable energy sources. • Accelerate the implementation of next generation desalination technologies that will further reduce energy consumption (e.g.	• Reverse-osmosis remains an energy intensive process. • Use of fossil fuels as an energy source for desalination plants (Symons, 2023). • Discouragement of both

	improved membranes, improved energy recovery devices; alternatives to reverse osmosis including: Humidification-dehumidification desalination (HDH); Semi-batch/Batch RO – CCRO/Batch+ brine concentration; Forward osmosis (FO) brine concentration and FO-RO; FO-RO hybrid; Radial deionisation (RDI); Desalination by freeze crystallisation) (Danfoss, 2021).	improved energy efficiency and the drive to reduce energy use due to increased use of fossil fuels in desalination plants (SCHEER, 2023).
Access to desalinated water for socio-economically vulnerable groups		• Achieving drinking water quality from desalination is three times more expensive than purifying water from a river. This difference in cost could result in increased taxes and potentially higher water bills (Symons, 2023).
Increased interest in iceberg utilisation as a source for freshwater in Europe's arid areas (wild card)	• The creation of new jobs (e.g. working in iceberg mining factories; serving as crew members on ships involved in towing icebergs).	• Disturbances to water and air temperatures during iceberg transportation (Karimidastenaei et al., 2021) • Water and air pollution from ships during iceberg transportation. • Iceberg transportation could impact water salinity in various regions (e.g. polar, southern Europe), and in turn cause shifts in ocean circulation patterns and climate conditions. • Potential direct negative impacts on marine habitats (e.g. displacement of species), affecting both shallow and deep polar, mid-latitude and sub-tropical seafloor ecosystems along the iceberg transport route from grounding and scouring of drifting ice (Karimidastenaei et al., 2021; SCHEER, 2023). • High energy demand and poor efficiency of transporting relatively small amounts of water over long distances (SCHEER, 2023)
Atmospheric water collection increasingly used by industries (e.g. agriculture sector) in locations with moderate humidity	• Invest in R&I to increase the water generation rate and reduce the cost (Zhang et al., 2022).	• Growing energy consumption if relative humidity of the air decreases due to climate change, as condenser must work harder to cool the air containing water vapor (Ahrestani et al., 2023). • Airborne contaminants in water vapor - water after collection will need to be treated. • The use of these technologies is not economically viable in arid and semi-arid regions

		(Ahrestani et al., 2023). • Extensive atmospheric water collection could disrupt the natural distribution of water vapor in the atmosphere and alter overall water cycle/weather patterns. It could also pose transboundary governance challenges and risk of conflicts (e.g. equitable water distribution and management across borders)
Expansion of local and traditional water sourcing practices	• Local communities embracing and taking ownership of solutions tailored to their needs, while maintaining independence from highly intensive financial capital investments (SCHEER, 2023)	• Mainstreaming rainwater collection could deplete water resources for river basins (and diminish environmental flows), adversely impacting ecosystems reliant on environmental flows. • Reservoirs and water retention ponds can cause loss of water due to higher rate of evaporation during summer (Staccione et al., 2021). • The creation of reservoirs poses a risk by altering natural ecosystems and landscapes, potentially displacing communities and affecting downstream habitats. Issues like sedimentation and pollutants may also compromise the long-term sustainability and functionality of these water storage systems (CIWEM, 2018).
Rise in water equity concerns	• Prioritise social and environmental justice in water management policies. • Implement targeted subsidies and financial assistance programs for marginalised communities to ensure affordability of and access to water sourced from the emerging technologies.	• Affordability and accessibility to novel water sourcing technologies may be limited to those who can afford it. • Water transfers through large infrastructure projects could deteriorate water accessibility for local (potentially socio-economically vulnerable) communities in favour of residents of large urban areas (Inman, 2023)
Reliance on expensive water sourcing technologies	• Continued research and development of more cost-effective water sourcing technologies. • Empower communities to develop their own sustainable water solutions, such as rainwater collection or communal water projects.	• Increased water privatisation and monopolisation, potentially compromising democratic control over water resources and reducing public access to a vital and finite resource. • Vulnerable communities may resort to using unsafe or contaminated water sources.
Increased presence of venture capitalists investing in novel and/or		• Attempts to monopolise water sourcing, which could have negative impacts on communities through lack of access to water, increased

alternatives sources of water		water costs, unequal distribution, and potential exploitation of vulnerable communities (Aljazeera, 2022).
Timeframe of emergence	While different technologies are likely to emerge and advance at different speeds, given the intricacies involved in scaling up innovative water sourcing solutions, it is expected that the commercialisation and widespread application of most of these technologies on an industrial scale will take place gradually and over the medium to long term. In addition, in spite of significant advancements in novel water sourcing technologies and methods, there is evidence that in general water markets tend to adapt slowly, regardless of the specific technology in question (Goergen, 2022).	
Uncertainties	As global freshwater demand is projected to exceed supply by 2030, the outcome of addressing the crisis through novel water sourcing technologies remains uncertain (Hemingway Jaynes, 2023). In addition, each novel water sourcing technology has its own distinct uncertainties and challenges, which must be evaluated individually. As some of these technologies are still in early prototyping stages, predicting their real-world impacts on human health and ecosystems remains challenging. The efficacy and long-term effectiveness of various emerging water sourcing technologies and methods are still highly uncertain (Kuhl, 2022). For example, the effectiveness of cloud seeding is still under debate, as distinguishing between natural precipitation and that influenced by cloud seeding has posed a long-standing challenge due to the lack of a reliable reference point (Ossola, 2022). While these innovations offer alternative approaches, they do not create new water. This raises questions about their long-term viability and whether they can truly provide a sustainable and substantial water source, given that the Earth has a limited amount of water within its water cycle and this imposes constraints on the availability of water resources. The water sector is known for being risk-averse and slow to adopt new technologies, which leads to the slow dissemination of innovation. For example, it typically takes 12 to 14 years for a water technology to become widely accepted by the majority of users after it is introduced to the market (O'Callaghan, 2020). The successful scaling up of water innovations will depend on effective governance, innovative policies, suitable financing models, and public support. It remains uncertain how the situation could change to speed up the implementation of innovative solutions that would improve water supply (Huber, 2023). The growing demand for water supply solutions creates potential for the rapid market expansion of entrepreneurial ventures that can offer sustainable and efficient water sourcing. However, the economic viability of these ventures depends on various factors, such as the cost-effectiveness of the technology, market conditions, and access to financing (Söderholm, 2020). In the short term, the ability of governments to facilitate the conditions necessary to benefit this emerging market remains uncertain. The conditions for commercialising these novel water sourcing technologies may be further affected by future regulatory frameworks. Evidence is limited for the impacts of emerging water sourcing technologies on the environment and human health, given their lack of industrial-scale implementation; this raises questions about the potential need for and nature of future regulatory measures and adequate impact assessments before their implementation at industrial scale. Entrepreneurs developing novel water sourcing technologies may face significant uncertainties regarding the future regulatory landscape governing their innovations. In addition, growing water demand could escalate the use of unsustainable and inefficient water sourcing methods that could limit the expansion of this market. However, if the large-scale implementation and commercialisation of new and alternative water sourcing technologies is achieved, this raises concerns about the potential neglect of water efficiency measures and water recycling (Gothe-Snape and Machan, 2019). While these innovations offer promising solutions to address water scarcity, there is uncertainty	

	regarding the extent to which they may overshadow the importance of conservation and efficient water use.
Additional research or evidence that may be needed	Research is needed to assess the environmental impacts of the wide-scale adoption of existing and new water sourcing technologies, ensuring their sustainable and responsible use. Examples include: • Cloud seeding – there is an ongoing scientific debate on the potential negative impacts from silver iodide, the technology most commonly used to seed clouds. The long-term impacts from bioaccumulation of this compound and the unintended consequences from weather modification activities need to be studied further (Kuhl, 2022) • Collection of water from icebergs – the activities involved in the commercial exploitation of Antarctic ice (e.g. towing or capturing water from icebergs) require careful scrutiny due to insufficient scientific knowledge regarding their efficacy and potential environmental impacts (Gothe-Snape and Machan, 2019; Karimidastenaei et al., 2021). Further research is necessary to comprehensively understand and characterise the impacts of these emerging water sourcing technologies on the hydrological cycle and the overall climate system, particularly when implemented on a large scale. A comprehensive investigation is also necessary to thoroughly explore the potential long-term impact of water consumption from emerging water sourcing technologies on human health. For example, there is still limited knowledge about how drinking demineralised water (from desalination) might relate to the development of cancer (Nriagu et al., 2016). Interdisciplinary research involving environmental scientists, engineers, public health experts, and policymakers would be essential to address these concerns. This research will need to encompass comprehensive life cycle assessments, rigorous monitoring programs, and robust risk assessments to provide evidence-based insights for decision-making and policy development. Lastly, to facilitate the commercialisation of emerging water sourcing technologies, such as novel desalination methods, further emphasis should be placed on optimising system design and conducting economic assessments to ensure successful upscaling.
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Issue 3: Circular economy as a driver for water resilience	
Emerging issue description	The European Commission defines the Circular Economy (CE) as a model of production and consumption which involves extending the life cycle of products for as long as possible to reduce waste and use of natural resources such as water (European Parliament, 2023a). Like most materials used in production, such as textiles and construction materials, water is traditionally managed in a linear fashion, following a Take-Use-Discharge strategy (Tahir, Steichan and Shouler, 2018). This linear model of water abstraction and use is one of the primary factors driving water resource shortages in Europe (European Environment Agency, 2021). But with the EU setting ambitious plans to transition to a CE model by 2050, there is growing interest in how CE principles can be implemented with regards to the water system to help drive water efficiency and resilience (Delgado et al., 2021; Qtaishat, Hofman and Adeyeye, 2022). The safeguarding of water is essential for socioeconomic development as it is a resource, a product, and a service which is integral to many of the Sustainable Development Goals (SDGs) and for which humans have no alternative (Sauvé et al., 2021; Morseletto, Mooren and Munaretto, 2022). As water systems intersect with all sections of society – from drinking water and sanitation to agricultural, industrial, and other municipal uses – the water sector represents one of the largest untapped sectors for the CE (Delgado et al., 2021; Mannina, Gulhan and Ni, 2022). CE principles focus on the behavioural Rs – reduce, reuse, recycle, replenish, and retain (Morseletto, Mooren and Munaretto, 2022) – and can be applied to the human-water cycle to create a circular water system that introduces loops, maximises the value of clean water, and better aligns with the natural cycle of water to improve water resilience (Tahir, Steichan and Shouler, 2018; Bouziotas et al., 2023; Water Europe, 2023). Alongside water reuse, this characterisation covers the reclamation of other products in a circular water system and how the EU's transition to the CE and increased reuse and recycling of other materials may impact water use and availability. It is also important to note that, while this issue characterisation focuses primarily on water resource availability in an EU context, this is intrinsically linked to water quality, as the pollution of water sources may prohibit different types of use (see Issue 1 on the interrelated challenges of water quality and quantity).
Key drivers: what is driving the emergence of this issue?	**Increasing water demands in EU Member States and freshwater crises** Europe faces increasing water scarcity risks, with on average ~20 % of the European territory and ~30 % of the European population affected by water stress every year; this is due to a variety of interconnected drivers such as rising populations, growing economies, and shifting consumption patterns (European Environment Agency, 2021). The Intergovernmental Panel on Climate Change has predicted that water shortages will be particularly prevalent across the Mediterranean region (Cyprus, Spain, France, Greece, Italy, Malta, Portugal), where an 11% reduction in water resources is expected by 2060 (Morote et al., 2019). This growing pressure on water resources has forced the consideration of a transition in the way that water is used, managed, and shared to ensure there is enough water available to meet future needs (Water Reuse Europe, 2020; Qtaishat, Hofman and Adeyeye, 2022) and to prevent irreversible changes in ecosystem structure, function, and provision of ecosystem services caused by water shortages and severe droughts (Chen et al., 2023). While water continues to be consumed in large quantities by sectors such as agriculture and energy, water use by most economic sectors has decreased in Europe since the 1990s, thanks to measures taken to improve efficiency, such as better water pricing or technological improvements in appliances and machines (European Environment Agency, 2023). There is also increasing recognition of the need for alternative sources of water to safeguard communities and industries in these regions. This has driven water reuse as an alternate water supply (Mannina, Gulhan and Ni, 2022). While the practice of using wastewater for irrigating crops is growing and is particularly well established in Mediterranean countries such as Spain,

Malta, Cyprus, and Greece, water reuse represents a very low share of total water use in Europe and there is large potential to mainstream water reuse and recycling processes in the EU (European Environment Agency, 2021).

CE policy and activity across a range of sectors

EU policy has promoted the transition to a CE since 2015, with the launch of the first EU Circular Economy Action Plan. This has recently been further developed by the European Commission's new Circular Economy Action Plan (CEAP), which was adopted in March 2020 and constitutes one of the main building blocks of the European Green Deal. The CEAP outlines 35 specific actions to be taken by the EU in support of its future CE transition in Europe and is supplemented by CE roadmaps implemented by several Member States to advance transitions to a CE (Mazur-Wierzbicka, 2021).

One aspect is that actions lower down in the waste hierarchy, rather than reduced resource consumption, may have implications for water availability and quality where certain materials such as batteries are reused or recycled (Rinne et al., 2021). In general, however, increased emphasis on product reuse might be expected to reduce the need for virgin material in water-intensive processes and thus help conserve water resources (Lancen, 2022; Universitat Politècnica de Catalunya, 2022).

Policies promoting CE principles and water reuse

Fundamentally, the Water Framework Directive (WFD) focuses on the sustainable use of water while, in the context of the European Green Deal, both the CEAP and the new EU Climate Adaptation Strategy refer to wider use of treated wastewater to increase the EU's ability to respond to increasing pressures on water resources (Qtaishat, Hofman and Adeyeye, 2022). However, research into CE roadmaps implemented by EU Member States has shown that water reuse is not commonly included and only specifically mentioned in roadmaps prepared by Montenegro and Finland (Mannina, Gulhan and Ni, 2022).

The Urban Wastewater Treatment Directive (Council Directive 91/271/EEC) (UWWTD) requires countries to reuse treated wastewater when appropriate. Recent revisions of the Directive aim to improve circularity by requiring Member States to systematically promote the reuse of treated wastewater whilst considering the WFD objectives of maintaining good chemical and ecological status of the receiving water bodies. The reinforced treatment requirements included in the revisions are expected to have a significant impact on the quality of treated urban wastewater, and thus the potential for its reuse (European Parliament, 2023b).

In addition, the Water Reuse Regulation (EU Regulation 2020/741), which became binding in June 2023, sets out minimum water quality, risk management, and monitoring requirements to ensure safe water reuse (Directorate-General for Environment, 2023). These regulations will help Member States and stakeholders apply common standards on the safe reuse of treated urban wastewater for agricultural irrigation and assure the quality of reused water. It also recognises the potential of water reuse within other industrial processes to further alleviate pressures on water resources (Citelli and Severin, 2021). Additionally, some EU countries such as Spain, France, and Greece have compulsory national standards on water reuse, enforced through specific water-reuse legislation. However, these standards are mainly geared toward agricultural irrigation and centralised wastewater treatment plants (Qtaishat, Hofman and Adeyeye, 2022).

The new CEAP also sets up plans to develop an Integrated Nutrient Management Plan with a view to ensuring more sustainable application of nutrients and stimulating the markets for recovered nutrients. This therefore has the potential to increase wastewater reuse and recycling to facilitate the recovery of nutrients and minerals such as biosolids, phosphorus, and nitrogen (Frijns et al., 2021). The EU Waste Framework Directive also considers wastewater reuse as a means of increasing water resource availability, as long its purpose does not compromise the achievement of environmental objectives for good water status (Cipolletta et al., 2021).

	Increased water efficiency alongside increased energy and resource efficiency Water efficiency technologies are widespread across sectors such as agriculture (e.g., innovative irrigation), and industries are increasingly under pressure to improve water resource efficiency for economic and environmental reasons. Relevant EU legislation related directly or indirectly to water demand management establishes frameworks to promote resource efficiency. The CEAP mentions the Commission's intentions to facilitate water reuse and efficiency, including in industrial processes, while the adopted revision of the Industrial Emissions Directive will also include further incentives for water efficiency and reuse in industry, including increased investment in new technologies (European Commission, 2023). However, it is recognised that much more political ambition within the EU is needed to improve water efficiency and reduce water consumption by European industries. A comprehensive EU policy for sustainable water management is required that includes a focus on water-intensive industries and the incremental introduction of water-efficient technologies (European Economic and Social Committee, 2023). The successful adoption of water-efficient technologies in industry and across other areas offers great potential to reduce water use and promote reuse and recycling, as well as improve water quality and minimise wastewater discharge in line with the resource efficiency principles of a circular economy. Recent research into water efficiency measures, such as reduction of leakage in water supply networks, water saving devices and more efficient household appliances, has shown that they have the potential to significantly reduce domestic water consumption across Europe (European Environment Agency, 2021). **Technological innovations and EU projects promoting the circular use of water** In the case of smaller, decentralised water reuse systems, advancements in small-scale innovative technologies (e.g., membrane filtration, advanced oxidation processes, and adsorption) have enabled the generation of high quality recovered/treated water that is available and ready to be used on-site for a range of potable and non-potable purposes (Cipolletta et al., 2021; Mannina, Gulhan and Ni, 2022). Ensuring present and future water security is a significant area of innovation within Europe and, as such, many projects have been implemented to promote the circular economy of water. Some examples of projects in this area are listed below: • NextGen is an EU-funded project that has brought together 30 different organisations to demonstrate technological solutions for the circular economy of water. Through 10 demonstration sites across Europe, the project has provided evidence demonstrating the feasibility of innovative technological solutions for wastewater reuse as well as the recovery of energy and materials from wastewater recycling (Frijns et al., 2023). • SUWANU EUROPE[17] is an EU-funded project exploring the use of reclaimed water for irrigation in agriculture across eight target regions: Belgium, Bulgaria, Germany, Greece, Spain, France, Italy, and Portugal. The aim of the project is to bridge the current innovation gaps and achieve effective implementation of reuse solutions in agriculture. • The EU-funded StormTre project[18] will estimate the risks related to pollutant substances in stormwater, which represent a significant barrier to reuse of urban wastewater, and investigate low-cost treatments. • Projects such as ECWRTI, iMETland, REMEB, and POWERSTEP have recently focused on improving wastewater treatment to enable the recycling and reuse of water in both industry and agriculture (CORDIS,

[17] https://suwanu-europe.eu/
[18] https://cordis.europa.eu/project/id/886525

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2020b).

The Horizon 2020-funded project Achieving wider uptake of water-smart solutions—WIDER UPTAKE aims to demonstrate the feasibility of water-smart solutions for wastewater treatment plants and help overcome barriers to wastewater reuse (Mannina, Gulhan and Ni, 2022).
The EIT Community Water Scarcity initiative has promoted the development of innovative solutions, including nature-based treatment technologies that either utilise or imitate natural processes to treat water for its reuse (see Issue 2).
In the laundry sector, the RECYCLO project, funded under the European Commission’s LIFE programme, aims to set up a treatment and recycling system for wastewater from laundries to enable water reuse (Moretti and Dizier, 2023).
Another LIFE-funded programme, LIFE GreenLED, will help to scale nature-based and LED-based rainwater treatment solutions to enable a safe and reliable decentralised water supply in green cities.

Water Commodification
Water commodification refers to the process by which water has been transformed from a public to an economic good, i.e., a tradeable commodity. Water scarcity has been shown to be a principal driver of prices in the water market (Zuo, Qiu and Wheeler, 2019); therefore, if water becomes increasingly unavailable, then abstraction and use in households or industrial processes will become very expensive. Hence, applying circular water reuse and reducing the amount of water abstracted from the mains system can be viewed as an economic imperative for households and certain industries (Water Reuse Europe, 2020).
However, it is recognised that water commodification may drive social and spatial inequalities in access to water between different social groups who can or cannot pay real costs for water resources (Scientific Committee on Health, Environmental and Emerging Risks (SCHEER, 2023).
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<tr><td>How might the issue develop in future?</td><td>
Utilising a range of water utility pathways in a circular economy
<u>Rainwater harvesting</u>
Rainwater harvesting involves the collection, filtering, storage, and re-use of rainwater, or recharging of underground water. Rainwater harvesting is primarily deployed at the household or community level, but the potential of rainwater harvesting in the retail sector in Europe has also been explored (Ferreira et al., 2023). At the household level, collected rainwater can be used as an alternative or complementary source to mains water for activities such as car washing, gardening, pond filling, toilet flushing, clothes washing, or general cleaning. This can reduce pressure on water resource during periods of scarcity.
In some European countries such as Germany, rainwater harvesting is widespread, with more than 1.8 million households using rainwater harvesting systems (Plester, 2022). Additionally, in Belgium, the Government of Flanders has introduced new regulations for new homes and buildings subject to major renovations as part of a plan to combat drought and water scarcity in the region (Walker, 2022). It is likely that rainwater harvesting will become more widespread across Europe in the short to medium term, as it has been gathering popularity online and through social media. For example, the annual ‘Pinterest predicts’ report placed rainwater harvesting among the top five biggest trends tipped to shape 2023 (Pinterest, 2023). Moreover, the legislative proposal to revise the UWWTD introduces local integrated wastewater management plans, which aim to reduce pollution from stormwater overflows and urban runoff. As such, EU Member States will have to consider preventive measures aimed at avoiding the entry of unpolluted rainwater into wastewater collection and treatment systems, for example through measures to increase natural water retention or rainwater harvesting.
<u>Direct and indirect wastewater reuse</u>
While water reuse is already successfully deployed in some Member States, there is an opportunity for greater reuse of wastewater in Europe. It is
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estimated that only 2-3% of total treated urban wastewater is being reclaimed and reused in the EU, and up to six times more treated water could be reused than these current levels (Directorate-General for Environment, 2023). Various technologies exist, based on biological, chemical, mechanical, and natural processes, which can currently be implemented to recycle water or reclaim water for other purposes (Santos et al., 2023). However, mobilising private investment in such water technologies will be crucial to mainstream them as part of a circular economy, as water is relatively cheap (given its vital importance in society) and is largely seen as a public good rather than an investment opportunity (Geschwindt, 2023). Analysis of Europe's wastewater reuse market and future trends has indicated that the market could grow at a compound annual rate of 15.22%; this would be largely led by projects focusing on reuse opportunities for agricultural irrigation (Bluefield Research, 2023).

Reclaimed water can be employed for direct uses (e.g., public drinking water or aquifer recharge for potable use), plus a variety of indirect uses, such as:

- Agricultural irrigation
- Landscape irrigation
- Aquaculture
- Industrial processes
- Household toilet systems
- Garden use
- Laundry systems

Standards and guidelines regarding the health and environmental risks related to wastewater reuse can vary significantly between EU Member States, with currently only five (Cyprus, Greece, Spain, France, and Italy) having developed legislation that sets specific requirements on the reuse of wastewater. The Water Reuse Regulation has been highlighted as improving clarity on wastewater reuse in agricultural irrigation at the European level and is expected to encourage and facilitate water reuse in the EU (Citelli and Severin, 2021; Mannina et al., 2021). However, this regulation is limited to water reuse for agricultural purposes and therefore additional legislation is required to outline and encourage wider uptake. A range of potential risks are associated with reused water that is likely to contain chemical and organic pollutants and pathogens, as these can lead to contamination of the environment and people. Therefore, a stringent regulatory framework and transparent reuse criteria are required to manage health and environmental risks and change public perceptions on water reuse.

Another major barrier to the reclamation and reuse of wastewater is public perception, the so called 'yuck factor'. There is generally low public acceptance of reuse solutions and even strong opposition to allowing reclaimed water as a source for drinking water. This perception can create genuine challenges for the integration of water reuse in the water supply, even though it is not necessarily based on the actual risks of recycled water (Diamanti, 2022). However, recent surveys completed in the UK, Spain, and the Netherlands have revealed that the public may be more open to wastewater recycling for drinking water and food production than previously anticipated (Smith, 2021). Additionally, large-scale, centralised systems for direct potable water reuse have already been implemented in certain parts of the world, such as Singapore, Windhoek (capital city of Namibia), and Texas, but there is only one full-time potable water reuse system in the European Union – the Torreele facility in Flanders in northern Belgium (Diamanti, 2022). Direct potable reuse of reclaimed water therefore comprises a large gap in the circularity of water systems, which could also be filled in Europe in the coming decades (Audenaert, 2020).

Resource recovery from wastewater

A central principle in a CE is to eliminate waste and keep materials and components in use and within the value chain for longer. Sewage sludge is residual, semi-solid material, a by-product of wastewater treatment that is rich in nutrients, such as nitrogen and phosphorus, and other resources such as metals and microplastics. Resource recovery from wastewater has received increasing attention as a pathway in the circular water system. Examples of resource recovery uses from wastewater are presented below:

- Use of reclaimed biosolids as fertilisers for agricultural and non-agricultural purposes (e.g., parks or golf courses)
- Use of recovered chemicals in industrial processes or for human health products (e.g., cosmetics/medicines) and detergents
- The conversion of the organic carbon contained in wastewater into bioplastics with the help of bacteria
- Recovery of cellulose from municipal used water to create paper
- Metals and mineral recovery
- Effluent gas reuse (e.g., nitrogen, sulphur, methane, and carbon dioxide)

The potential for resource recovery from wastewater and sewage is an area of interest in EU research. Projects such as WOW! (Wider business Opportunities for raw materials from Wastewater), alongside SMARTplant, POWERSTEP, SCALIBUR, and NEREUS are developing techniques to help Europe realise its potential in recovering these valuable resources. However, the European Fertiliser Regulation (2009, No 1069/2009) has been identified as a barrier limiting the expansion of small, decentralized systems utilising sludge for agricultural purposes, since compost derived from digestate and sewage sludge cannot be labelled and marked as EU fertilising products (Cipolletta et al., 2021). As such, fertilisers produced from materials recovered from wastewater may be more likely used for non-agricultural purposes in the future, as usage for non-edible crops has less stringent regulation.

Also, the proposal for a revision of the Urban Wastewater Directive includes provisions on minimum reuse and recycling rates for phosphorus and nitrogen from sludge, in relation to better monitoring and reduction at source of pollution from non-domestic discharges, which will help improve the quality of sludge. Minimum reuse and recycling rates for phosphorus and nitrogen from sludge would then be defined by the Commission through a delegated act to take into account the available technologies.

<u>Energy recovery from wastewater</u>

Thermal energy from wastewater from industrial, commercial, and domestic sources (e.g., showers, dishwashers, and washing machines) can be recovered through technologies such as heat exchangers and heat pumps (Nagpal et al., 2021; Diamanti, 2022). These processes therefore have significant potential to supply clean energy at a scale ranging from buildings to large communities and districts. Meanwhile, biogas can be produced as an energy source to supply the wastewater treatment plant itself, helping create potentially energy neutral wastewater treatment (Guven, Ersahin and Ozgun, 2022).

The wastewater treatment industry consumes large amounts of energy, accounting for ~0.8% of the electricity generated in the European Union (Adamovic et al., 2019). However, recent research has calculated that the potential chemical energy contained within European municipal wastewater is about 87 500 GWh per year (CORDIS, 2020a), up to five times the amount of energy needed for the wastewater treatment process (Diamanti, 2022). Therefore, there is huge potential for energy recovery from wastewater treatment to support the circularity transition and decarbonisation of the EU's energy sector (Kehrein et al., 2020). This potential is aided by EU Directive 2018/2001, which qualifies urban wastewater treatment sites as 'go-to' areas for renewables, meaning a location designated as particularly suitable for the installation of plants to produce energy from renewable sources (in particular, potential for solar energy production or biogas production from sludge). The proposal for a revision of the UWWTD also includes provisions on GHG emissions reduction and energy neutrality of wastewater treatment plants at Member State level.

<u>Nature-based Solutions for circular water systems</u>

Nature-based Solutions (NbS) in water management and constructed wetlands can be used to help water systems transition from human-managed to nature-managed and enable circularity (Tsatsou, Frantzeskaki and Malamis, 2023). Some of the key NbS that can promote water circularity are outlined by Tsatsou and colleagues (2023) and include:

- Permeable pavements
- Constructed wetlands
- Living/green roofs or walls
- Retention ponds
- Bioswales – vegetated, shallow, landscaped depressions designed to capture, treat, and infiltrate stormwater runoff from developed surfaces.

Recent research has shown that the implementation of NbS in conjunction with advanced treatment technologies for water reuse projects can both increase the reliability of the process and overcome key barriers to water reuse, such as social acceptability and financial problems (Castellar et al., 2022; Gonzalez-Flo, Romero and García, 2023).

Circular Economy transition and impact on water resources

Increasing battery recycling requirements

Battery demand is set to soar in Europe to meet the rising demand for electric vehicles and home and grid-scale storage systems for renewable energy; therefore, battery recycling will be vital to achieve CE principles (Hodgkinson, 2023). The new proposed EU Battery regulation provides for the obligation to recycle batteries and, as such, recycling of lithium-ion batteries is predicted to increase strongly in Europe (Schmaltz, 2023). This may have implications for water availability, as water is integral to battery recycling processes in both the initial shredding of cells and the subsequent chemical treatment of black mass (Arvia Technology, 2023). Despite this, it has recently been suggested that using recycled materials could reduce water consumption from battery production by up to 50% (Veolia UK, 2022). Therefore, increased battery recycling could have a positive impact on water resilience in Europe if battery manufacturing using primary materials is reduced. The circularity of this process would also be improved if the water used in battery recycling could be reclaimed and reused in the recycling process itself, but there is little information on whether such technologies are under development yet.

Circularity in the textile industry and associated wastewater recycling

The EU is one of the most important global textile markets, holding the second largest share of the world textile market in 2020 (World Trade Organisation, 2021). Conventional textile production, particularly dyeing, is extremely water-intensive and generates highly polluted water that must be subject to costly treatment processes prior to discharge into rivers. In the EU, it has been calculated that the water consumption of the textiles sector is the third highest household consumption domain, after food & recreation and culture (European Environment Agency, 2022b).

Over the coming decades, it is expected that the EU will implement textile recycling at scale, driven by the upcoming strategy for sustainable and circular textiles; this aims to ensure that by 2030, textile products placed on the EU market are long-lived and recyclable and made as much as possible from recycled fibres (European Commision, 2022). This strategy is expected to mitigate the pressures exerted on water resources by the sector by imposing stricter standards on water use (Citelli and Severin, 2021). However, since a large part of textiles consumed in the EU are produced outside the bloc, it is estimated that 92% of the water used to produce footwear and household textiles consumed in the EU is abstracted in non-EU countries, along with 85% of primary raw materials used and 93% of land used (Manshoven et al., 2019). Therefore, if the EU continues to import most of its textiles, increasing circularity in the EU textile industry may not greatly benefit water resilience in the EU.

In addition, several European-based clothing brands and retailers have been advocating for water recycling and sustainable water management in their supply chains, with Swedish-based H&M setting a target of 30% reduction in absolute freshwater alongside the use of 15% recycled water in its production (World Business Council For Sustainable Development, 2023). Meanwhile, technological advancements have ensured that dry or

	waterless dyeing methods, which use carbon dioxide instead of water, are being implemented in textile factories in Asia; these have the potential to generate significant reduction in water withdrawals when compared to conventional dyeing methods (Tahir, Steichan and Shouler, 2018; Flood, 2019). <u>Co-transitions and the water-energy nexus</u> The EU's shift towards a more circular economy is not happening in isolation but alongside several other interrelated transitions, such as the green, digital, and energy transitions, all of which will have implications for water availability in Europe (as outlined in Issue 9). The energy transition, and the eventual decarbonisation of the economy through increased use of renewable energy sources, will potentially have the greatest implications for water given the close relationship between water and energy (Bryan et al., 2021). This is known as the 'water-energy nexus', whereby water is required for energy production, while energy is needed to purify, deliver, heat, or cool water. Energy is also needed to treat water/wastewater, which is a key component in achieving circularity of water systems, as discussed previously. Models have predicted that the transition to a 100% renewable system will lead to a reduction in water consumption in the energy sector across most parts of Europe; certain scenarios suggest that a reduction in water demand of up to 28.3% could be realised by 2050 when compared to 2015 levels (Lohrmann, Child and Breyer, 2021). Renewable energy sources such as solar power have been presented as a viable treatment option for industrial and domestic wastewater to facilitate reuse (Pandey et al., 2021). Therefore, more renewable energy contributing to increased water/wastewater recycling and reuse should provide future benefits for water security in Europe. However, this is an emerging area of interest, and more research is required to optimise treatment systems for renewable energy sources.	
Potential implications for water resilience, the wider environment and human health	**Opportunities**	**Risks**
Battery recycling as part of the transition to the circular economy	• Lithium-ion battery recycling is a future priority, given tight global supplies of metal elements such as lithium, nickel, and cobalt. New technology allows old lithium-ion cells to be recycled with just water, which can make battery recycling cheaper and less toxic (Ohnsman, 2023).	• Lithium-ion batteries, such as those typically used in electric vehicles and to store energy from renewables, are currently hard to recycle (Hirschlag, 2022). • Unintended consequences of lithium-ion battery recycling include the release of polyfluoroalkyl substances into the environment (Rensmo et al., 2023).
Resource recovery from wastewater systems	• Reclaimed nutrients and organic matter can be used as fertiliser in agricultural and recreational processes (e.g., parks and golf courses). This may help reduce synthetic fertiliser production, as well as reducing the level of nutrients being discharged into the environment	• Large capital costs ensure it is not currently economically viable to reclaim certain under-exploited resources from wastewater, such as nitrogen, bioplastics, and metals (Bohra et al., 2022). • Mono-incineration of sewage sludge to recover resources requires extensive changes to existing infrastructure. Therefore this risks being a lock-in solution that is currently very expensive and complex

	(Tahir, Steichan and Shouler, 2018). • Mineral recovery can help meet demands for mineral resources such as phosphorus. • One notable opportunity for industrial wastewater reuse and recycling is through ‘industrial symbiosis’ – i.e., cooperation between industries located next to each other geographically so as to take advantage of various wastewater flows and water recycling opportunities (Delgado et al., 2021).	to implement (Wagner et al., 2020). • Wastewater treatment can generate significant direct emissions of nitrous oxide, a greenhouse gas with large global warming potential. However, emissions are very variable between plants, and reductions in emissions of nitrous oxides can be achieved by applying control strategies to prevent incomplete nitrification or denitrification during wastewater treatment (Valkova et al., 2021; European Environment Agency, 2022a). • Reuse of sludge to recover nutrients has not been strongly enforced in the EU due to a lack of EU standards on how to do this without endangering human health.
Energy recovery from wastewater	• Thermal energy can be recovered from wastewater through technologies such as heat exchangers and heat pumps. The recovered energy can be used in heating/cooling buildings and play a significant role in reducing reliance on non-renewable forms of energy (Pintér, Vessey and Tissot, 2020). • The potential exists for thermal energy recovery to exceed that for chemical energy through sludge treatment (Diamanti, 2022).	• Complete recovery of all the energy contained in wastewater may be unrealistic due to conversion losses (Kehrein et al., 2020). • Not viable if there are large distances between wastewater sources and households/industry using the energy. • Current energy recovery technology for wastewater has high investment costs as well as significant operating and maintenance costs and so is unlikely to be viable at household scales (Nagpal et al., 2021).
The transition to a renewable energy system in Europe and use for circular water systems	• In general, renewable energy technologies, particularly wind and solar power, consume considerably less water to generate electricity compared to conventional fossil-fuelled power stations (Bryan et al., 2021). Therefore, increased use of renewables water/wastewater recycling and reuse should enhance water security in Europe. • Treatment of wastewater using renewable energy such as solar power reduces the use of conventional power and thereby reduces GHG emissions.	• Increased implementation of some renewable energy sources (e.g., hydropower) could impose additional strain on water resources in certain parts of Europe (Lohrmann, Child and Breyer, 2021). Moreover, EU ambitions to increase the share of renewable energy in transport could contribute to a significant increase in the amount of water required for agriculture in Europe if achieved through increasing biofuel production.
Rainwater harvesting at the household	• Only minor treatment is required prior to usage for laundry and/or toilet	• Rainfall harvesting could impact water available through runoff from catchments and recharge rates to

or community level	flushing. • In more advanced systems, harvested rainwater can also be treated to achieve drinking water quality and for irrigation in urban farming. • Large-scale harvesting can reduce soil erosion and contamination of surface water with pesticides and fertilisers from rainwater run-off. • Harvested rainwater can not only act as a store of water during shortages but can also protect public sewer and stormwater systems during periods of heavy rainfall.	aquifers (Sauvé et al., 2021). • Rainwater harvesting will be impacted by climate changes and reduced precipitation levels in many European regions over the coming decades (Gwoździej-Mazur et al., 2022). • Potential issues surround the distribution of installation costs and benefits generated in communal living situations (e.g., apartment buildings). • Initial high costs to set up rainwater harvesting systems and regular maintenance requirements. • Human health impacts due to metals or other chemicals leaching from rooftops or storage tanks. Other risks include damages from water leaks if systems become damaged or are poorly maintained.
Water reclamation from wastewater for potable and non-potable uses	• As freshwater supplies become more limited and water demand increases across Europe, water reuse can reduce the gap between water availability and demand (Mannina, Gulhan and Ni, 2022). • The ability to implement decentralised systems ensures that this water reclamation process is less energy-intensive than desalination or long-distance freshwater transfers and hence more cost effective (Van der Bruggen, 2021). • In decentralised systems, reclaimed water can be reused without the need for intensive transportation and, despite potentially high upfront costs, can reduce water bills for small- to medium-sized enterprises. • Other economic benefits can be generated related to new businesses and jobs.	• Effective wastewater reuse requires coordination amongst several bodies and institutions, with this process needing to be sufficiently transparent to gain public acceptance (Berbel, Mesa-Pérez and Simón, 2023). • Deficient/insufficient treatment of wastewater may pose a risk to farmers, consumers, and the environment. • The additional process required in water reuse ensures it is currently more expensive to utilise than conventional sources of freshwater (Morris et al., 2021), and so reuse not be an economically attractive option during years when water scarcity is not an issue. • If stricter effluent quality regulations are implemented in the future across the EU, then this will require more advanced treatment processing, which can be more energy-intensive (Kehrein et al., 2020). • Water reclamation from wastewater could be vulnerable to water terrorism (Hindiyeh et al., 2021).
Wastewater recycling in the textile industry	• Technological advances in membrane design and application have significantly reduced the cost of wastewater recycling in the textile industry.	• The capital costs are still considerably high for small- and medium-scale industries, particularly in regions where freshwater extraction is expensive (Sarker, 2022). • The process of recycling textile wastewater can be very energy-intensive, which can also reduce economic feasibility for some producers. • Textiles manufacturers' work will not meet the very high certification standards for their products if the

		recycled wastewater utilised is of insufficient quality (Gmurek and Bilińska, 2023).
Waterless dyeing in the textile industry	• Has the potential to generate significant reduction in water withdrawals when compared to conventional dyeing methods.	• The technology has yet to be implemented at large scales in Europe and is also limited in its capacity to dye a range of fabrics.
Increased implementation of Nature-based Solutions (NbS) to facilitate wastewater reuse	• NbS, such as natural or constructed wetlands, can help realise the potential for industrial wastewater reclamation and reuse by removing chemical and microbial pollutants. • These features generate a range of ecological, social, and economic co-benefits, such as recreational/leisure benefits, flood protection, carbon sequestration, increased local biodiversity, and adaptation to climate change. • They are largely accepted by communities so there is little opposition to implementation in urban areas.	• Limited land availability in many large European cities can be a major barrier to the implementation of NbS in urban water management (Oral et al., 2020). • There is still limited knowledge or understanding among decision-makers of NbS operations and benefits in the management of wastewater. This can inhibit the implementation and acceptance of NbS schemes. As such, harder engineering solutions may be preferred to achieve short-term results even where they do not represent the best long-term solution.
Timeframe of emergence	It is expected that this topic will emerge in the medium to long term. With the EU aiming to achieve a circular economy by 2050, many industries are changing the way they operate and the practice of water reuse and wastewater recycling in Europe is steadily growing (Smol, Adam and Preisner, 2020). Despite this, the issue of water resilience and security in the EU is an urgent one and so we would expect the presented range of circular water uses and associated technologies to develop rapidly for implementation over the coming decade.	
Uncertainties	A fundamental uncertainty when analysing how the CE will impact water resilience is around the shape of the CE transition in Europe. It is hard to predict what CE trends will emerge within the EU over the coming decades, with some recent analysis suggesting uncertainty in the pace of change towards a more circular economy in the EU (European Court of Auditors, 2023). Circular water systems are an increasingly important area of research, with lots of new technologies and projects focussing on water reuse for potable and non-potable uses, plus the reclamation of valuable resources and energy from wastewater. However, when it comes to these circular water solutions, most innovations discussed in the literature are exemplar pilot and demonstrative projects that have yet to be scaled up to wider, mainstream applications (Qtaishat, Hofman and Adeyeye, 2022). Therefore, there is limited information on their future feasibility and how they might become more mainstream in a European context. It has also been recognised that localised building and planning regulations will influence the feasibility, implementation, and operation of circular-water solutions at household and community scales (ibid).	
Additional research or evidence that may be needed	• In general, academic literature on the circular uses of water does not fully consider the hydrological cycle or seek to understand the environmental implications of water reuse in different sectors. As such, there is a need to better understand how changes in water abstraction and discharges into catchment basins may impact downstream water	

	availability (Berbel, Mesa-Pérez and Simón, 2023). This additional understanding will be particularly important in more water-scarce regions. • While there has been increased attention on the value of wastewater in a range of uses, including extracting contaminants with economic value, its potential as a source of resources has so far been underexploited (Voulvoulis, 2018). Examples of other under-exploited resources in wastewater, which if extracted more commonly could contribute to the circularity of EU economies, include enzymes, metals, minerals, and even energy, but more research by scientists and engineers is needed to make their reclamation economically viable (Diamanti, 2022). • A holistic water circularity assessment framework is lacking (Nika et al., 2020). There is also a gap in the body of knowledge regarding methods for assessing the economic impact of circular models in the water system, for example using NbS to manage water (Ghafourian et al., 2021). • Investment in the development, manufacturing, and use of water-efficient technologies and training of new professionals to support the implementation of new technologies will be essential. Measures like these will enable the EU to become a low-water-footprint production area (European Economic and Social Committee, 2023).
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Issue 4: Emerging challenges for the governance and equality of access and use of water at the local and regional level	
Emerging issue description	In the face of increasing water scarcity and droughts, projected for many parts of Europe, fairly managing equal access to water at the local and regional levels will be a growing challenge. Making water governance more participatory, for example, is one of many approaches that can be pursued to find and agree on solutions. Participatory governance was identified by expert participants in the FORENV process (i.e. through the sense-making workshops) as an interesting solution to explore in the context of this priority issue, hence the emphasis in this characterisation. Water governance and participation involve two key elements. On the one hand, the design of water governance systems, such as centralised, decentralised, and multilevel structures (Pahl-Wostl and Knieper, 2023), forms the basis for how water resources are managed and defines the roles and responsibilities of different actors involved in water resource management. Secondly, within these governance systems, participatory tools can be used to actively include relevant local and regional stakeholders in water management decision-making. In this context, the EU Water Framework Directive (WFD) states that water is "not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such" (European Commission, 2000, p. 1). Based on the principle of global Sustainable Development Goal (SDG) 6 on ensuring the availability and sustainable management of water and sanitation for all (United Nations 2022), there have been growing calls to treat water as a public common good that is universally accessible. In this spirit, Slovenia, for example, introduced the right to drinking water in its constitution in 2016 (Loen and Gloppen, 2021). The UN has also recognised access to drinking water and sanitation as a human right (United Nations General Assembly, 2010), and the EU has supported this. This is reinforced by Principle 20 of the European Pillar of Social Rights, which recognises that "Everyone has the right to access essential services of good quality, including water" (European Commission, 2017, p. 22). The EU has also set out a green and just transition as an overarching policy ambition of the European Green Deal, which includes several policy initiatives (e.g. Zero Pollution Action Plan and the EU Adaptation Strategy) in which water plays an important role (European Commission, 2023a; European Commission, n.d.). The EU Drinking Water Directive states that "Member States shall take the necessary measures to improve or maintain access to water intended for human consumption for all, in particular for vulnerable and marginalised groups" (Council Directive 2020/2184, p. 28). Despite this and many other legal tools that already exist to ensure equal access to water, the implementation of such access at all levels, especially at the local level, is challenged by the fact that, as droughts and water scarcity worsen, tensions and the likelihood of social conflict between different users and uses of water are likely to rise as well (Unfried et al., 2022). We are already seeing clashes between citizens and governments, for example in France, where communities are challenging the construction of reservoirs to improve water supplies for irrigation (Reuters, 2023a; Porter, 2022). While the necessary legal instruments exist to address such issues, including Strategic Environmental Assessments (SEA) and Environmental Impact Assessments (EIA), or territorial planning at the local, regional, and even national level, these conflicts nevertheless persist. Moreover, these disputes underscore the importance of water as an essential input for the agricultural sector and food production, particularly in already water-stressed parts of Europe with established agri-food industries, such as Spain (see also Issue 7 on agriculture). Other types of demand for water may also be changing, in part due to changing settlement patterns such as the global trend towards urbanisation (UN Habitat, 2022) and the use of water for non-essential leisure activities, like golf and skiing (Vorkauf et al., 2022), and for luxury lifestyles that include residential swimming pools. Moreover, these uses of water are largely symbolic of a coveted social status, and can be by the

	same decision-makers who are responsible for ensuring equitable access to water. As these demands on water evolve, so too does the governance challenge of ensuring equitable access to an increasingly limited water supply. This issue examines how current competition for access to water between different water users – including businesses, industry groups (e.g. energy production), and the general public – may escalate into more recurrent and intense conflicts in the future, and how these disputes may challenge the provision of equal access to water. Today's water demands are based on a wide range of uses, from recreational (e.g. swimming pools, skiing, and golfing) to economic (e.g. agriculture and manufacturing) and essential (i.e. drinking and cleaning). By investigating present trends, we aim to anticipate how these conflicts may evolve. In turn, participatory approaches are one of many that can provide a mechanism for addressing these conflicts locally. The intrinsic water needs of nature and biodiversity are also coming into conflict with increasing human water use, as highlighted by many environmental and nature NGOs. Illustrating this issue, the Doñana National Park in Spain is facing a severe water crisis due to climate change and intensive agricultural practices, leading to a conflict between conservationists and farmers who rely on the park's aquifer for irrigation (Zimmermann and Weise, 2023). Following the WFD – and the Common Implementation Strategy of the Directive – river basin planning by Member States has indeed been carried out through public participation processes (European Commission, 2003). Another way forward is the growing adoption of multi-level approaches to water governance, which include greater decentralisation at the local level in order to strengthen cooperation between community stakeholders alongside a centralised system to ensure coherence with national environmental standards (Rowbottom et al., 2022; Ricart et al., 2019). The growth in the use of participatory river contracts in Italy (recently included in national water legislation) offers another interesting example (Venturini and Visentin, 2022; Cialdea and Pompei, 2021). Experiences from implementation of the WFD across Member States as well as from around the world can provide further insight as well. This issue draws on these current experiences to explore the challenges and opportunities of governing equal access to water in the context of increasing water scarcity and how water governance systems can be adapted to meet future challenges.
Key drivers: what is driving the emergence of this issue?	**An environmental context of dry conditions, greater water scarcity, and more frequent droughts** Water scarcity affected almost 30% of territory in the EU for at least one season in 2019 (European Environment Agency, 2023a), while drought impacted almost two-thirds of Europe in 2022 (JRC, 2022). Climate change is expected to further reduce water availability in many regions in the coming years, particularly in western, southern, and eastern Europe (European Environment Agency, 2023a). Currently, these problems are acute in many southern European countries, as shown by the European Environment Agency's (2023a) Water Exploitation Index; Spain, Italy, Portugal, Turkey, Greece, Malta, and Cyprus have experienced the most severe water scarcity conditions in Europe. In these already drought-prone countries in particular, climate change is leading to longer and more intense dry spells as well as greater variability in rainfall patterns, resulting in dramatic swings from prolonged drought to flooding in a short period of time (Browne, 2023; Hervás-Gámez and Delgado-Ramos, 2019). While many parts of southern Europe are already experiencing instances of water scarcity, future projections expect these impacts to spread across the entirety of Europe in the coming decades (Toreti et al., 2019). Looking beyond, the World Wildlife Fund's water risk filter analysis projects that by 2050, 75% of the population and GDP of Spain and 82% of the population and GDP of Greece will be at high to extreme risk of water scarcity (WWF, 2022). As climate change increases the prevalence of drought-like conditions, previously rare events in historically hot and dry climates may become more common. For example, during the period

1991-1995, parts of the Iberian Peninsula, including Portugal and Spain as well as France, southern Italy, and Greece, experienced recurrent and sustained droughts (European Drought Centre, n.d.). The impact of these recurrent episodes peaked in 1994-1995, when millions of users lost access to household water, particularly in the Spanish areas of Palma di Mallorca, Seville, and Cadiz (European Drought Centre, n.d.).

More recent examples from communities in dry and arid climates outside Europe can shed light on how such environmental contexts may challenge the governance of water access in the future. For example, a community located in the desert-like climate of Arizona in the United States lost all access to domestic water services due to an extended drought affecting the entire region (D'Annunzio, 2023). Similarly, in South Africa, the City of Cape Town issued a notice to residents in 2018, warning that it would turn off household taps due to critically low water supplies (Calverley and Walther, 2022).

Competing interests between stakeholders over access to water

As water scarcity increases, so does competition between stakeholders motivated by their own interests in access to it (Hervás-Gámez and Delgado-Ramos, 2019). For one, businesses, especially those with activities in agriculture, energy, transport (i.e. inland navigation), or manufacturing, need water as an essential input for their operations. For instance, farmers in Spain organised protests to oppose the government's plan to redistribute water across several regions of the country to boost struggling crop yields (Heller, 2023). Additionally, in the Murcia region of Spain, the competition for access to water between different users raised the issue of water governance during their 2023 regional election, in large part due to the high demand for water from prominent agricultural stakeholders (Bousmaha, 2023). Moreover, in Malta, one of the most water-stressed countries in Europe, the water demands and perceived unsustainability of the agricultural sector is a point of tension, as other key societal actors (i.e. tourism, the environment, urban residents) are competing for limited water resources (D'Agostino et al., 2020).

Energy production also creates significant demand for water, even though the water used in hydroelectric power generation, or in cooling thermal power generation, can be reused downstream. There is the problem of thermal pollution, as the water heated during energy production requires a cooling period before it can be reused – an issue that becomes more pronounced in times of energy crisis. For example, amid Russia's invasion of Ukraine, the demand for nuclear power has surged due to limited access to natural gas; this has led to higher demand for water for cooling in nuclear power plants, a process which produces water that cannot be immediately reused, as it requires treatment and time for adequate cooling (IMF, 2022).

High-tech manufacturing processes can also have high water needs. German authorities denied a request from Tesla for permission to extract more groundwater for its electric car factory near Berlin (Water News Europe, 2022). Additionally, semiconductors, which are essential to the development of most electronic products made today, require a significant amount of water to produce (Belton, 2021).

On the other hand, the general public relies on water for a wide range of uses, from essential (drinking, food preparation and processing, hygiene) to recreational (gardens, swimming pools). Also, the public's willingness to sacrifice their personal water use in the face of government-imposed water restrictions is strained when large businesses or multinational corporations are seen to be using significant amounts of water (Perlmutter, 2022).

As an example of these inter-group conflicts, in northern Germany, the Coca-Cola company withdrew its application for an additional groundwater well in the city of Lüneburg in the face of growing protests from a local citizens' initiative that had been opposing the plans for years (NDR, 2022). These issues are seen in examples elsewhere in the world. In Monterrey, Mexico, for example, large multinational corporations maintained access to large water reserves in the midst of a prolonged water shortage, while at the same time residents were subjected to water rationing by local authorities, leading to conflict at the local urban level (Perlmutter, 2022).

According to projections, 17% of Europe's population could be at high risk of water scarcity by 2050 (WWF, 2022). If the problem is not addressed, Europe's local communities – from large metropolitan cities to smaller or more rural towns and villages in already drought-prone and arid climates, particularly those in parts of southern Europe – may soon face similar challenges. The impact on small towns and villages may be particularly acute, as water is extracted from these communities to meet the needs of larger cities with much larger populations; this underlines the varying challenges faced by different scales of communities (Hommes et al., 2019).

Economic advantage shaping access to water resources and ensuing conflicts between socio-economic classes

The European Strategy and Policy Analysis System (ESPAS, 2019) highlights conflict as a potential fallout from unchecked economic inequality in its forecast of global megatrends through 2030. This is particularly relevant in the context of the EU, where, as Eurofound (2021) reports, the wealth gap is stark: the top wealth quintile in the 21 evaluated EU Member States holds gross assets 60 times larger than those in the bottom quintile. These socio-economic divides can extend to water resource accessibility as well, fuelling conflict and tension among different socio-economic groups over an increasingly scarce resource. Examples outside Europe with a history of dry and arid environmental conditions, especially in cases where water scarcity conditions are already more acute, can provide insight as to how water scarcity and its related impacts can interact with socioeconomic disparities.

For instance, in 2018, the residents of Cape Town, South Africa, faced a critical water crisis in which the municipal government threatened to turn off the taps of every household within the city limits (Savelli et al., 2023). Further examination of this example illustrates how rising water scarcity can not only challenge the ability of water governance systems to provide equal access to water but can also exacerbate existing socio-economic divides and inequalities. A socio-economic analysis of water use in the Cape Town metropolitan area found that urban elites consumed disproportionate amounts of water compared to less economically advantaged people (Savelli, et al. 2023). Ultimately, the Cape Town example illustrates how one's economic status can be a driving factor in the extent of their access to water (Calverley and Walther, 2022). However, when drawing parallels between this case and how water scarcity induced challenges may develop across Europe over time, the importance of contextual factors cannot be overlooked; these include the legal, socio-economic, institutional, and cultural fabric as facilitators of conflict. For instance, the WFD calls for water pricing that incorporates environmental and resource costs, and stipulates that the implementation of water tariffs in Member States should mitigate overconsumption at the household level. However, a study on water demand management (WDM) policies by Stavenhagen et al. (2018) indicates that the ability of water tariffs to reduce consumption relative to other measures may be limited. The effectiveness of several different WDM policies in Berlin, Copenhagen, Tallinn, and Zaragoza were assessed for their impact on reducing household water use over the 1995-2015 period. It found that water tariffs were among the least effective compared to other measures, such as network maintenance and renovation, advertising water-saving technologies, water meter installation, and several other more impactful measures (Stavenhagen et al., 2018).

Moreover, instances of economic disparities driving different levels of access to water are already surfacing in the United States, where water bans imposed during recent droughts have been circumvented by wealthier individuals (KCAL-News Staff, 2022). Furthermore, socio-hydrological modelling conducted in drought-prone areas of California shows that rising costs due to water scarcity have a disproportionate impact on low-income households (Wichman 2023). Yet, there are already contemporary examples in Europe of more affluent households being able to afford higher

	water prices to maintain their water-intensive luxury goods and facilities, while low-income families face significant economic constraints as water scarcity increases (Zimmermann, 2023). In Germany, for example, as the district of Sächsische Schweiz-Osterzgebirge struggled with drought, some of its wealthiest residents were found to be consuming more than 600 times the average household amount per day, with local authorities finding that the fines at their disposal were unable to deter such behaviour (Zimmermann, 2023). This exemplifies the socio-economic dimension to water access, in which there is a clear gap between those who can afford to use water freely and those who must comply with imposed restrictions. Other signs of how this issue may develop can be seen in the recent protests in France against exemptions from water restrictions for golf courses, which are widely perceived as a luxury activity. These provide an early indication of how socio-economic status may drive this issue over time (Thomas 2022). **The constitutional right to water and its trade-offs** The momentum behind legally enshrining the right to water for human consumption as a means of ensuring equal access to it has grown in the years since its inclusion in the Slovenian constitution in 2016 (Loen and Gloppen, 2021). However, as a growing number of countries across Europe face more acute conditions of water scarcity, with governments making explicit decisions about which types of users can access water and how much, embedding the human right to water in national constitutions faces a number of trade-offs that may hinder its wider adoption in Europe (Benöhr, 2023). The challenge is reconciling an unwavering right to access water with the fact that governments across Europe are already restricting its use and how much can be accessed. Policy measures could mitigate these challenges. For one, Benöhr (2023) suggests the use of financial incentives, such as water pricing in accordance with the cost recovery principle of the WFD (cited above), to reduce overconsumption. At the same time, however, in the absence of specific support measures, such pricing measures could exacerbate inequalities in access, especially among low-income households and vulnerable groups; this would instead impede the ability to realise the right to water. While the EU does not have the power to influence or modify the constitutions of its Member States, progress made at the level of national governments, such as in Slovenia, still plays an important role in setting precedents for the tools policymakers can use to ensure equal access to water. Similarly, recognising and enshrining the right to water at the national level may indirectly influence future action at the EU level. Ultimately, the actual impact of enshrining the right to water in national constitutions is only one step in a more complex process involving several complementary policy measures to ensure access to water (Schiel et al., 2020; Benöhr, 2023).
How might the issue develop in the future?	**Moving from demand-driven to sufficiency-driven water governance** An example of competition and conflict between stakeholders at the local and regional levels can be seen in the transition from demand-based to sufficiency-based water governance (Lieberherr and Ingold, 2019; Hervás-Gámez and Delgado-Ramos, 2019). The transition represents a shift from the provision of water based on consumer and sectoral demand, often without consideration of the environmental impacts, to allocating water based on pre-defined ecological and societal needs. However, this shift poses challenges. For instance, as water scarcity becomes more pronounced, governing authorities will have to decide what constitutes sufficient water use; this will necessarily involve prioritising which activities can be carried out and by whom and to what extent (e.g. agriculture, industry, energy, tourism, and leisure). For example, the key challenge, as described by the European Environment Agency (2021a), is that “people, nature and the economy all need water” (p. 5). These competing demands from different stakeholders, including individual users and different economic sectors, can lead to heightened tensions and potentially conflict (Zikos and Hagedorn, 2017). Furthermore, these competing demands must

be reconciled in the face of changing water governance systems that, in certain circumstances of limited supply, must prioritise certain uses for water over others. For instance, under the EU WFD, it is a legal obligation of EU Member States to maintain ecological flows, which are defined as a "hydrological regime consistent with the achievement of the environmental objectives of the WFD in natural surface water bodies as mentioned in Article 4(1)" (European Commission, 2016, p. 3). An example in Spain highlights how tensions can arise from such changes to water governance systems, in this case due to transboundary considerations: farmers protested against government plans to maintain a minimum ecological water level by reducing the amount of water diverted from the Tagus River for irrigation (Reuters, 2023b).

This conflict illustrates the tensions that can arise when trying to move from demand-driven to sufficiency-driven water allocation, while also trying to manage competing economic, environmental, and domestic water needs in a way that is perceived as fair by these competing societal actors (Lieberherr and Ingold, 2019). Taken together, these considerations underscore the complexity and challenges to be expected in the transition to sufficiency-based water management.

Escalating group tensions drive growing water conflicts

There is uncertainty about the direction and extent to which water governance systems can adapt reforms to ensure equal access to water in the face of increasing environmental and socio-economic pressures (Di Vaio et al., 2021). Due to many of the challenges described earlier, such as different water use cases between stakeholders (e.g. agriculture, industry, public) (Zikos and Hagedorn, 2017), water governance systems may not be able to adequately manage the various pressures from these competing groups seeking to secure access to water for different uses as availability becomes more limited.

Although the WFD incorporates provisions for public participation, Member States have typically shown a preference for conventional administrative structures when implementing these requirements (Voulvoulis et al., 2017). For instance, river basin committees have not consistently integrated the views of regional and local stakeholders (Voulvoulis et al., 2017). As such, the inability of water governance systems to facilitate access to water in a way perceived as fair by local and regional stakeholders may further escalate intra-societal conflict. This has already been seen in France between protesters and the government over proposed agricultural development (Porter, 2022), and in Spain with the response of farmers to the government's decision to maintain an ecological water level in their rivers (Reuters, 2023b).

Given recent environmental conditions in Europe, the scale and frequency of these inter-group conflicts may increase significantly in the short term. For example, between 2018 to 2020, north-western Europe experienced three consecutive years of uncharacteristically dry weather and the emergence of multi-year drought events (Van der Wiel et al., 2023). The study also found that such multi-year droughts are likely to become more common in areas not traditionally exposed to such conditions, such as the Netherlands.

Water justice amid the EU Just Transition Agenda

Water scarcity could feature more prominently in the EU's Just Transition agenda, particularly in the drought-prone regions of southern Europe. While the essential right to water at the EU level has been recognised by Principle 20 of the European Pillar of Social Rights, and tools to realise such outcomes are in place (namely the WFD), their effectiveness and their implementation across Member States vary. As already seen outside the EU in places such as Cape Town and Monterrey, the failure to ensure unequal access to water could manifest itself across Europe and create a sense of water injustice among affected local and regional populations, potentially leading to demands for the development of transformative water governance systems that prioritise human well-being, democratisation, and ecological integrity (Perreault, 2014).

Furthermore, the worsening situation of water scarcity and its increased visibility could shift the lens through which these issues are examined. Rather than viewing water scarcity solely from an ecological perspective, it may lead to water scarcity taking on a more social character (Perreault, 2014). This broadened perspective may require water governance institutions that are able to promote both environmental and social justice, aligning broadly with the spirit of the EU Just Transition agenda (European Commission 2023c).

Growing use of different participatory approaches to water governance

Under the WFD, a cornerstone of EU water management policy that entered into force in 2000, the involvement and participation of non-state actors in, for example, the development of river basin plans is already an important aspect of its implementation (Rimmert et al., 2020). For example, the Common Implementation Strategy for the WFD recommends the involvement and participation of local stakeholders at an early stage in the river basin planning process to ensure that their views are incorporated into the final plans (European Commission, 2003). Despite this, studies indicate that the extent to which the views of citizens have been included in implementation outcomes has not led to meaningfully different environmental outcomes (Rimmert et al., 2020). In turn, local communities face increasing water scarcity amidst multiple water users seeking access to a diminishing supply; this may contribute to greater demand for more autonomous and participatory approaches to water governance.

Among various approaches to participatory water governance, participatory river contracts (RCs) and Water Basin Councils are two examples that have been implemented with success in Europe and Latin America respectively (Rossi, 2022; Garciá and Bodin, 2019). Studies indicate that these participatory water governance models can contribute to resolving competing demands from different water users at the local level, particularly due to their role in building consensus among diverse societal and community stakeholders (Rossi, 2022; Cialdea and Pompei, 2021; Garciá and Bodin, 2019).

One specific model, participatory river contracts (RCs) have proven successful in several European contexts by facilitating participation and cooperation at the local level, while still working in line with national water management plans used in several EU Member States. In Italy, RCs are described as "voluntary agreements between stakeholders for managing water bodies and involve participatory, evidence-based action plans" (Venturini and Visentin, 2022, p. 1). In terms of their ability to facilitate access to water between groups, one study of the use of RCs along the Italian coast in the Lazio region found that they were an effective means of resolving water governance issues while integrating the perspectives of different community stakeholders (Rossi, 2022). Similarly, a study of the use of participatory river contracts in the Friuli-Venezia Giulia region of Italy found that they were an effective tool for facilitating greater involvement and collaboration among local stakeholders (Venturini and Visentin, 2022).

Belgium also has a successful history of implementing river contracts, first introduced in 1990, with a strong focus on encouraging the participation of community members (Rosillon, 2015). This form of participatory water governance has been widely adopted in the Walloon Region of Belgium, where nearly 90% of the territory is covered by river contracts. However, Venturini and Visentin (2022) caution against relying on RCs as a panacea for resolving all stakeholder conflicts over water management decisions; they stress the importance of actively cultivating the participation and meaningful involvement of relevant territorial stakeholders throughout the development process.

While RCs have been tried in several EU Member States, such as Italy, Belgium, and France, other models have been introduced outside Europe.

In Brazil and Peru, for example, participatory Water Basin Councils were used with some success to bring in the voices and perspectives of local stakeholders who had previously been excluded in less open systems (Garciá and Bodin, 2019).

Expanding the use of multi-level systems of water governance

Contemporary water governance systems are complex, involving various levels of government and stakeholders: anywhere from two to over ten different authorities are involved in water decision-making in European countries (OECD, 2011). However, the multifaceted nature of many water governance systems does not in itself imply excessive complexity or fragmentation. Instead, it illustrates the current reality of multi-stakeholder and multi-level approaches in use, which vary depending on the institutional context of the Member State, such as decentralised or centralised government structures.

Among the myriad of strategies, hybrid water governance emerges as a promising approach to ensuring equality of access to water. Already implemented in many cases across Europe, this governance approach involves greater decentralisation at the local level to strengthen cooperation between community stakeholders, alongside a centralised governance system to ensure compliance with environmental standards and regulations at the national level (Rowbottom et al., 2022; Ricart et al., 2019). These hybrid, multi-level governance systems are a form of what is referred to as multi-level meta-governance, an approach that is effective for its adaptability and capacity to forge effective relationships across authority levels (Meuleman, 2023).

Capturing these governance principles, studies have found polycentric water governance systems to be highly effective in facilitating collaboration between stakeholders (Pahl-Wostl and Knieper, 2023). For instance, an analysis by Pahl-Wostl and Knieper (2023) of 26 cases of water governance authorities from jurisdictions both within and outside Europe – including polycentric, fragmented, centralised, and centralised rent-seeking regimes – demonstrated that polycentric water governance performed best in terms of facilitating effective coordination. In particular, high-performing cases included the Emscher and Lippe River basins in Germany and Enschede in the Netherlands. Moreover, it has also been found that multi-level water governance systems, especially when developed according to the specific spatial dimension of the water body in question, can better facilitate communication between the different jurisdictions involved in water management, while producing results that strengthen ecological integrity (Newwave, 2020).

Cities take the lead in water allocation

Projections suggest that an increasing proportion of the world's population will live in urban environments (UN Habitat, 2022). In Europe, almost three-quarters of the population already live in urban areas, and this is expected to rise to 80% of all inhabitants by 2050 (European Environment Agency, 2023b). According to a UN report, by 2050, the number of urban inhabitants without access to safely managed water is set to double (UN Habitat, 2022). Another factor to consider is the increase in the number of climate refugees, which the IPCC (2022) projects will rise from 25 million to 1 billion by 2050; many of them will seek refuge in cities from areas made uninhabitable by the effects of climate change. Compounding these trends, EurEau's (2020) assessment of the governance of water services across Europe found that most countries use a mix of public and private management and that, in the case of the former, the responsibility of the public entity often rests with the municipality (e.g. France, Greece, etc.). Given the prominent role of local government in the provision of water services (EurEau, 2020), compounded by projections of greater urbanisation (UN Habitat, 2022), water governance frameworks will be challenged at the local, municipal level, straining its role as a public service provider. This may prompt the need for new or reformed approaches to facilitating local water governance systems to focus on operating effectively at this scale.

<table>
<tr><td></td><td colspan="2">At the same time, however, many European cities have a high concentration of technology and expertise and are well-placed to provide local solutions to environmental challenges (European Environment Agency, 2023b). Accordingly, given that European cities have already taken a leading role in addressing both climate mitigation and adaptation and that Europe is already highly urbanised (European Environment Agency, 2023b), it is likely that they will play an important role in addressing water scarcity and drought issues as well.

An important consideration is whether cities will expand the use of participatory mechanisms in water management in response to the twin challenges of increasing water scarcity and urbanisation. Recognising that different institutional contexts require their own tailored solutions, a study by Romano and Akhmouch (2019) suggests that the path to a more participatory approach to water governance at the city level can yield positive results through the use of multi-stakeholder dialogues, with the aim of better informing municipal policymakers about stakeholder expectations on how water governance can better serve them.

Cascading crises caused by water scarcity and its wider implications

The future stability of water governance and wider democratic structures is increasingly threatened by the complex interplay of cascading crises. Lawrence et al. (2020) highlight the diffusion of climate change impacts through interconnected systems, creating cascades that extend beyond the initial environmental disruption. These cascades, exacerbated by extreme weather events such as droughts, present challenges that can affect a broad cross-section of different sectors, complicating traditional risk management approaches (Niggli et al., 2022).

For example, extreme weather events such as prolonged droughts can have profound direct and indirect impacts, particularly on sectors such as health, energy, agriculture, and food production (Niggli et al., 2022). Impacts in these sectors can generate economic cascades, affecting public services and potentially shaking the foundations of entire socio-economic systems. For example, prolonged droughts can severely disrupt agricultural productivity, leading to food shortages, economic stress, and increased competition for water – challenges that water governance structures will need to address. Furthermore, Butsch et al. (2023) examine the societal impacts of extreme weather events and identify specific population groups that are disproportionately affected by the health consequences of these environmental stressors in the specific context of water scarcity and drought. Among these, individuals with low socio-economic status are identified as more directly exposed, as they may lack the resources or infrastructure to effectively cope with the impacts, such as limited access to safe drinking water during droughts (Butsch et al., 2023). This reinforces the nuanced socio-economic dimensions of water governance in the face of increasing water scarcity. Looking ahead, the resilience of water governance structures may be tested by the cascading crises of increased water scarcity and prolonged drought.</td></tr>
<tr><td>Potential implications for water resilience, the wider environment and human health</td><td>Opportunities</td><td>Risks</td></tr>
<tr><td>Socio-economic inequalities and poor governance perpetuate unequal access to and use of water</td><td>• Assessments could draw public and political attention to unequal access of water, especially at the local, community (or municipal) level.
• This information could lead to the reform of water</td><td>• Failure to ensure water governance systems are equipped to facilitate equality of access to water could lead to escalating social tensions and widen the gap in access between different socio-economic classes, leading to potential conflict and further water scarcity.</td></tr>
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	governance systems, in particular to ensure that people of higher socio-economic status do not have greater access to water resources at the expense of less affluent individuals.	• Widening socio-economic disparities could exacerbate health risks and health disparities for populations already suffering from poor access to clean water and sanitation (see Issue 1 on the interrelated challenge of water scarcity and water quality).
In some areas, escalating inter-group conflicts lead to collapse of local or regional water governance systems	• Heightened awareness of the potential for conflict encourages proactive steps to establish stronger governance systems that better manage water resources and distribute access to water more equitably.	• The breakdown of water governance could lead to a 'tragedy of the commons' scenario, where unregulated use of water resources results in their more rapid depletion. • Collapse of governance systems could lead to short-term, self-interest driven decisions by competing stakeholders, prioritising short-term consumption over long-term sustainability. If political parties take positions with different stakeholders, this may even affect electoral results. • Deepening mistrust between local stakeholders and decision-makers makes it more difficult to establish effective water governance in the future, thereby entrenching a broken water management system.
Limited water resources are not evenly shared among economic sectors and industries, leading to job losses	• Water-intensive industries innovate and diversify to reduce their water reliance, which may stimulate entirely new sectors and jobs. • Protection of water ecosystems via remediation of externalities, prevention, and good land management may help maintain ecosystem services for all economic sectors in the area. For instance, the recovery of Lake Balaton in Hungary demonstrates the positive synergies that can result from the recovery of an aquatic ecosystem (ESPON, 2021).	• The economic impacts could mean that certain sectors that depend on water for their operations, such as agriculture and many manufacturing processes essential to the global economy (e.g. electric cars, semiconductors), could face increased instability, leading to job losses. • Reduced access to water increases the cost of doing business, which in turn increases the price of goods and services in water-intensive sectors of the economy, leading to inflation. • Decreasing water availability in water-stressed regions, particularly in southern Europe, could lead to the relocation of water-intensive industries, resulting in job losses and economic downturns in certain communities and regions. • Depletion of water ecosystems due to intensive agriculture and poor land management negatively impact the residential, tourism, and fishery sectors. For example, the Doñana National Park World Heritage Site in southern Spain has been adversely impacted by the over-abstraction of groundwater (Camacho et al., 2022), while the Mar Menor lagoon in the Murica region of south-eastern Spain suffered from a decline in ecological status due to agricultural pollution (Policy Department for Citizens'

		Rights and Constitutional Affairs, 2022).
Participatory water governance approaches are widely adopted in areas at risk of water scarcity and drought	• Participatory water governance models at the local level can increase the involvement of community stakeholders, facilitate greater cooperation, and reduce conflict, leading to locally appropriate solutions to water scarcity. • Greater cooperation can promote innovative, community-based solutions among key local actors that create alternative water sources (see Issue 2 on water sources). • Greater participation among local stakeholders encourages experimentation with new techniques in sectors such as agriculture (see Issue 7). • Similarly, the participatory spirit of this new approach to water governance may establish a more holistic community-wide approach to protecting local environmental spaces, including forests and wetlands. • Greater stakeholder involvement contributes to deeper appreciation of water among local inhabitants, who then place a higher value on the health and protection of their community's waters (see Issue 5 on societal change). • Local governance approaches lead to a wider adoption of circular methods for water, increasing efficiency (see Issue 3 on the circular economy and water)	• Potential barriers to implementing more participatory water governance models include resistance from stakeholders who benefit from the current system and conflicts between local actors due to diverging interests. • Participatory forums used for local water governance systems are captured by the interests of powerful industry actors (e.g. agriculture), resulting in an erosion of trust and legitimacy among other involved stakeholders (e.g. local residents). • The legitimacy of scientific advisory panels is challenged due to a biased selection of their members or to external political factors, undermining their credibility. • Many local water governance systems may turn out to be ineffective in addressing water conflicts, adding a layer to a complex governance system that is unable to reach decisions. • The social and economic interests of the local or regional stakeholders involved are prioritised, resulting in reduced water availability and compromised ecological integrity. For instance, in the case of farmers in Spain protesting government plans to maintain minimum ecological water levels (Reuters 2023b), an alternative water governance approach with stronger participatory tools might have led to an outcome more in line with farmers' preferences, resulting in a degradation of ecological status. This is of particular concern in the context of transboundary rivers, where upstream decisions to increase water abstraction can adversely impact downstream communities, underscoring the importance of pan-regional arbitration to ensure fair and sustainable water distribution (see Issue 10 on future water-related disputes and geopolitical conflicts driving transboundary cooperation on water).
Existing water governance systems shift towards more decentralised, multi-level models	• Improved communications between jurisdictions responsible for decisions involving water bodies (Newwave, 2020). • Cooperation between stakeholders in the community is strengthened	• Lacking sufficient guidelines on practical implementation from higher levels of government, a decentralisation of decision-making authority at the local level can lead to ineffective water management outcomes (Amaruzaman et al., 2022).

	while maintaining regulatory compliance with EU and national environmental standards (Pahl-Wostl and Knieper, 2023).	• Giving more decision-making power to local government does not necessarily ensure fair and equitable access to water, as a decentralised approach may lead to an unequal distribution of power, favouring more powerful local stakeholders over others. • Decentralisation leads to greater confusion over the water management responsibilities and mandate of different levels of government, stalling action (Amaruzaman et al., 2022).
A transition from demand-based to sufficiency-based water governance takes hold	• In response to changing expectations of water availability, sufficiency-based governance may encourage agriculture and industries where water is an essential input to develop innovations, such as more water-efficient technologies. • Sufficiency-based governance could encourage more water-efficient consumer products, thereby having a wider impact on reducing water use.	• The shift from current demand-based to sufficiency-based water governance could exacerbate tensions between stakeholders and competing water users at the local and regional levels over different definitions of what should constitute sufficient water use.
As cities grow, so does their role in managing equitable access to water	• Municipal governments successfully implement innovative water management strategies, informed by a wide range of stakeholders and technologies (see Issue 6 on water resilient cities). • Cities could invest in innovative techniques such as urban hydroponics, where plants are grown in a soil-less system, and vertical farming, where crops are grown indoors in vertically stacked layers to minimise space. These investments could help overcome current barriers to wider adoption, such as high start-up costs and energy demands, leading to greater scalability. This in turn could increase water efficiency and lead to improved self-sufficiency at the level of individual cities. • Cities can restore water ecosystems and implement nature-based solutions to improve the quality of drinking water and promote the use of tap water. The success of this strategy has been exhibited in the case of	• The significant scale and diversity of competing water users in cities may overwhelm their capacity to facilitate equitable access. • Furthermore, if water management challenges accelerate in severity, they could contribute to widening inequalities in access to water in urban areas in Europe, as in the case of Monterrey and Cape Town (described above). • Managing the water resource needs of rural agricultural areas in the face of continued urban expansion could become a growing challenge. The water demands that arise from urban growth may increasingly compete with the rural water needs of the same region, which are crucial for agriculture and impact food production. If not managed carefully, this imbalance negatively impacts food security, as urban agriculture alone may not be sufficient to achieve self-sufficiency. • Priority given to urban areas for water resources may deprive water-dependent ecosystems (such as rivers, lakes, and wetlands) of water, harming biodiversity. • Efforts to adopt participatory approaches to water governance can lead to conflicts due to competing interests between the needs and

<table>
<tr><td></td><td>Lahti, Finland, whose recovery of the Vesijärvi lake contributed to its designation as the 2021 European Green Capital (Green Lahti, n.d.).
• Cities can develop the necessary infrastructure on a large scale to treat and reuse wastewater, including runoff water – for example, facilitating indirect infiltration, as demonstrated in Grenoble, France, the 2022 European Green Capital (Green Grenoble 2022, 2022). Together, these actions could reduce pressure on limited freshwater sources (see Issue 5 on changes in society).</td><td>values of different water users.
• The adoption of participatory approaches to water governance in cities can lead to water management decisions that prioritise the needs of the largest or most influential community actors at the expense of ecological integrity.</td></tr>
<tr><td>Timeframe of emergence</td><td colspan="2">Challenges to the governance of equal access to water are already emerging and likely to accelerate in the short term (1-5 years), particularly in parts of southern Europe that are already vulnerable to water scarcity (e.g. Spain and Greece).

In the long term, projections of climate impacts over the coming decades to 2050 and beyond suggest that water scarcity and droughts will become increasingly frequent, severe, and longer in duration. The emergence of this problem is expected to be particularly acute in southern Europe, affecting a growing proportion of the respective populations and economic sectors of the countries concerned, especially agriculture.

Consequently, challenges to existing water governance systems are likely to grow, which will increase the need for new approaches.</td></tr>
<tr><td>Uncertainties</td><td colspan="2">While current climate projections indicate that southern European countries such as Spain and Greece are expected to face the most severe impacts of water scarcity in the EU (EEA, 2021), these challenges are not limited to these countries. Given the unpredictability and uncertainty of future environmental conditions, all of Europe is likely to face more extreme droughts in addition to changing precipitation patterns, posing broad challenges for water management across the Continent. For example, the impacts of climate change have accelerated in recent years faster than predicted by scientific climate models (Tollefson, 2022). Therefore, when, where, and to what extent water governance systems in these already water-stressed communities will be challenged further may come sooner and with greater intensity than anticipated (Harvey, 2023).

Studies have noted the lack of research on how to operationalise more locally decentralised water governance models on a wider scale (Pahl-Wostl and Knieper, 2023; Di Vaio et al., 2021). The limited number of studies of current examples have identified the benefits of more localised governance models with greater autonomy that can foster collaboration between community stakeholders. However, the exact pathways that would make this possible are not well understood, thereby contributing to a significant degree of uncertainty as to the extent of future adoption of more decentralised and participatory water governance models (Pahl-Wostl and Knieper, 2023).

The WFD, the central legal framework for water management in the EU, has encouraged river basin management plans that use participatory processes to inform and actively engage a range of stakeholders in water management (Jager et al., 2016). While the WFD has encouraged greater stakeholder involvement in river basin-level planning, the extent of its impact on addressing specific challenges such as water scarcity, as opposed to more conventionally identified environmental pressures such as flooding and water quality, is less certain. Furthermore, it is not known to what extent participatory governance approaches, such as river contracts,</td></tr>
</table>

	are well suited to managing water scarcity specifically, as opposed to other challenges such as flooding, biodiversity loss and coastal erosion – areas in which where they have had some success (Caneva et al., 2021; Rossi, 2022). A critical element inherent in participatory approaches to water governance systems is cooperation and collaboration between different local stakeholders with competing needs for water use. However, the ability of such participatory approaches to manage what could, over time, evolve into high-conflict situations between competing water users (e.g. agriculture, manufacturing, energy, households, etc.) in a context of limited supply is largely untested, contributing to greater uncertainty. Therefore, the ability of river contracts and other participatory models to facilitate equal access to water better than current governance systems, especially in the face of water scarcity, is uncertain.
Additional research or evidence that may be needed	**Operationalising other forms of water governance systems** Studies on how more participatory water governance models can better achieve equality of access to and use of water have shown that more research is needed on exactly *how* to operationalise principles of cooperation, coordination, and stakeholder consultation between local actors in water resource management on a wider scale (Di Vaio et al., 2021). Research on participatory river contracts and their effectiveness in governing equitable access to water, as well as more water quantity-based issues as the key policy outcome benchmark, would add significant value. Furthermore, the examples in the literature have focused on a limited number of cases, many of them in Italy; a better understanding of how different models of participatory water governance can work in different environmental and institutional contexts across Europe would be useful. In turn, an improved understanding of the key factors for the success of such models would add significant value to enabling more widespread implementation. Not only research but practical experimentation with different participatory methods would be valuable. **City-centric water governance challenges and opportunities** Cities play a critical role in managing the competing demands and interests for water, using the scope of their administrative powers. This includes their role as public service providers, where they can impose water restrictions for certain use cases, as well as urban planning and development, which requires balancing the aspirations of a city's future with the need to maintain its water supply (Garcia et al., 2019). With projections that an increasing proportion of the world's population will live in urban environments over time (UN Habitat, 2022), further research is needed on how cities can use the available policy tools to help ensure equitable access to water. This research could focus on approaches to water governance that are uniquely suited to the difficulties faced by city governments in managing the interests and demands of their key stakeholders, such as the public, businesses, and special interest groups. Furthermore, in recognising that rural regions are often the source of a significant proportion of water resources, it is crucial to better understand the future interplay between urban and rural areas as the increasing water demands of the former are placed on the latter. **Participatory approaches in a multi-level governance system** Europe's multi-level governance of water starts at the EU level and extends to national, regional, and local actions. Future research should therefore focus on integrating more robust local, both rural and urban participatory water governance systems into EU and national frameworks, taking into account the cultural context. For instance, the feasibility and effectiveness of bottom-up approaches may vary based on societal and institutional norms; some regions may be more accustomed to grassroots initiatives, while others may continue to rely on stronger central government intervention to maintain a greater sense of fairness. As such, future research should better identify the conditions under which a shift from top-down to bottom-up approaches can work effectively, recognising the region-specific, socio-cultural factors that

	influence such transitions to meet the diverse needs of all local stakeholders. **The impact of socio-economic inequalities on access to water in Europe** Extensive research on the critical water shortage in Cape Town, South Africa demonstrates how wealthier residents consumed significantly more water than less economically advantaged residents and were a significant contributor to the crisis (Savelli et al., 2023). However, comparable research on how socio-economic inequalities impede equality of access to water in a European context is far more limited.
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Issue 5: Will societal change drive water resilience or will our shared ambition for water change society?	
Emerging issue description	Water plays a vital role in ecosystem maintenance and human life, influencing public health and living standards (Fan et al., 2014; Singha et al., 2022). This issue delves into one aspect of the intricate relationship between societal change and water resilience, examining how, amidst accelerating climate and environmental change, greater societal awareness of water could influence water consumption behaviours and physical systems – as well as the legal systems of both the European Union and the individual Member States. Water conservation is crucial to ensure the availability of this precious resource in the future (Singha et al., 2022). Understanding the factors that shape water consumption and drive both individual and collective actions for its preservation is of paramount importance (Savari et al., 2022). A growing number of environmental studies highlight the importance of psychological and sociological factors, such as attitudes, beliefs, values, norms, behavioural control, emotion, and environmental awareness, which play a pivotal role in shaping our relationship with water (Singha et al., 2022). Research has shown that awareness of water issues can lead to water conservation behaviours (Corral-Verdugo et al., 2002; Singha et al., 2022). This is even more important considering the multiplicative effect of behavioural changes. Individuals acquire knowledge not solely through personal experiences but also by observing and learning from the outcomes and experiences of others: therefore, when people observe relatives, friends, and acquaintances applying water conservation behaviours, their motivation increases to do the same (van Valkengoed and Steg, 2019; Savari et al., 2022). Peer pressure within social networks may thus drive behavioural changes and create a culture of water conservation, reinforcing resilience-oriented actions within society. Furthermore, when we consider that residential water demand is often resistant to economic incentives due to factors like non-salient bills, misinformed customers, and price misperceptions (Bruno and Jessoe, 2021), the role of social influence becomes even more pronounced. In many parts of Europe, water use patterns are unsustainable or at risk of becoming unsustainable, in part where climate change may reduce overall water availability or make precipitation more variable (see Issue 1 as well as other issues and the context section). These patterns are rooted in societal values that (at least in developed societies) do not sufficiently envision or accept limitations on water consumption, whether at an individual or collective level (Savari et al., 2022). However, increasing awareness of water scarcity has the potential to catalyse a shift in these values. Awareness is a first step, and to encourage the adoption of sustainable behaviours at the societal level, part of the solution may be to shift norms through visible, clearly articulated individual actions (Kubit, 2020). In this way, such changes will go beyond individual behavioural changes and extend to various sectors of society and the economy. This issue, therefore, centres its focus on how heightened societal awareness can trigger transformative shifts and yield significant outcomes in two critical domains: on the one hand, our urban water-use systems and infrastructure (including domestic and industrial water use); and on the

	other, our legal frameworks and legal tools for protecting ecosystems and water bodies.
Key drivers: what is driving the emergence of this issue?	**Climate change and water scarcity increasingly affect people and communities** The latest EEA assessment on water stress in Europe affirms that droughts and water scarcity are no longer rare or extreme events, and approximately 20% of the European territory and 30% of Europeans experience water stress annually (EEA, 2021). Climate change is expected to exacerbate this issue – as droughts are increasing in frequency, magnitude, and impact – in particular in southern and south-western Europe, where river discharge (flow volume) during summer could decline by up to 40 % under a 3°C temperature rise scenario (EEA, 2021). These drought episodes and related water stress cause communities and individuals to directly experience the impacts of limited water availability. Examples of such impacts at community level are the decision of Milan's mayor, during a major drought in 2022, to shut off public decorative fountains and impose restrictions on water use (Associated Press, 2022). This measure was adopted by many local and regional governments in Italy – such as Emilia Romagna, Piemonte, and Campania (Skytg24, 2022) – and Europe (The Brussels Times, 2022). Similar actions were already in place in Rome during a serious drought in 2017, which obliged the city to shut down public drinking fountains (Hughes, 2022). In March 2023, the Government of Catalonia imposed severe restrictions on water use amidst a serious drought; among the restrictions, the City Council decided to stop watering lawns in public parks to conserve drinking water and to turn off the city's decorative fountains (Iolov, 2023). In many European cities, public fountains are landmarks in the cityscape, often located in city squares where people come to meet, and they are symbols of cultural heritage: for many city dwellers, they are a key interaction with water, and their temporary closure can underline the severity of drought events. This is also because public fountains can provide much-needed relief from heat in the city by offering opportunities for cooling, as flowing water reduces air temperature through evaporation, heat absorption, and transport; in some locations, these fountains also provide drinking water, which can help residents and visitors during hot periods (Climate ADAPT, 2023). **Growing concern across society over environmental and climate challenges** Increasingly frequent instances of drought and water scarcity are among the events that most raise societal awareness of ongoing climate change. According to the EEA's European Environment State and Outlook Report (SOER) 2020, knowledge about systemic challenges in the context of tackling climate change is growing and European citizens are increasingly voicing their frustration with the shortfalls in environmental and climate governance (EEA, 2019a). In the 2019 Eurobarometer survey 'Attitudes of Europeans towards the Environment', a majority of people in all EU countries (53%) affirmed that protecting the environment is important to them personally, with over half of those rating it as very important. Around three-quarters (76%) saw climate change as a very serious problem in their country and a similar proportion (77%) considered it a serious problem for the EU as a whole (Eurobarometer, 2020). As individuals become more informed and conscious of climate change and its impacts,

they may develop a deeper understanding of the broader range of environmental impacts and issues involved, including the links between climate change and water scarcity. As a result, they may be more likely to actively engage in efforts to address these issues and support initiatives that promote water conservation and sustainable use of water. However, the relationship between increased information about environmental and climate challenges and changes in behaviour is not straightforward. Quantifying behavioural responses remains challenging (Blandino, 2023), and the extent and consistency of behavioural changes can vary depending on cultural and demographic factors (for further discussion, see the section on uncertainties below). Previous FORENV exercises have also warned of the risk that too much information about environmental issues could create a cacophony of different narratives, potentially creating confusion and even apathy, at least for some citizens (EC, 2022).

NGO actions to raise public awareness

NGOs and civil society groups have played a key role in raising awareness of environmental and climate issues and changing public attitudes. While many NGOs warn of the impacts of climate change, there are also growing examples of NGOs launching campaigns, outreach programmes, and educational activities to promote water conservation and sustainable management. Their work encourages individuals and households to adopt new types of behaviour, while drawing attention to water issues and engaging communities in addressing challenges. As the problem of water scarcity has increased, efforts to reduce water demand by raising awareness of water conservation and promoting water conservation behaviours have multiplied (Fan et al., 2014).

One example is the European Pact for Water, an informal coordination and advocacy network established in January 2016. It aims to create Europe-wide Aquawareness – promoting the importance of water and sanitation, disseminating information, building capacity, and facilitating collaborative efforts to achieve the goals outlined in international and European agendas concerning water-related issues (EPfW, n.d.). Similar activities can be found at national level. In Belgium, Join For Water works together with education bodies, civil society organisations, companies, and local authorities to raise awareness on water scarcity among citizens, with the aim of changing behaviours and building conscious consumption (Join for Water, n.d.). In Italy, Fondo per l'Ambiente Italiano (FAI) is a non-profit foundation with the aim of protecting and enhancing Italy's historical, artistic, and landscape heritage. It spreads awareness among citizens of the value of water and their consumption by inviting them to save, recover, and reuse it, promoting conscious and virtuous behaviour, trying to build what it calls hydro-activism (FAI, n.d.). Art initiatives are also raising awareness around topics such as water resilience and droughts (Treeartfestival, n.d.).

NGOs are not the only groups raising awareness and promoting changes in behaviour. Among other groups in society, some governments have also acted, as have certain scientific communities. For instance, four Knowledge and Innovation Communities joined forces to establish a group of experts on water scarcity in southern Europe; they have organised workshops and engaged in events and media to raise awareness about water scarcity among public bodies, stakeholders, and citizens across different regions

(EIT Food, 2020). Water companies and providers may also play an active role in this context. For instance, Affinity Water (a UK supplier of drinking water) teamed up with the company Behavioural Insights Team and design agency Outré Creative to redesign customer bills using behavioural insights to make the perception of water consumption more intuitive, achieving a 0.8%-0.9% reduction in consumption compared to a normal bill (BI Team, 2022).

Expansion of rights and legal protection that may influence environmental law, affecting the way we view and interact with water bodies and resources

Alongside the growing awareness of environmental issues in society, there has been a movement to not only strengthen legal protection for the environment but also address environmental issues through recognising new rights. This has occurred as part of a broader trend in recent years for the expansion of rights and legal protections that can be observed in various areas of law, such as human rights, animal welfare, indigenous rights, and social justice. This trend reflects the evolving values and priorities of societies worldwide. As societies evolve and become more conscious of the interconnectedness between humans, ecosystems (including those related to water), and the environment, there is a growing recognition that legal systems should reflect these interdependencies (UN, n.d.).

This broader trend of recognising and protecting rights has the potential to influence the development of new rights from an environmental perspective. Environmental protection has undergone several stages, starting from a scattered set of rules, going through integrated environmental policies and international cooperation agreements (Orlando, 2013), and now developing toward climate change litigation. This is an ongoing, extensive trend that will probably continue to evolve and trigger further changes in the legal systems of both the European Union and individual Member States (Cassotta, 2021).

The right to clean drinking water is already affirmed in the EU legal system (see Issue 4). Economic and environmental analysis has highlighted the importance of ecosystem services, estimating the value of ecosystems for society (Keenan et al., 2019). At EU level, the Water Framework Directive affirms the polluter and user pays principles and calls for water pricing policies that incorporate environmental and resource costs as well as financial costs, with the goal of promoting efficient water use.

The rights discussed here go further. They are, on the one hand, the rights of citizens to a clean environment and, on the other, rights of the environment itself (known as rights of nature (RoN)).

For the first topic, over 80% of UN member states have recognised the right to a safe, clean, healthy, and sustainable environment (UNEP, 2020). Nineteen out of 27 EU countries have enshrined this right in their constitutions (some implicitly) and 17 in their national law (European Parliament, 2021b), such as Finland (UN, 2020b), Slovenia, and Hungary (UN, 2020a) (as discussed under Issue 4 - Emerging challenges for the governance and equality of access and use of water at the local and regional level). However, constitutional inclusion alone may not adequately support claims of human rights violations due to climate change, considering its extraterritorial impacts (Cima, 2022). There has recently

	been an important development at international level, as the United Nations General Assembly adopted a resolution recognising the human right to a clean, healthy, and sustainable environment, calling upon states to scale up their efforts in this regard (UN, 2022). This universal recognition could drive transformative change (IISD, 2022) worldwide and in the EU. In 2021, the European Parliament passed a resolution advocating for the recognition of the right to a healthy environment in the EU's Charter of Fundamental Rights (European Parliament, 2021a). Water is a fundamental component of a healthy environment and therefore such recognition may lead to a range of positive outcomes for it (see below for future developments). Inger Andersen, UNEP Executive Director, affirmed that this resolution has historical potential, sending the message that "nobody can take nature, clean air and water, or a stable climate away from us – at least, not without a fight" (UNEP, 2022). The second area is the possible recognition of the rights of natural bodies, such as rivers, lakes, and other water sources. The RoN concept aims to grant legal entitlements to natural features (including water bodies), enabling individuals or designated entities to sue on their behalf for their preservation (Stone, 1972; Lawton, 2023). RoN respect and protect the environment for its autonomous dignity and not only for its utilitarian aspect and combat the treatment of nature as mere property; the latter view has driven the triple planetary crises of climate change, biodiversity loss, and waste and pollution (Petel, 2018; Lawton, 2023). In other words, these steps move from increased environmental awareness to the next level: changing societal attitudes towards the environment. In recent decades, Stone's theory has been put into practice. Examples include the 2008 Ecuadorian Constitution (Republic of Ecuador, 2008); the Law on the Rights of Mother Earth approved in Bolivia (Bolivia, 2010); and the recognition of rights to national parks and rivers in New Zealand (Parliament of New Zealand, 2014; 2017) and to the Ganges River India (High Court of Uttarakhand, 2017). In the years since the implementation of national legislation recognising the rights of nature, there have been notable outcomes. For instance, in Ecuador, these rights have been cited in several cases where nature has been granted legal standing in court, allowing affected ecosystems to be represented and defended in legal proceedings (Berros, 2021). The first successful case concerned the Vilcabamba River, where citizens demanded protection for the river against an environmentally damaging road project. The court ruled in favour of the river, emphasising the importance of precautionary measures and the responsibility of the government to protect the environment (Greene, 2011). In New Zealand, the recognition of the rights of national parks and rivers has empowered indigenous communities to actively participate in conservation efforts and decision-making processes, thus fostering more bottom-up governance (Talbot-Jones and Bennett, 2022). This doctrine is starting to gain ground in Europe, as summarised in the Database of European Rights of Nature Initiatives (IACL-IADC Blog, 2022). Spain has given protected status to the Mar Menor Lagoon; while it is not recognised as a full person in law, the ecosystem now has a 'legal right to exist, evolve naturally and be restored' and it also has legal guardians (Science, 2022). Another example is in the Netherlands, where a group of campaigners is proposing that the North Sea should be recognised as a

	legal person (Bäunker, 2023). Similar calls arose in Poland concerning the Oder River (Osoba Odra, 2022) after a massive fish kill, totalling 360 tonnes of fish, occurred in July and August 2022. The fish kill was triggered by a significant toxic algal bloom, likely caused by the high salinity resulting from discharges of industrial wastewater (e.g. from activities like mining) with a high salt content (Free et al., 2023). As these examples show, rivers, seas, and other water bodies are prominent among the natural bodies proposed for legal rights. These initiatives represent a potentially significant paradigm shift in societal and legal attitudes towards water and its ecosystems. They emphasise the need for their protection and preservation and – in practice – they mean that any actions or decisions that may adversely impact water bodies will be subject to legal scrutiny and potential intervention by legal guardians or designated protectors. Specifically considering the rights of water bodies, it may be argued that prioritising the establishment of environmental flows – which entail determining the quantity, timing, and quality of water flows necessary to maintain the health and functioning of ecosystems in a natural or near-natural state (Dourado, 2023) – could serve as a foundational step towards invoking the RoN at a later stage. However, the two systems may encounter very similar challenges. Allocating water resources to maintain ecological flows can sometimes conflict with human needs and interests, such as agriculture, industry, and urban development (Maskey et al., 2022; Dourado, 2023). Balancing these human demands while better meeting ecosystems needs can be a complex challenge (Viers, 2017). This happened during the implementation of environmental flows in California, where political and legal battles originated from the complex web of human and natural systems with competing demands for freshwater (Stewart et al., 2020; Dourado, 2023).
How might the issue develop in future?	**Increased social acceptability of new approaches to water use in public spaces** The increase in drought and water scarcity episodes poses a challenge for the future of city parks and fountains amid competing priorities (see also Issue 6 on water resilient cities). Moreover, the use of water in public spaces is a high-profile issue for city governments. Restrictions, however, are likely to exert an adverse influence on the overall quality of life in urban areas. The potential reduction of green and blue spaces due to water deficits could lead to a temporary or permanent curtailment of recreational services offered by these areas. The situation could pose concerns for people's wellbeing, given the evidence supporting the potential benefits of blue spaces for overall health and wellness (Vitale et al., 2022). These issues will probably lead to the emergence of new approaches to water use in public spaces, to maintain the functioning of green and blue areas. Italy's association of amusement parks suggested using filtered seawater at attractions near the coast (Hughes, 2022), though desalination is expensive and is not available for inland areas (Gross, 2022) (see also Issue 2 on new sources of water). As cities and communities grapple with the challenges posed by drought and water scarcity, the adoption of smart irrigation technologies in public parks, such as weather-based controllers and soil moisture sensors (Wright, 2022), may become more prevalent in the future (link to Issue 6 – Water resilient cities – new challenges and

solutions). These technologies can help optimise water use by adjusting irrigation schedules based on actual weather conditions and soil moisture levels. City parks and fountains could also better explore options for recycling and reusing water – such as capturing and treating stormwater runoff for irrigation purposes or using treated wastewater – a technique already used for non-potable water demands (EPA, n.d.). Through these new developments, cities can mitigate the strain on water resources while simultaneously preserving the visual attractiveness and functionality of parks and fountains. The significance of this aspect extends beyond mere functionality; it holds societal importance, as it can foster a higher level of acceptance for these technological changes, given that the aesthetic appeal of these public spaces remains intact.

In the realm of public gardening, low or zero water techniques like xeriscaping may experience increased popularity. Xeriscaping involves designing landscapes that eliminate or reduce the need for irrigation, and it offers environmentally friendly and cost-effective alternatives to traditional gardening methods (Ismaeil and Sobaih, 2022; Allaway, 2022; Yardzen, 2023). While these methods are now used mainly in desert and semi-desert areas, such as the southwestern US, they could spread to many locations in southern Europe and elsewhere, where water scarcity is (or will become) a growing concern.

If the public sphere increasingly adopts these approaches, this could also encourage changes in the private sphere and the way gardens are maintained through a ripple effect and by increasing awareness of and expertise in adapting gardens and public spaces. The use of drinking water for gardening in cities – already restricted during recent (and historic) drought events – could be increasingly regulated. Therefore, techniques such as xeriscaping may become a forced necessity for homeowners, in particular those in southern Europe, as water for non-essential purposes becomes increasingly scarce. This would not only conserve water but also promote more sustainable and responsible water use practices at an individual level.

Some downsides, however, should be noted. Xeriscaping may not have the same cooling effect in cities as traditional green areas, especially in dry climates. Some research has affirmed that xeriscaped landscapes show little ability to cool urban regions; however, these landscapes may be desirable for other reasons such as habitat, aesthetic value, and water conservation (Dialesandro, 2019). Moreover, xeriscapes can be costly to install, particularly when considering the type of rock and its local availability; overall, their installation expense surpasses that of traditional lawns (ION, 2019).

Growing public acceptance of water reuse for households

The global water crisis could force more and more territories to seek unconventional water sources, and this would include the use of reused water (UNESCO, 2023). One of these is highly treated wastewater (Tortajada and van Rensburg, 2020; Liu et al., 2022). (See also Issue 2, which discusses new and alternative sources of water.)

Increased awareness of water scarcity could pave the way to a shift toward conservation and reuse practices (Puchol-Salort et al., 2022). Some studies have already shown that the level of public acceptance of recycled water is influenced more by the perception of the problem than the actual water supply situation (Fielding et al., 2018). Therefore, perceiving water scarcity as an immediate threat to humanity is a crucial factor that can determine acceptance (Gómez-Román et al., 2020). This growing acceptance may lead to the creation of a social norm; since individuals tend to make behavioural decisions consistent with social norms, the acceptance of water will increase even more (Liu et al., 2022). The extent of direct contact between treated wastewater and the human body may be a crucial factor influencing the observed degrees of acceptance (Saurí and Arahuetes, 2019). More precisely, water reuse options are divided between: low-contact uses, such as agricultural irrigation or orchard irrigation; medium-contact uses such as garden irrigation or WC flushing; and high-contact uses such as groundwater recharge for drinking purposes, domestic laundry, or food processing (Friedler et al., 2006).

To date, water reuse in Europe has focused mainly on irrigation, i.e. a low-contact reuse (Meyer, 2023). However, the technology has been proven successful in high-contact use in other parts of the world such as California, Singapore, and Australia, and nothing precludes these developments from taking place in Europe (Gross, 2022; Meyer, 2023). Clearly, these potential developments for households would include bigger changes to the water infrastructure at city and regional scale; these may be difficult to put in practice, above all for old buildings, where retrofitting could be complex and costly. However, it may be easier to integrate such approaches in new developments, encouraging reuse at the household or individual level. At this scale, changes may take the form of recycling water from showers and rooftop rainwater harvesting (Aqua Tech, 2021), which might reach a higher acceptance threshold when used in low-contact reuse contexts.

Implementing these kinds of water reuse technology can, however, involve significant upfront costs, and therefore many individuals or communities might find these investments too challenging, especially in regions where water prices are relatively low. However, it is important to keep in mind that the long-term benefits of water reuse – such as sustainable water management, conserving freshwater resources, and addressing future water scarcity issues – can extend beyond immediate financial returns. To enhance financial viability, government incentives, subsidies, or progressive water pricing structures could be explored to encourage and support the adoption of water reuse systems.

Emergence of new urban developments and urban water systems

As discussed in more detail in Issue 6 on water resilient cities, the form, pattern, and function of urban environments will heavily influence critical social and environmental challenges such as climate change (Keeler et al., 2019). With regard to water, the way in which urban systems are built is considered not sustainable enough to address water scarcity; to cope with this challenge, conventional thinking needs to change (Pokhrel et al., 2022). In other terms, water scarcity can trigger a broad social transformation which may include a rethinking of urban design.

Future urban planning and water systems may encourage the design of water-neutral housing and drive sustainable development (see also Issue 6). For instance, systems such as CityPlan-Water conceptualise water neutrality as a planning approach for new urban developments; the project aims to minimise the effects on urban water security and, if any residual pressures remain, to address them through retrofitting the existing housing stock (Puchol-Salort et al., 2022). Other projects point to the introduction of the innovative ‘one water’ paradigm, which considers urban water as a single entity and aims to unify the management of urban water services (Pokhrel et al., 2022). Such innovations would increase the resilience and reliability of water services. The use of digital technologies (see also Issue 8) could help to implement these approaches.

The above-mentioned innovations and the general rethinking of urban design may also trigger the emergence of urban labs that aim to explore new urban development plans and reuse systems and their social acceptability. These participatory platforms for open innovation can act as facilitators in generating quick urban solutions and supporting experimentation with real users in real contexts (Krebs, 2018; Scholl et al., 2017).

There are, however, some challenges connected to water-neutral urban design. Implementing water-neutral design and rethinking urban water systems often requires a significant overhaul of existing infrastructure. This can be logistically challenging, expensive, and disruptive to communities. Moreover, developing such systems and ensuring their proper functioning and compatibility can be complex from a technical and budgetary point of view.

Greater recognition of the rights of water bodies and the vision of water in society

Despite the strong reputation of the EU environmental law system for environmental protection (Lorubbio et al., 2020), SOER 2020 highlights insufficient progress in addressing environmental challenges (EEA, 2019b). This discrepancy may be attributed, according to some authors, to the limitations of retrospective principles like prevention and precaution, outlined in Article 191 of the Treaty on the Functioning of the European Union (Somsen, 2017). The expansion of environmental rights, specifically RoN and/or the right to a clean and healthy environment, have been proposed for the EU legal system, as they can offer a prospective approach (Somsen, 2017) and may succeed where regular environmental laws fail (Lawton, 2023). These rights may lead to stronger legal protections for water resources and result in the development of prospective legislation and policies which will promote sustainable water management practices. For instance, it may promote greater accountability and responsibility for the protection of water sources; therefore, governments and other stakeholders may be required to take proactive measures to prevent pollution, safeguard water quality, and mitigate the impacts of climate change on water resources.

The recognition of these rights, especially RoN, could shift societal views of water from a focus on human uses to a deeper recognition of its inherent value. These changes could also foster community empowerment: by elevating the place of water and its ecosystems in society, they can foster a sense of responsibility and stewardship towards these vital natural elements (Leonard, 2019). It should be considered that the recognition of these rights and their implications can vary across jurisdictions, as legal frameworks and societal attitudes toward the environment differ. Consequently, the actual impact on water and its place in society will depend on the specific implementation and enforcement of these rights.

Potential implications for water resilience, the wider environment and human health	**Opportunities**	**Risks**
Growing recognition of the rights of natural bodies – in particular those of rivers, lakes, and other water sources – within the European Union	• Promotion of the integration of ecosystem considerations in water management practices (Science, 2022). • Greater success for legal actions against activities that harm or degrade water ecosystems. • Greater emphasis put on the inherent value of water bodies and their need for better protection and restoration; this could drive measures to preserve and rehabilitate aquatic ecosystems, prevent pollution, promote nature-based solutions for floods and drought, reduce habitat destruction, and restore degraded water bodies and aquatic ecosystems. • The use of RoN could support changes in economic sectors with high water use, such as agriculture (see Issue 7). • The introduction of these rights could in turn encourage a new link between nature and society, reversing long-held views of nature as separate from society. • New institutions could be developed to manage the issues arising from RoN, possibly including "nature courts" or "ombudsmen".	• The introduction of RoN could be difficult to balance with the legitimate needs and interests of different people, and may also generate conflicts with existing human rights, such as property rights (LMU, 2022). • The RoN approach may not fit with the anthropological dimensions of long-standing legal systems in Western society (Hermitte, 2011). It could also present challenges in reconciling western cultural heritage, such as the significance of urban fountains, and lifestyle practices with the concept of granting legal rights to natural entities. It may also cause negative impacts on economic activities, such as agriculture, fishing, navigation, hydropower generation, and in turn, further conflicts. • It may be difficult to integrate these new rights into the current EU legal framework: confusion and legal uncertainty could arise. • Differing perspectives on the recognition of RoN and their scope among Member States, stakeholders, and society as a whole may make achieving consensus among these actors challenging.
Treated wastewater reuse is increasingly used for drinking water supplies	• Design of more water efficient homes and/or cities. • Available water resources are used efficiently, minimising reliance on freshwater sources (Cagno et al., 2022). • Strengthening of water security, reducing vulnerability to water shortages, droughts, and climate variability. • Enhanced protection of the environment through reducing the discharge of treated wastewater into water bodies.	• Greater reception and acceptance of water reuse for indirect uses of water from the public but strong rejection of direct reuse (Faria and Naval, 2022). In some studies, health risk is a major concern for people when it comes to reusing water for drinking purposes (Vila-Tojo et al., 2022; Fielding et al., 2018); this is the case even if recycled wastewater is not only as safe to drink as conventional potable water, but potentially even less toxic than many sources of water we already consume daily

		(Lau et al., 2023). This is a relevant risk since mistrust and prejudice may pose significant challenge to projects' implementation (Liu et al., 2022). • Water reuse schemes and projects still face substantial economic challenges (Meyer, 2023). Implementing water reuse for potable systems often requires sophisticated treatment processes and infrastructure upgrades that can pose technical challenges and financial burdens, given the high initial investment in the absence of subsidies, particularly for smaller communities or regions with limited resources (Cagno et al., 2022).
Houses and apartment buildings increasingly install methods to recirculate water, contributing to a more sustainable and responsible water use culture in society	• New products are developed, such as 'smart' showers, toilets, and appliances that reduce water use during drought and water scarcity periods. • Household water use of freshwater resources declines steadily as water reuse grows. • Implementing water recirculation methods fosters community engagement and collaboration, enabling neighbourhoods to develop shared water recycling systems and strengthening community bonds. • Through these new installations, residents perceive the importance of water conservation and the role they play in mitigating water scarcity.	• High-income households are better able to adopt new reuse methods, and thus are more resilient in the face of drought events and water scarcity periods than lower-income households. • A backlash against water reuse slows adoption of these methods in households. • Technical complexities in the implementation of these new methods, especially for existing buildings, slow adoption.
Economic activities largely dependent on water, such as car washing (Ramos 2022), adapt their business to better reflect the changing societal perspective toward water use	• Innovative approaches can help save significant amounts of water, such as the No H2O process tested in the United States to wash cars (Ramos, 2022). • Businesses that proactively adapt their operations to align with changing societal attitudes toward water use can differentiate themselves in the market and attract environmentally conscious customers who prioritise sustainable practices.	• Transitioning to low or zero-water use alternatives may require upfront investment in new technologies, infrastructure, or employee training. This initial investment may pose financial challenges and operational disruptions for some businesses (Ekins et al., 2019). • Certain low or zero-water alternatives might involve the use of chemical solutions, potentially leading to higher concentrations of these substances entering the

	• Embracing sustainable water practices can provide businesses with a competitive advantage over their rivals. • The need to adapt to changing societal perspectives on water use can drive innovation within industries dependent on water.	environment compared to traditional water-diluted methods, which could raise environmental concerns. • If the forced obsolescence of water dependant services and the related changes will be so strong that it will also quickly lead to modifications in the regulatory frameworks, businesses that fail to adapt to new regulations and requirements may face penalties or legal challenges, on top of financial and technical ones. • The effects may trigger a consumer backlash, alienating those who do not prioritise environmental concerns.
The societal change to a low-water use future leads to consumer-driven change in the context of the fashion industry, promoting slow fashion and second-hand purchases	• This shift presents an opportunity to reduce water consumption, considering that the fashion industry annually requires 79 billion cubic meters of water (about 20% of the world's total water consumption) (Centobelli et al., 2022). It could then alleviate the industry's pressure on water resources. • The change may help reduce water pollution, as the fashion industry is responsible of 20% of global clean water pollution (European Parliament, 2020). • Slow fashion aims also to bring benefits which go beyond the environment, such as providing workers with living wages and healthy working conditions (Vito, 2022). • This societal trend can expand the second-hand market and create opportunities for businesses specialising in vintage clothing, thrift stores, online marketplaces for pre-owned fashion, and clothing rental services. Second-hand purchases are beneficial for the environment, reducing water use and waste (Centobelli et al., 2022). • The need for low-water use practices can drive research and development in innovative textile	• Transitioning to low-water use practices and promoting slow fashion may pose economic challenges to business that want to adapt to this new trend, since it requires significant investments in new technologies, supply chain adjustments, and consumer education. • While there is a growing interest in sustainable fashion, not all consumers may be willing to change their purchasing habits. Slow fashion clothes are in general more expensive than fast fashion ones. This is because slow fashion focuses on producing high-quality, durable clothing in small quantities, which requires more time and better craftsmanship, durable materials, and limited production. This results in higher costs for slow fashion items compared to mass-produced and low-cost fast fashion alternatives; moreover, slow fashion pays more attention to working conditions, which can contribute to higher production costs and, consequently, higher prices for slow fashion items (Jung and Jin, 2016). As a consequence, some people may prioritise affordability and money saving over

	technologies and thus stimulate technological advancements in the fashion industry.	sustainable options (Jung and Jin, 2016). • The increase in use of peer-to-peer online platforms for second-hand clothes, such as Vinted, highlights a potential downside: the acceleration of buying and selling activities. Active sellers are more inclined to purchase items again to stay competitive. For instance, when an item is added to a wish list and purchased by another user, it remains on the wish list with the label 'sold', which may lead to users feeling frustrated about missed opportunities. This may cause impulsive purchases driven by the fear of missing out, rather than giving buyers the time to reflect on the necessity of their purchase. This consumerism is contrary to sustainability. It is encouraged by the platforms themselves, as they rely on increased activities to maintain competitiveness in the market. This acceleration in the consumption and turnover of items may have negative implications for sustainability and environmental concerns (Juge et al., 2022; Parguel et al., 2017). • As sustainable fashion gains popularity, there is a risk of counterfeit products and greenwashing practices, where companies falsely claim their products are sustainable. This can mislead consumers and undermine the credibility of the movement towards low water use and sustainable fashion.

Timeframe of emergence	In the short term, the increasing frequency of droughts and water shortages can lead to greater individual awareness of water issues and to temporary changes in behaviour. However, the issue is expected to emerge more prominently in the long term, with repeated water crises leading to growing awareness and more lasting changes in behaviour that will embed sustainable water practices in the daily routines of a large share of the population. It may take a considerable amount of time to reshape cultural norms and, from there, to see changes in both legal rights and water infrastructure.
Uncertainties	Even though, as demonstrated above, several studies point to the fact that greater awareness of water scarcity as an issue may lead to changing perceptions of water use and driving water resilience, several uncertainties

	accompany this issue. First, behavioural response remains a variable factor that is very difficult to quantify (Blandino, 2023). Therefore, while greater awareness can lead to behavioural changes, the extent and consistency of those changes can vary. Moreover, cultural factors and demographic variables such as gender and age can significantly impact behavioural change dynamics (Fan et al., 2014). Besides, increasing awareness of water scarcity and promoting behavioural change carry potential risks. In some cases, heightened awareness might inadvertently trigger behaviours such as hoarding or securing water rights to the exclusion of others, highlighting the importance of carefully considering the broader societal implications of promoting water resilience initiatives. When examining the societal dimension of water use, it is important to consider the entire production-consumption chain and not only water use *per se*. The production and consumption of goods and services have a significant impact on water usage and contribute to an overall water footprint. The complexity of the production-consumption chain can introduce uncertainties in impact analysis, making it challenging to fully grasp the water footprint of various products and activities. Understanding and managing these uncertainties are essential for making informed decisions and implementing effective water conservation strategies that may – in their turn – influence social behaviour. It should also be considered that, even if there were indeed behavioural changes, there is further uncertainty as to how these might lead to changes in legal rights or in systems for water reuse. Above all, economic considerations come into the spotlight. Implementing changes in legal rights or water reuse systems often requires significant financial investments. The availability of funding and their economic viability is uncertain and can variably impact the feasibility and speed of implementation of changes in society. Moreover, technological limitations must be considered and there may be uncertainties around the availability, scalability, and efficiency of the required technologies; this may impede efficient implementation of widespread changes in water reuse systems. To give a specific example, income growth and water pricing structure (which are variable factors), more so than any of the demographic or building characteristics, impact household adoption of water conservation and reuse technologies, and it is thus uncertain what the result of these impacts will be on the spread of new technologies (Rasoulkhani et al., 2018).
Additional research or evidence that may be needed	**How to implement RoN effectively in European legal systems** As much as RoN may seem (and probably are) effective tools to better protect water bodies and achieve water resilience, they cannot be treated as a panacea. Additional research is needed on how to implement them in practice in legal frameworks, including the European legal framework. A current EU research project, Rivers, is looking at experiences around the world (Rivers, n.d.). At present, a very limited number of proposals can be found in the available literature. In 2017, the NGO Nature's Rights presented a Draft Directive on the Rights of Nature (Ito, 2017). However, this proposal would use secondary legislation to incorporate rights, which would fail to comprehensively implement the fundamental principles underpinning RoN (Borràs, 2016). Another approach is proposed by a study for the European Economic and Social Committee, which suggests inserting RoN through an inter-institutional, non-legislative act called an

EU Charter of the Fundamental Rights of Nature (Lorubbio et al., 2020). Further analysis is needed on the feasibility of such proposals and/or the consideration of other solutions. Further research should also encompass the procedural aspect, since constitutional rights of nature are only going to prove valuable if they are actionable in court (Rühs and Jones, 2016). A water body cannot go directly to court; therefore, a guardianship approach is needed (Stone, 1972). Further analysis should specify who will be the guardian. Among the options proposed, this could be the general public (Lorubbio, 2020), the creation of new representatives such as an Environmental Ombudsman (Darpö, 2021), or the work of environmental NGOs, taking inspiration from Article 11 of the Aarhus Regulation (Borràs, 2016; Jayatilaka and Cliquet, 2017). Additionally, while numerous sources have highlighted the positive aspects of RoN, it is imperative to emphasise the importance of delving into its societal implications. This includes both potential challenges and the consequences for social justice. For instance, one concern is that prioritising RoN might lead to restrictions on resource use and allocation, which could impact industries, jobs, and economic opportunities. In some cases, this might disproportionately affect marginalised communities or individuals who rely on certain resources for their livelihoods. Moreover, conflicts may arise when RoN collide with human rights or property rights. Balancing these interests is a complex task that may have implications for social justice.

Ways to build and improve social acceptance of water reuse for potable systems

As climate change exacerbates issues related to water scarcity, understanding and addressing the social determinants of individual acceptance of reused water will be critical to implementing large-scale water projects and reducing pressure on freshwater resources. While there are already signs of growing acceptance of water reuse, further research is needed to increase public willingness to use recycled water, especially for potable systems. Special attention should be paid to reducing perceptions of health risks. Here, the opinions of the scientific community will be important – however, a key issue may be to ensure public trust in the consensus opinions of scientists (Vila-Tojo et al., 2022; Saurí and Arahuetes, 2019). Ways to build trust in the organisations delivering reused water and in the government agencies responsible for water quality should also be analysed further (Water Reuse Europe, 2021; Saurí and Arahuetes, 2019).

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Issue 6: Water resilient cities - new challenges and solutions	
Emerging issue description	Human civilisation has always relied on access to fresh water to thrive. While they were historically predominantly developed close to water sources, throughout time cities have sought to secure adequate water supplies, as illustrated by Roman aqueducts, Mayan chultuns for collecting and storing rainwater in underground chambers, Egyptian basin irrigation systems, and large, manmade reservoirs such as the West Baray at Angkor. With growing urbanisation combined with the threats posed by climate change, pollution, biodiversity loss, and the decline in natural ecosystems, cities are faced with increasingly pressing water security issues. The EEA estimates that in Europe, water scarcity affected 29% of the EU territory during at least one season in 2019 and, even though estimated water abstraction declined by 15% in the EU between 2000 and 2019 (although these data may omit unregistered abstraction), there has been no overall reduction in the area affected by the water scarcity conditions (EEA, 2023b). While more severe in southern Europe, it is not limited to this region; for example, in western Europe, urban areas with high population density (combined with high levels of abstraction for public water supply, energy, and industry) are a primary cause of water scarcity (EEA, 2023b). While, according to EEA, in 2017 agriculture accounted for 58.3% of water use in Europe (EEA, 2022b), urban areas have the highest water consumption per unit area: water use in urban areas is less overall but is more concentrated than for agriculture. With urban areas being one of the largest collective users of water, improving and changing the ways they acquire, distribute, consume, and discharge water could significantly contribute to achieving water resilience ambitions. In many European cities, modern systems for drinking water and wastewater were introduced in the 1800s, greatly improving public health. Though many improvements have been made since, urban water systems largely retain their original linear design: they take water from rivers or from the ground, distribute it to users, and then collect the wastewater, which is (normally) treated and discharged back to the environment. Today, cities use a range of methods and technologies to collect, conserve, distribute, and supply water. However, to deal with increasing water scarcity in the future, they may need to adopt a range of approaches – either to increase supply or ensure water is used more efficiently, thus reducing demand. Approaches may include trying to meet demand by getting water from distant regions, installing water saving appliances, establishing water saving behaviours, implementing water rationing, modernising infrastructure, rethinking urban planning design, and moving away from the linear approach of current urban water systems to more circular models. This issue explores the ways that European cities might go about tackling water scarcity and achieving water resilience in the future and what challenges and opportunities this may bring for the environment, economy, and society.
Key drivers: what is driving the emergence of this issue?	**Increased water scarcity in cities** Water scarcity in cities is manifested as insufficient quantity but also compromised quality of available water due to contamination from human activity, the effects of climate change, and ecosystem degradation. Challenges such as more frequent droughts, flooding, and extreme temperatures are resulting in damaged water infrastructure, the intrusion of saline water, and the contamination of freshwater sources. Decreasing precipitation and capillary water supply also increase the need for watering city green spaces, maintenance of which is essential to managing water quality and the adverse implications of climate change in the urban environment. Some authors estimate that, as of 2015, only 40% of surface waters (rivers, lakes, and reservoirs), which provide approximately 75% of annual water needs in Europe, had good ecological status (Trémolet and Karres, 2020). The same was reported in the 2018 European waters assessment of status and pressures (EEA, 2018). For drinking and other water needs,

two-thirds of the European population relies on groundwater, which is under increased pressure from pollution and abstraction (EEA, 2020). According to data reported by EU Member States in 2021, '77% of the total groundwater body area was reported to be of good chemical status and 14% of groundwater area failing due to nutrients and 10% due to pesticides' (EEA, 2024). Approximately 38% of groundwater bodies under urban areas were reported to be of less than good chemical status during the WFD RBMP 2nd reporting in 2016 (EEA, personal communication, 13 July 2023). Once such sources are polluted or depleted, restoration is not only expensive; it also takes decades (EEA, 2020). For more on this, Issue 1 explores the interrelated challenge of water quality and quantity.

The EEA's report *Urban adaptation to climate change in Europe* stated that water scarcity in cities affects 'living, working and moving' by posing discomfort and health and safety risks to residents, reducing productivity, causing power and water system failures, and constraining transport, such as inland shipping (EEA, 2016).

Ageing water distribution systems

In many European cities, water infrastructure is old and has already surpassed its intended use life. With some segments in operation for over 100 years, pipeline ageing resulting in pipe corrosion and failure is a significant threat to the efficiency and resilience of urban water systems across Europe (Ramm, 2018). This, coupled with the aggravating effects of extreme weather events (e.g. heatwaves and flooding affecting the soil) and increasingly heavy-load road networks (Barbosa, 2022; Ramm, 2018), is leading to unnecessary water loss (e.g. due to damaged cording[19] and leaky pipes) resulting in inefficient distribution, as well as health risks (Ramm, 2018). In Europe, drinking water losses from the distribution system are estimated to be 30% on average in most countries (EEA, 2020). While this may vary significantly across regions, municipalities, and cites, leakage in urban areas is estimated to be substantially higher, reaching 70-80% in some cities (EEA, 2020). As reported by the EEA, 'finding and repairing leaks is costly, and since the losses do not translate into higher water prices (losses potentially translate to higher subsidies to water companies, which increase either taxes or state borrowing), thereby remaining unnoticed by the public, suppliers are often reluctant to spend money dealing with this problem' (EEA, 2020).

Unsustainable and inefficient water use

Water use becomes unsustainable when it is extracted from the source more quickly than it can be replenished. Unsustainable water use can cause or contribute to problems such as loss of wetlands; low river flow (including exacerbating natural variability); the intrusion of salt water in coastal aquifers; the degradation or loss of groundwater-dependent freshwater, terrestrial ecosystems, and habitats; and even desertification (when overexploitation is accompanied by prolonged droughts over a long period of time) (EEA, 2020). The EEA estimates that about 60% of large European cities (i.e. with populations over 100,000 inhabitants) in total have '140 million people living within or near areas of such groundwater over-exploitation' (EEA, 2020).

According to the EEA (2020), 'reliable data on water use efficiencies by economic sector and European country are not yet available, however large differences in use efficiencies are likely', and the same is likely the case in cities. Gathering and sharing this information will help to achieve more efficient water use across Europe (EEA, 2020).

Urbanisation, population change, urban expansion, and shift in urban demographics

According to the European Commission's Competence Centre on Foresight, Europe's level of urbanisation is expected to reach 83.7% by 2050 (EC, 2020b). With the expansion of urban fabric, built-up areas are likely to comprise 7% of the EU territory by 2030 (EC, 2020b). This is also related

[19] Pipe cord is a threaded pipe and fitting sealant. It is a thread nowadays usually made of polyamide material (e.g. nylon) used for threading pipes and acting as sealant to prevent pipe leakages

to the rising number of smaller and single person households. There were 198 million households in Europe in 2022, with 2.2 members per household on average (Eurostat, 2023). Of these, single adult households without children accounted for 71.9 million, a 30.7% increase from 2009 (Eurostat, 2023). These developments are increasing burdens, not only on urban water infrastructure and supply systems but – with the rising need for urban space – also on non-built-up land such as (but not limited to) green areas within and adjacent to urban centres. Growing built up urban space is increasing surface impermeability in cities and decreasing the capacity (of soil and non-built up green and other surfaces) to retain and filter water. This is increasing the pollution pressures and other risks associated with urban water run-off during (flash) flooding events, as well as hindering the replenishment of water sources.

Addressing water security challenges in urban areas is central to achieving wider international and European water policy ambitions

Water has been referred to as a 'common currency' that links nearly all of the 17 United Nations Sustainable Development Goals (Wong et al., 2020), with SDG 6 aiming to 'ensure availability and sustainable management of water and sanitation for all.' There are many EU regulations and policies that encourage and require actors within urban water systems (e.g. cities, water companies, households, services, and industries) to take actions to improve the quality and quantity of water sources and achieve better water resilience in Europe. These regulations are continuously evolving and are likely to set increasingly ambitious targets for urban areas in the future.

The Water Framework Directive (WFD) (Directive 2000/60/EC) is a cornerstone of European water policy, aiming to achieve good ecological and chemical status for European waters. According to the WFD, Member States are required to identify and monitor pollution and significant water abstraction from urban uses. The Communication on Addressing the challenge of water scarcity and droughts in the European Union suggests 'fostering water efficient technologies and practices' and in this section specifically flags leakages in cities as a challenge that needs dealing with to address water scarcity (EC, 2007). Recognising that urban wastewater is one of the main sources of water pollution, the EU's Urban Wastewater Treatment Directive came into force in 1992; this requires the proper collection and treatment of wastewater from cities (but also towns and settlements) (EC, 1991). The Directive is currently under review, and it will aim to 'improve access to sanitation especially for the most vulnerable and marginalised', 'make industry pay to treat micropollutants' and 'lead to a more circular sector', along with other aims. With three out of five wastewater operators owned by public authorities (Eurocities, 2023), cities clearly have an important role to play in achieving their own and wider European water resilience ambitions.

To improve their water management practices, cities can tap into assistance, including financial incentives, capacity and knowledge building, and networking that the EC provides to urban areas. This assistance is available through various initiatives to implement research, innovation, and demonstration projects for investments in green, circular, and bio economy and sustainable urban development, design, and management practices. Examples include the European Urban Initiative (EUI), Circular Cities and Regions Initiative (CCRI), Intelligent Cities Challenge Initiative (ICC), and the Green City Acord. In addition, the European Regional Development Fund (ERDF) offers financial incentives and support for projects exploring water resilience in urban areas (e.g. WE@EU- Water Efficiency in European Urban Areas, 2017 funded under FP7- Regions).

EU's resilience agenda

In the EC's 2020 Strategic Foresight Report on Charting the course towards resilient Europe, water quality and the necessity to move to circularity to prevent overexploitation is often mentioned as a way of supporting the actions Europe should take to move towards resilient future (EC, 2020a). The Recovery and Resilience Facility (RRF) is a temporary instrument and the centrepiece of *NextGenerationEU* – the EU's fund for supporting economic recovery from the coronavirus pandemic and building

	a green, digital, and resilient future (EC, 2021). Linked to the European Green Deal, which amongst other things aims to provide clean water for EU citizens, the RRF supports investments in green technologies (EC, 2021). Although not specifically targeted at cities, at least some of these investments are likely to take place in urban areas and include technologies for more sustainable water management practices. Cities also have their own motivations to boost resilience and become more self-sufficient. In addition to water scarcity, many systemic environmental and social challenges are felt acutely in cities (EEA, 2022a). The recent COVID-19 pandemic showed not only that cities are vulnerable, but that their ability and jurisdiction to act and respond to crises can be limited. Achieving water resilience may contribute to their ability to better respond to future challenges, as well as empower them both politically and financially.
How might the issue develop in future?	Radical changes related to water systems in existing urban areas are hard to implement and will take time to realise. This is due to challenges such as existing infrastructure, buildings, lack of and competition for space, ownership complexities related to land and infrastructure (e.g. the user or the city may not own the water infrastructure), and existing urban land uses (e.g. retail, residence/housing, manufacturing, industrial activities). Therefore, any changes may tend to be incremental rather than transformative. European cities are likely to apply a portfolio of methods, technologies, and behaviours to tackle water scarcity in the future. Although some new ideas may be adopted, especially as scarcity worsens, it is quite possible that most cities will focus on scaling up and refining existing approaches. **Gathering more precise data on water use to increase efficiency** One way to reduce water consumption in cities is by gathering more precise data on water usage, as improved data can help focus efficiency measures and infrastructure or water use changes. In comparison to other systems (e.g. energy or transport), less data is generally captured for water systems (beyond water availability and quality, also including water infrastructure) (Malloy, 2021). To better understand and manage their water use, cities may adopt and mainstream existing technologies such as smart meters and nest-like devices, measuring water usage by different categories, and informing consumers and alerting them if they are overspending on certain activities (Malloy, 2021; EMR, 2023). Smart meters could also detect water losses and contribute to better management of these, as well as enable the integration of advanced metering infrastructure with Internet of Things-enabled platforms (EMR, 2023). Projections show that the smart meter market in Europe is expected to grow at a compound annual growth rate (CAGR) of 8.6% in the next five years (EMR, 2023). This is due to ambitions to reduce non-revenue water (i.e. water that has been produced but is lost before it reaches the consumer), stricter regulations on water use, and other favourable EU and national government policies (e.g. green and digital transitions – see Issue 9). Like smart energy meters, such devices could become a standard part of water installations in cities, contributing to their transition to smart city infrastructures (EMR, 2023). As part of the smart infrastructure transition, in the future cities may make significant investments to integrate their water management processes with the Internet of Things (IoT) systems. This will enable water operators to better manage water allocation as well as distribution systems by getting real-time data, receiving alerts of potential issues sooner, more easily detecting leaks and improving distribution, better monitoring and managing the wastewater process, and reducing spills (Water Resources Alliance, 2023). Along with smart meters, smart water sensors and smart irrigation systems are another supporting technology necessary for the successful integration of water infrastructure with IoT (Water Resources Alliance, 2023). Next to consumption, smart sensors can provide information on water pressure and quality, enabling distributors to quickly identify and address potential issues with the water distribution network. By measuring

moisture in the soil and taking into account real-time weather conditions, smart irrigation systems could improve water use efficiency for city greening (Water Resources Alliance, 2023).

Transition to water saving behaviours

Another element of reducing water consumption in urban areas is encouraging water-saving behaviours (EEA, 2016; Mahr, 2018; Wong et al., 2020). Cities might do this by launching water scarcity raising awareness campaigns. They might also encourage people to take actions such as: installing a smart meter; buying water-efficient appliances (e.g. washing machines, dishwashers, low flowing and timed taps, dual flush toilets); taking less frequent and shorter showers; or reusing water at home (e.g. using dishwater for the lawn, putting the shower attachment in a bucket while the water is warming up and using the retained water to wash dishes, or reusing bath water to wash rugs etc.) (Shearer, 2022). Green roofs and rain harvesting reservoirs can also help complement drinking water supply.

While awareness is the first step, noticeable and clearly articulated individual actions can also encourage behavioural change (Kubit, 2020). Cities may also try to influence residents' water-saving behaviours by showcasing and demonstrating their water-saving behaviours in public spaces such as parks, city squares, and public buildings, and at public events. As discussed in Issue 5, some examples include using smart irrigation controllers in public parks; using treated wastewater and stormwater runoff to water city greenery as well as in urban water design features (e.g. fountains, ponds, reflecting pools, waterfalls, rain curtains, streams); and installing water smart meters in public buildings. When organising public events, cities may want to demonstrate their commitment to improving water efficiency by taking actions such as: considering the likely temperature and taking water availability and requirements into account accordingly; choosing a venue with water efficiency measures in place (e.g. that use recycled water for watering to reduce drinking water consumption); choosing a venue with or installing water-efficient appliances (City of Adelaide, 2019).

In severe water scarcity conditions, cities might increasingly implement more stringent approaches, such as water rationing, with the intention of instantly influencing citizens' water consumption behaviours and mitigating disruptions to the water supply. Water rationing measures can include anything from hosepipe and car wash bans to having water available only on certain days of the week or installing water meters that shut off water once a consumer's allowance for that day has been reached. While water rationing is already happening in cities across Europe (Symons, 2023), it is mainly seasonal. However, it may become a more common and, in some cases, permanent form of urban water management in the future as water scarcity issues worsen.

Decisions to implement rationing measures will involve prioritising which activities can be carried out and by whom, and also what constitutes a sufficient water supply for different types of residents (the elderly, families with young children, disabled, people living alone, etc.) and other commercial and public sector users (industries, health and social services, transport, energy supply etc.). This indicates a possible transition away from demand towards sufficiency-driven water governance.

Sufficiency-led water governance in future cities may be further driven by their need for just sustainable development, including addressing growing social and economic inequalities (also related to aging populations and changing urban demographics) and adhering to the UNSDG 'Leave no one behind' (LNOB) principle to ensure everyone has access to clean water. To maintain a just water supply, cities may make more efforts to implement and enforce a fair pricing system. These may include enforcing the principles of WFD, including the user pays principle and the demand to include environmental and resource costs (ERCs). In addition to making sure that users who consume more also pay a higher price, the user pays principle could also encourage water-saving behaviour on an individual level. While social tariffs already exist – reducing bills for customers who may otherwise struggle to pay – socially affordable water pricing may further evolve in the future. See also Issue 4 on emerging challenges for the governance and equality of access and use of water at the local level.

Improving and modernising urban water infrastructure

To keep pace with future challenges and increase their water resilience, cities might make more efforts to better monitor and maintain their water distribution and supply infrastructure (e.g. transmission pipes and canals, reservoirs, pumps). This could include transitioning to new, more efficient technologies to detect water leakages, such as distribute acoustic sensing (DAS) (Barbosa, 2022).

The modernisation of infrastructure is also likely to require substantial investments in developing new and improving existing drainage (i.e. piping that conveys sewage, rainwater, or other liquid to a point of disposal). It will also demand investment in water treatment and sanitation capacities to efficiently collect and treat wastewater and remove chemicals, bacteria, excess sediment, and nutrients from source water and increase the supply of usable (potable or grey) water. Cities might decide to build more and/ or modernise existing wastewater facilities and invest in implementing new technologies to remove emerging and increasingly complex pollutants. These include pharmaceuticals, microplastics, pesticides, and endocrine disruptors, which create hazardous cocktail effects that are challenging to predict and poorly understood (Ramm, 2018; Trémolet and Karres, 2020).

Updating infrastructure with the aim of improving water quality is also likely to be encouraged by the revised WFD, which will set out the framework for minimum hygiene requirements for materials in contact with drinking water.

Transition to circular water management approaches

See also Issue 3 on whether the circular economy will drive water resilience. According to the Interreg City Water Circles project (2014-2020), greywater (waste-free recycled water coming from sinks, showers, dishwashers, washing machines, etc) typically represents 50-80% of wastewater from European households (Interreg CWC, 2019). Some of the water demands in cities (such as maintaining urban greening, gardening, and toilet water) could be met by using greywater as these do not require potable water quality (Malloy, 2021). To improve water resilience, in the future cities in Europe might focus their investment in infrastructure that supports their transition from linear to circular water management practices (Malloy, 2021; EEA, 2016; Ellen MacArthur Foundation, 2019).

An example of a long-lasting and regenerative circular model named Biopolus is already being tested in the Hungarian capital Budapest (Ellen MacArthur Foundation, 2019). Biopolus was designed to 'help cities transition from their current linear system of consumption and waste to a long-lasting and regenerative circular model' in which a decentralised network of urban, odour-free, metabolic hubs (BioMakeries) is powered by Biopolus metabolic network reactor (MNR) technology. Biopolus MNR technology harnesses clean water, energy, nutrients, and minerals from wastewater and organic waste. The system is modular and fully integrated into the urban environment. In addition to treating and recycling wastewater, BioMakeries provide a platform for circular urban infrastructure integration as well as green garden space to be enjoyed by residents (Ellen MacArthur Foundation, 2019). Such systems could be applied and scaled up across European cities in the future as a feature of urban green infrastructure, further contributing to climate change adaptation.

Increasing water supply

Historically, many European cities have been built around rivers and lakes, which provided not only fresh water, but also transport infrastructure (Trémolet and Karres, 2020). To meet demand for water and secure their supply, cities across Europe mainly rely on their hinterlands (EEA, 2016).

	Some large cities in Europe rely on several water sources from distant catchments. For example, natural spring water for Vienna (1.8 million inhabitants) originates in the Lower Austrian Limestone, and Madrid and its region gets water from 11 distinct sources with a total catchment area of 550,000 hectares (Trémolet and Karres, 2020). Cities often interact with and invest in surrounding regions and rural areas far beyond their boundaries to protect the water sources on which they depend (Trémolet and Karres, 2020). As the pressures on water supply increase, some cities might invest more in protecting and enhancing natural sources within the regions they rely on to secure their water supply (Trémolet and Karres, 2020). However, it may be that some cities in Europe with sufficient (regional, national, international) economic and political power decide (with the support of higher governance levels) to prioritise (short-term) economic growth. To maintain water supply and continue meeting demand, they might invest in large water diversions that bring water to the city from distant regions with more abundant water resources) (EEA, 2016), storing as much as they can capture in large reservoirs and maintaining a linear water management model. Large water diversion projects may include the construction of dams, reservoirs, levees, pumping stations, canals, and other manmade structures that modify the natural morphology and flow of waterways to extract, move, store, and distribute water. Decisions to increase investment in water diversions to supply European economic capitals may be taken at governance levels that surpass the jurisdictions of city governments. To tackle water scarcity challenges, in addition to conventional sources (e.g. rivers, lakes, aquifers), cities might augment their abilities to harvest water from alternative sources such as seawater, rainfall, or even air or fog, thus relieving pressure on surface and groundwater sources (Wong et al., 2020; Malloy, 2021). While fog harvesting is an option, some authors argue that it does not work well for cities due to space constraints and the water needs of the urban environment (Chen, 2018). New and alternative sources of water are discussed in Issue 2. As discussed in Issue 2, desalination (the process of turning salt water to fresh water) may become an increasingly important water source for cities. Cities across Europe are already harvesting and increasingly relying on desalination. For example, with reservoirs on Catalonia's rivers at 28% capacity (in June 2023), Barcelona's Llobregat desalination plant provides 33% of the city's drinking water and has been operating at full capacity since last summer (Novo, 2023). Spain is now fourth in the world for desalination capacity and is planning to expand further (Novo, 2023). To reduce pressure on water supply, small-scale rainwater harvesting may become prevalent in cities in the future, as it is simple and affordable to implement (Gur and Spuhler, 2019). Rainwater is collected on the roof, transported via gutters to a storage reservoir, and used for groundwater recharge or to provide water at the point of consumption) While large-scale rain water collection systems are also possible, they are more sophisticated and take more effort to implement (Gur and Spuhler, 2019). **Changes in urban planning and design** Cities might increasingly adapt their urban planning and design practices and approaches. They may move from predominately grey infrastructure (on which existing water systems in Europe rely) to a combination of grey and green infrastructure to increase resilience and ensure quality water supply. Due to their potential for tackling challenges such as water scarcity, floods, and surface and groundwater quality (Trémolet and Karres, 2020), nature-based solutions for water security (NBS- WS) might become key to the design of future urban water supply infrastructure. Cities across Europe are already experimenting with and implementing NBS-WS, such as (natural or artificial) aquifer recharge and wetland restoration. Barcelona is building infiltration ponds next to Llobregat River to fill and recharge water back to groundwater stores, while the Netherlands has been relying on artificial

	aquifer recharge since the 1950s to manage water availability during dry periods (Trémolet et al., 2019). Research by the Stockholm Environment Institute highlights that policy that promotes urban wetlands restoration can improve urban ecology and human well-being (Anyango Onyango, 2023). These practices might become prevalent in the future, as they can play a significant role in increasing resilience to water scarcity and stress in urban areas and beyond (Trémolet et al., 2019; Anyango Onyango, 2023). The transition to hybrid water supply systems that include elements of grey and green infrastructure might be further encouraged by cities' wider shift to green urban planning that considers current and future climate change (Deloitte Insights, 2021). NBS-WS and other interventions that cities commonly use in the future may vary in scale. They could include large green infrastructure interventions to protect and restore natural ecosystems as well as green roofs, sustainable drainage systems (SUDS), and permeable pavements to improve water retention, storage, filtering, or replenishing of water sources. Urban greening in relation to wider urban resilience has been discussed in Issue 5 (Will urban greening emerge as a key tool in thriving cities of the future?) of FORENV cycle 2021-22 (EC, 2023).	
Potential implications for water resilience, the wider environment and human health	**Opportunities**	**Risks**
Cities may increasingly act as role models, facilitators, initiators, test beds, and innovation hubs for water sustainability transitions	• Cities lead by example and encourage wider social change towards energy-saving behaviours. • Cities share knowledge, build networks, and learn from each other about the risks and benefits of new practises, enabling a quicker, more streamlined transition to more sustainable urban water management systems.	• As cities are complex and diverse, some (good) practices may prove to not be transferable across all cities, although that may only become evident after their implementation, resulting in costly failures to improve water efficiency and resilience.
Smart meters become mainstream, a standard part of water installations in cities (in and outside buildings, for example in parks)	• Better water metering might improve citizens' home usage understanding and therefore encourage behavioural change towards water conservation (including the use and purchase of more water efficient devices/ appliances) and decrease their utility bills. • It might do the same for businesses and industries and encourage the use of more water-efficient technologies and production practices. • Water metering might help city authorities and water utility companies to make better investment decisions and improve their management practices,	• Old water and building infrastructure in (some) cities might not be of good enough quality (e.g. old and worn-out pipes) to fully harvest the benefits and justify the investment in smart meters. • Some consumers (including households and businesses) resist having smart meters installed and thus do not receive the benefits they provide.

	providing high quality, reliable, and affordable services. • Smart meters could decrease water losses by enabling the early detection and mending of leaks. • Smart meters support the transition to just and fair water pricing systems, helping to address wider urban social and economic equality issues and the implementation of LNOB as well as WFD user pays principles.	
Cities' water infrastructure is integrated with IoT	• Beyond smart meters for households, IoT provides real time data at city or even regional level, helping city authorities and water utility companies to better manage and act quickly in (crisis) situations like wastewater over spillage, droughts, or floods, improving urban resilience. • IoT could also support policy makers and water suppliers to improve and develop future water (efficiency) management strategies, not only at city but also catchment, regional, national, or even international scales. • Better management leading not only to improved water efficiencies and quality, but also wider benefits for the environment and people (e.g. enhanced biodiversity, improved human health).	• Security and privacy issues related to data breaches pose threats to the wider resilience of cities and their citizens (Water Resources Alliance, 2023). • Increased costs for cities and rising water (and potentially also energy) bills due to the substantial investments needed to integrate the urban water system with IoT as well as to assure and manage cybersecurity. • As with other digital technology systems, IoT may constantly evolve, requiring constant maintenance. This may again lead to increased costs. • Implementation and maintenance will require shutting down the water supply (Water Resources Alliance, 2023) which can be disruptive for cities and their residents.
Increase in campaigns encouraging water-saving behaviours in European cities	• Awareness campaigns are low-cost, soft, simple measures that cities can plan and launch relatively quickly (in comparison to other measures, such as implementing new technologies or infrastructure changes). • Citizens' increased awareness of and transition to water-saving behaviours (e.g. shorter showers, home water recycling, increased use of water saving appliances etc.), leading to water quantity and related cost savings for the city and its residents.	• Very slow pick-up times, lack of motivation, and in some cases resistance of citizens to adopt new voluntary behaviours, along with the time needed to learn new water use habits, result in inefficient campaigns and the maintenance of business as usual.

	• Improved water resilience of cities.	
Water rationing across European cities becomes common (seasonal to permanent), especially in water-scarce regions	• Relatively instant solution to reduce water use in cities, particularly in situations of 'current' (urgent) or long-lasting water shortage. • Residents' (including industries, businesses, public services etc.) abrupt change to water-saving behaviour might extend beyond the duration of water rationing measures, also potentially influenced by wider understanding of the severity of water shortages. • Water rationing may lead to restructuring the way water is priced. In a 'progressive pricing' scheme that 'essential' water would be free or very cheap, with consumption beyond 'essential' becoming more expensive. This is progressive pricing. This is contrary to current pricing where the largest consumers (often) pay less per unit than smallest.	• Social unrest as citizens may feel their right to water has been violated. • Hosepipe bans could lead to damage and decay of urban green and blue infrastructure, further aggravating water shortages and other climate change related challenges over time. • Permanent water rationing might lead to water supply plans for consumers based on a similar principle to mobile data plans – ranging from basic, offering the lowest amount of water for basic needs, to premium, offering unlimited water access and supply. In addition to perpetuating established water use habits (for some), such plans could lead to immense social disparities, not only between poorer and wealthier citizens but also among cities, regions, and even countries, causing social tensions, unrest, and conflict (see Issue 4 and other risks related to social unrest in this table).
Cities transition from linear to circular water system management practices	• Circular water systems significantly increase cities' water resilience and supply and decrease water demand, helping to improve the ecological condition of freshwater surface and groundwater sources (e.g. rivers, lakes, aquifers). • Modular systems could be applied faster, so water efficiency benefits could be realised sooner. • In addition to improving water efficiency, odourless, modular, circular systems such as Biopolus can replace traditional wastewater facilities, not only freeing up space but also providing green space for residents and contributing to wider green transition ambitions (Ellen MacArthur Foundation, 2019). • As with Biopolus, the implementation of similar systems could also contribute to harvesting energy from organic waste and contributing to energy	• The transition to completely circular systems could be slow and require substantial investments as well as social acceptance to support radical changes in infrastructure technologies. • The problem of water scarcity in cities is acute, and approaches and technologies to transition to circular systems are only emerging and will need time to evolve before they can be implemented on a large scale. • Insufficiently planning for measures to transition to circular models now may lock cities into long-term linear water consumption practices.

	efficiency (Ellen MacArthur Foundation, 2019).	
Cities increase incentives for household and businesses to install rainwater harvesting and greywater reuse systems, or even make such adjustments mandatory	• Increase water resilience and supply of cities. • Decrease pressure on and improve the ecological condition of traditional surface and groundwater sources (e.g. rivers, lakes, aquifers).	• Changes in the visual appearance of buildings could be disruptive for some residents. • Increase in health risks due to potential contamination, as rainwater quality may be affected by air pollution, animal or bird droppings, insects, dirt, and organic matter (Gur and Spuhler, 2019) • People feel pressured and resist the change. • Although regulations exist that should prevent it, inadequate or faulty construction of household or business rainwater harvesting, or greywater reuse systems can lead to contamination of the public water supply. This may become more common if people feel the need to apply do-it-yourself solutions to improve their water security.
Increase in construction of desalination plants in and around cities (see also Issue 3 on new and alternative sources of water)	• Sea water is an abundant source which cities could harvest freely through desalination, increasing their water resilience and supply. • Desalination could decrease pressure on and improve the ecological condition of conventional surface and groundwater sources (e.g. rivers, lakes, aquifers). • Desalination plants can act as a safety net for cities in situations of extreme water shortage (assuming they have spare capacity) (as happened in Barcelona in 2023).	• Might increase the cost of water for city residents, as the desalination process is expensive as well as energy-intensive. • The desalination process can damage local ecosystems by putting extremely salty brine (a byproduct of the process) back into the sea.
NBS-WS become an integral part of the urban water supply and drainage infrastructure	• Increase in ecosystem services (water retention, climate regulation), more green space, better life quality for residents. • Reducing surface sealing as well as breaking its connectivity by implementing green infrastructure interventions (including NBS-WS such as SUDS) would help slow down urban rainwater runoff as well as drain rainwater, leading to enhanced infiltration and better flood risk management, including decreased pollution risks related to flooding in urban areas (creating so-called sponge cities).	• Pressures on water supply in future cities with hot summers, draughts etc. for the maintenance of urban greening. • Increased costs for cities related to the maintenance of urban greening.

	• If they are well-designed, planned, and implemented, city greening projects have several co-benefits – urban climate change adaptation (e.g. use of native, drought-resistant species), better life quality for residents, and making cities better places to live.	
Increase in investment and implementation of large water diversion projects across Europe to cities of economic and political significance	• Undisturbed day to day life, growth and urbanisation of Europe's economic centres, bringing (potentially short lived) financial, economic, and social gains (e.g. health benefits due to improved and undisturbed water supplies).	• Hinders the implementation of and progression to more sustainable urban water management practices. • Inter-basin water transfer can create negative impacts on the donor basin (e.g., changing the hydrologic cycle, ecological flow, etc.). • Increase in the need for artificial water storage creates hydro morphological pressures (i.e. changes in physical characteristic of water bodies), which may lead to further habitat fragmentation and degrade the ecological status of surface water bodies. • Tensions between larger, more powerful cities and a complex variety of other actors due to competition for access to water resources, leading to social unrest and economic instabilities (see issue 4). • These tensions could extend beyond national borders, potentially jeopardising the security and stability of the EU bloc. • Social unrest might also hinder the construction and completion of water diversion projects, causing not only economic but also ecological damage. • Population displacement and the loss of ecosystem services, landscapes, and heritage due to the potential submergence of villages and smaller towns to build water diversion infrastructure (e.g. dams, reservoirs). • Emergence or aggravation of water scarcity challenges in regions supplying water to cities, leading to economic, food security, and social security issues. • Increased economic and social disparities between large, developed cities and their hinterlands, including the potential socio-economic decline of smaller regional and local urban centres across Europe. The latter are extremely important for achieving territorial cohesion and

		the delivery of essential services (e.g. education, groceries, telecommunication services, public transport etc.) to European citizens, including in remote regions.
Modernised water infrastructure across European cities, including transitioning to more efficient technologies to detect and address water leakages as well as water treatment and sanitation improvements	• Decreased water losses related to outdated infrastructure lead to significant improvements in water resilience and efficiency, not only in cities but in Europe as a whole. This is further improved by new and enhanced treatment and sanitation, increasing the supply of usable (potable or grey) water in cities. • Fixing leaky pipes and implementing revised Drinking Water Directive hygiene requirements for materials in contact with drinking water might result in health benefits for cities' residents by preventing the intrusion of pathogens into cities' water supply and distribution system and decreasing the need to add potentially harmful chemicals like chlorine to improve water quality. • Preventing underground leakage stops or reduces damage to other infrastructure and buildings (related to, for example, leaky water supply and sewer pipes as well as sinkholes), resulting in economic savings and improving public safety. • Transition to modern technologies such as distribute acoustic sensing (DAS) enables more efficient and timely identification of water leaks or thefts, so that faults can be found and repaired more quickly with less disturbance and cost than with more traditional methods. The latter may take days of excavation to find wet soil and identify the source (Barbosa, 2022).	• Challenges with the (fair) attribution and distribution of cost between users to implement necessary improvements in cities. The Water Framework Directive states that costs for water services should be recovered according to the polluter pays principle. Across EU Member States, this usually works well for households (provided water bills are not subsidised), while other users such as industries and agriculture often pay significantly less in relation to the pollution they generate (Ramm, 2018). Increased and unfairly distributed costs could result in protest, issues with bill payment discipline, and potentially the obstruction of infrastructure improvements in cities. • Hindrance of transport/ energy infrastructure over prolonged periods of time due to construction sites (causing economic risk to businesses, life quality of citizens, etc.) resulting in economic losses and health and wellbeing risks (e.g. noise, pollution) to residents. • Environmental risks related to the disposal of used pipes, concrete, and other construction material releasing CO_2.
Timeframe of emergence	While cities have always been grappling with challenges of securing water supply, including the development of collection and distribution infrastructure and assuring enough water of adequate quality for their residents, the importance of achieving water resilience is increasing due to the urgency of threats posed by climate change, pollution, and the	

	destruction of natural ecosystems. As such, this issue is already being acknowledged and addressed in the short term. However, changes to urban water supply management practices, the modernisation of infrastructure, and the transition to more sustainable urban planning models (prioritising green solutions) will require medium- to long-term action.
Uncertainties	Cities are unique in terms of their economic, social, health, and environmental characteristics. Therefore, the measures needed to deal with water scarcity will be diverse according to the specific context. They are also likely to vary hugely in the rate at which they are taken up across Europe; there is no one-size-fits-all solution to all problems and risks related to urban water scarcity in the future. Cities may also not be in control of all the decisions taken in relation to water resilience, as (public or private) water supplies and regional and/or national authorities have significant agency in this regard. Other initiatives towards urban sustainability transitions may create synergies and support cities' water resilience, such as adopting green design and development practices and prioritising NBS over traditional grey approaches. However, cities' attempts to achieve water resilience might cause tension with their other objectives. For example, efforts to increase food resilience might create more pressure on water systems (e.g., due to pollution and water abstraction needs related to urban farming). Similarly, any transition to renewable energy sources could also further burden urban water supply (e.g., through installing water powerplants on streams and rivers within city catchments). As discussed in Issue 9, cities will also be influenced by wider European (and global) transition pathways, such as those towards green, digital, and net-zero transitions and the shift to renewable energy sources and their influence on water use and demand. While larger cities are projected to grow (in the short to medium term), the populations of many cities across Europe are already declining, with 10% of cities projected to lose more than a quarter of their population between 2015 and 2050 (EC, 2020b). Therefore, it can be assumed that in these cities water consumption is likely to decrease and water quality and quantity may improve. However, oversized water infrastructure might become a problem from the maintenance perspective, as it could start decaying and causing health issues related to water quality. Although already paramount, rural-urban relations and interactions between neighbouring and more distant regional players (as well as national, potentially international, and city players) for securing water supply in urban areas may grow in importance. However, the power dynamics and types of arrangements between the cities and actors beyond city boundaries are uncertain and are likely to vary significantly across Europe.
Additional research or evidence that may be needed	To improve cities' water resilience, there is a need to better understand multilevel water governance across Europe. It is also important to understand power dynamics and the types of arrangements between cities and private and public actors within – as well as beyond – city boundaries, including water suppliers, (national, regional, municipal and city), governments, businesses, industries, and other sectors (e.g. agriculture, energy, transport). There is a need for reliable data on water-use efficiencies by economic sector and European country, and ideally at a city level to better understand how water is used in urban areas across Europe (EEA, 2020). Generally, there is a great need for data at the scale of regions or cities (e.g., on water use per capita and the amount of water wasted, recycled, or reused) to better understand water scarcity challenges in cities and their diversity across Europe, and to encourage knowledge sharing, learning, and adoption of successful management practices. To better plan for future water resilience, cities and national governments also need to have a better understanding of urbanisation processes, demographic changes at city scale, and the phenomena of not just growing

	but also shrinking cities. To accommodate urban water resilience transitions, it is crucial to estimate the investments needed to implement relevant measures and for these to gain the attention of and become priorities for policy and decision makers, as well as to secure funding for the water sector.
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Issue 7: Rethinking Agriculture for a Drought Resilient EU	
Emerging issue description	Climate change is projected to increase the frequency and severity of drought in many parts of Europe. The decrease of water availability due to droughts and quality issues (see also Issue 1 on the interrelated challenge of water quality and quantity) will be in addition to the structural overuse of freshwater (water scarcity), which is also increasing due to demographic growth and economic activity. A substantial part of the territory of the EU is already affected by water abstraction that exceeds available supplies and recharge rates. These combined effects can have substantial impacts on agriculture and the production of food commodities. In June 2023, the European Commission mobilised €330 million to support Member States to adapt to adverse climatic events, high input costs, and trade-related issues. Particularly in the Iberian peninsula, this will in part support EU farmers impacted by drought (European Commission, 2023a), in response to some of the worst droughts seen in years (European Commission, 2023d). Southern European countries like Spain, with large areas of semi-arid landscape, have suffered particularly badly. In 2023 alone, drought is estimated to have destroyed 3.5 million hectares of crops in the country (Pleitgen et al., 2023) and in May 2023, the Spanish government spent €2.2 billion to alleviate drought impact (Reuters, 2023). At the same time, agriculture is a major consumer of water. There is increasing recognition of the need to act to ensure that agriculture will reduce its overall water consumption by improving farm water use efficiency. In the EU, the agricultural sector is responsible for approximately 24% of all water abstraction, with significant variation across the Continent. This has fallen by approximately 28% since 1990 due to improved efficiencies (European Court of Auditors, 2021). Nonetheless, the use of water for irrigation in agriculture in some Member States is still unsustainable given the current overall drought pressure. In 2015, Member States reported to the Commission the share of water bodies under significant pressure from agricultural water abstraction; this showed that, for many countries (including Italy, France and Spain), at least 20% (in the case of Spain more than 40%) of surface and ground waters are under such pressure (European Court of Auditors, 2021). The ECA found that agricultural policies at both EU and Member State level were not consistently aligned with EU water policy. The ECA therefore presented three recommendations to the Commission: to request justifications for exemptions to Water Framework Directive implementation in agriculture; to tie CAP payments to compliance with environmental standards; and to use EU funds to improve the quantitative status of water bodies (European Court of Auditors, 2021). Within agriculture, there are significant differences in water use depending on climatic conditions and on agricultural practises, crop varieties, and types of products. Focussing on the blue (or net abstracted) water footprint, given localised scarcity and the quantity produced in the EU (AWARE methodology), wine production uses the most water. Beef and milk – two products for which the majority of what is consumed within the EU is also produced there – are also significant users of water (García-Herrero et al., 2023). A range of approaches can support the development and implementation of sustainable and effective management strategies at farm scale. These include techniques to improve soil health and water retention, natural storage measures, and measures to minimise yield losses. These techniques and measures are further described in the Key Drivers section, under the Sustainable Agriculture heading. Additional measures that can improve water efficiency in agriculture include: adopting a dynamic crop-variety approach to minimise the risks and impacts of climate extremes and poor water quality (Toreti et al., 2022); using (digital) technology for more efficient irrigation; and combining precision techniques and tools with innovative water management strategies. Finally, developing an EU agro-food system that accounts for changes in crop-specific producing areas will be an important part of adapting to a future of increased uncertainty and risk. For example, the demand for durum wheat is increasing globally but, due to climatic change, net reductions in suitable areas for its growth are

	forecast (Ceglar et al., 2021). Other advances in technology are making indoor farming (using green houses, hydroponics, vertical farming) more feasible. Whilst these forms of production require high capital investment, they can be much more water-efficient for various kinds of crops. Other social, political, and economic drivers within the food system may also emerge that enable the agricultural sector to embrace less water-intensive practices. These include a move to a more plant-based diet and an associated reduction in intensive livestock farming. Livestock farming typically requires large amounts of fodder (imported and/or produced in the EU with high water footprints).
Key drivers: what is driving the emergence of this issue?	**The implications of climate change and its effects on farming and water use** Among a large range of impacts on the agriculture and food sector, climate change will have a direct impact on water use in farming. Firstly, there will be a reduction in the overall water supply through reduced precipitation and increased evaporation rates from water storage bodies, and this will reduce the availability of water for farms. Even in those regions expected to have stable or higher annual precipitation, more frequent and intense water extremes (i.e., drought and heavy precipitation events) are projected. Secondly, increases in temperature will increase the rate at which soil moisture evaporates. The combined effects of higher temperatures and reduced water availability may cause more stress for crops and potential damage in crop sensitive phases. In addition, crop evapotranspiration, the rate at which plants consume water, will also increase (Vila-Traver et al., 2022). Grasslands – used for livestock rearing – will also require more water, as will the crops used to produce animal feed. Projected seasonal instability and increased occurrences of extreme weather will nonetheless vary significantly across Europe (see Intergovernmental Panel on Climate Change, 2023), and therefore the effects on regional farm systems will also vary. Drought also makes topsoil more vulnerable to erosion and removal by sudden onsets of water (flash flood events). The data shows that climate change has been exacerbating crop water deficits. Between 1995-2015, there was an increase in crop water deficit for large parts of southern and eastern Europe (European Environment Agency, 2021). **Water scarcity and the production of different food types** Within agriculture, there are significant disparities in water use depending on the type of food being produced. To understand the water use of different products and their impacts, there has been a recent shift from attempting to quantify only the volumetric water consumption of certain foods, based on global averages, to the AWARE methodology. This quantifies environmental impact based on volumetric water use across the entire life cycle and also considers the impact on the local context given relative water availability (García-Herrero et al., 2023). Using the AWARE methodology, tea is the most water-intensive product, with its production and consumption involving 160 times more water than potatoes. However, to quantify the scale of impact, it is also necessary to consider how much is both produced and consumed within the EU. Weighting water use according to *both* the AWARE methodology and how much is consumed within the EU, the most water-intensive product is wine (1014 m^3/citizen). This is followed by chocolate (769 m3/citizen), tea (582 m3/citizen), tomatoes (136 m3/citizen), bananas (188 m3/citizen), beef (126 m3/citizen), rice (123 m3/citizen), milk (120 m3/citizen), oranges (98 m3/citizen), apples (92 m3/citizen), and beer (92 m3/citizen) (García-Herrero et al., 2023). A full consideration of impact within the EU alone should consider the proportion of these foods that are produced in the EU. In the case of beef, for example, the EU produces 6.8 million tonnes and imports 300,000 tonnes (Vinci, 2022). Conversely, 70% of almonds sold in the European market are produced in the USA (García-Herrero et al., 2023). It is also important to note that relative water impact takes into account global averages, and these will vary in their relevance to the EU

context.

European Agricultural Policy

Through the Common Agricultural Policy (CAP), the EU has promoted sustainable water use. Under current CAP rules, farmers must follow cross-compliance rules in order to receive payments (including those related to green actions), all of which can bring benefits to water sustainability. CAP payments linked to compliance with the Water Framework Directive (WFD) support farmers who adapt their land as part of river basin management plans (European Commission, 2023c). The CAP can also cover costs to implement agricultural practices aimed at reducing water consumption. These include sensor-supported irrigation, precision irrigation, photovoltaic irrigation systems, wastewater treatment, and agronomic practices that improve soil health (EPRS, 2019).

The new CAP 2023-2027 includes stronger protections for water use in agriculture. There are requirements for the preservation of soils, such as practicing crop rotation, as well as introducing new performance monitoring and evaluation systems for sustainable water use (European Academies Science Advisory Council, 2022; European Commission, 2023c). However, the CAP has also hindered sustainable water use in agriculture in some respects. It has relatively weak mechanisms to discourage unsustainable water use, whilst projects that are funded by the CAP and likely to increase pressure on water resources are more common than those associated with sustainable water use (European Court of Auditors, 2021). In addition, Member States may be too lenient in how much abstraction by farms they are permitting, because of a reliance on out-of-date hydrological data and/or difficulties in predicting the future effects of climate change. In some cases, lenience may also be applied for political gain. This has been suggested in the case of the 'water wars' in the Doñana Protected wetlands of Andalusia, where in 2022 the regional parliament voted to support a plan to legalize 1,500ha of irrigated land that were formerly being farmed illegally by farmers, abstracting water from the wetland in the process (Camacho et al., 2022).

Some environmental policies under the CAP may also have negative unintended consequences for water use. The management and conservation of peatlands, for example, requires rewetting to keep carbon sequestered. Given that the current degradation of peatlands in the EU is high in many regions (more than 80% in Central Europe (UNEP, 2022)), implementing this policy may have negative consequences for water availability.

The CAP is also a source of funding to relieve drought affected farmers. As noted above, in June 2023, the CAP budget provided €330 million to Member States to adapt to adverse climatic impacts (notably droughts) as well as high input costs and trade-related issues (European Commission, 2023a).

Technological innovation

Innovations in genetic modification and gene editing show potential for improving drought resistance or water quality tolerance in crops, as well as developing saline tolerance. For example, scientists have been able to genetically modify wheat to grow deeper roots for greater stress tolerance during periods of low water availability. However, generally, the focus of the agri-tech industry is on traits like herbicide resistance more than drought resistance (Brezezinski, 2022).

Currently the EU has some of the strictest rules for GMO crops in the world, although there is some evidence that attitudes towards GMO are softening. Stimulated by increasing drought scares, in September 2022, agriculture ministers from the 27 Member States urged the speeding up of a re-examination of GMO regulations; subsequently, on 5 July 2023, the European Commission put forward a legislative proposal to adapt the legal framework to the specificity of gene edited plants.

In recent years, efficient irrigation technologies like real-time irrigation scheduling are increasingly being explored to improve on-farm water efficiencies. These include projects like the Italian IRRONET – IRRFRAME project, which resulted in water savings of more than 50 million m^3 over six years (European Commission, 2023c). Whilst this is a tiny fraction of the entire total water abstraction per year in the EU from agriculture – approximately 40 billion m3 annually (Eurostat, 2018) – it is still a significant figure in a region that often suffers periods of drought. Drip-irrigation – compared with sprinklers – allows water savings of 10-35% for arable crops, whilst field sensors to map irrigation needs could allow water savings of 20-25% for arable crops and 45-50% for fruits and vegetables (European Parliamentary Research Service, 2019). Advances in satellite monitoring also provide potential for efficient monitoring and irrigation. However, it can also be subject to significant uncertainty and errors in measurements (Foster, Mieno and Brozović, 2020).

The dairy industry is known to be particularly water-intensive. However, according to industry claims, improved tank cleaning technologies can clean milk storage silos whilst saving 30% more water (FoodBev Media, 2023). Similarly, major packaging manufacturer TetraPak has reported that water use in the cheesemaking sector can be reduced by 40% using reverse osmosis water-recirculation technology (Cervera, 2023).

Increasing adoption of indoor vertical farming is being driven by the growing availability of unused urban spaces. For example, some post-pandemic unused office space and physical retail space has the potential to be converted into food production centres (Cousins, 2022). Driven by rapid advances in technology, urban farming is generally more productive than traditional outdoor agriculture, with some researchers and advocates of this approach claiming it can produce significantly higher yields with substantial savings in water use. Research undertaken in the private sector on indoor hydroponic vertical farming, for example, estimates that it can save 90-95% of water compared to traditional outdoor farming (Castle Water, 2022). Nonetheless, climatic control and artificial lighting mean that, in the case of lettuce, energy use for an indoor farm is approximately 14 times greater than for traditional agriculture (Jenkins, 2018). Despite increased yield potential, and a potential increase in the availability of unused buildings for repurposing, it is unlikely that indoor and vertical farming would be able to replicate the scale of production of traditional farming. It is also only relevant as an alternative to traditional agriculture in crop production, although some farms combine aquaculture and crop cultivation (known as aquaponics).

Adoption of more sustainable agriculture[20] approaches

Another factor is the absorption, retention, and availability of water in the soil. This is influenced not only by the soil's intrinsic characteristics but by its management and how the land is used (resulting in higher or lower soil compaction, crusting, or imperviousness). Intensive crop production, with a focus on producing high yields from smaller parcels of land, invariably is associated with higher water use to achieve these yields. The growing demand for food globally is a driver of intensive farming methods, particularly in the short term. In areas of lower population density and poorer quality soils, extensive agriculture is more likely to be practiced.

Sustainable farming approaches, which incorporate agro-ecology and organic farming, are a means by which agriculture can become more water-efficient and drought-resistant. various techniques can improve soil health and porosity and therefore its infiltration and water retention capacities (no or minimum tillage, shallow tillage, mulching), whilst techniques like contour cropping, strip cropping, cover cropping, and agro-forestry improve water retention and infiltration and prevent erosion. Indeed, drought is particularly damaging to soil through wind-driven erosion. Measures to increase resilience to drought-driven erosion, like no-till, are therefore particularly relevant. In no-till agriculture, the farmer uses a no-till planter to create a narrow furrow, just large enough to

[20] It is acknowledged that 'sustainable agriculture' is a very broad term and in some ways problematic, as a huge range of approaches can be labelled 'sustainable'. We use the term here in a generic sense to encompass the range of approaches that generally aim to reduce the environmental impact of farming.

	contain a seed. By not ploughing or disking, cover crop residue remains on the surface, protecting the soil from crusting, erosion, high summer temperatures, and moisture loss (USDA, 2016). The potential use of no-till without pesticide application is discussed in the Issue Development section. Sustainable agriculture is also associated with natural water retention measures, such as infiltration ponds and renaturation, as well as the restoration of wetlands. This issue was explored in detail in the 2020-2021 cycle of FORENV, Issue 4 on sustainable farming. Recent years have seen increasing interest in such practices at both the policy and practical levels. The EU Soil Strategy for 2030 (European Commission, 2021), for example, sets a path for the achievement of healthy soils by 2050. The adopted proposal for a Directive on Soil Monitoring and Resilience specifies the conditions for healthy soil, determines the requirements for monitoring soil, and lays down sustainable soil management principles. Meanwhile, an indicator of the growing interest in sustainable practices at the practical level is the increase by 46% in the total area of organic farming between 2012 and 2019 in Europe (Eurostat, 2021). **Changing patterns in the consumption of animal foods** As already detailed, the meat and dairy sector are responsible for a very large proportion of water use in agriculture in Europe, as well as globally. EU citizens consume on average twice as much meat as the global average (Henley et al., 2022). Meat consumption in the EU increased by about one million tonnes per year in the last decade (2012-2022). However, it is expected to fall by 1.6 kg per capita by 2032, to 66kg per capita (European Commission, 2022). The majority of meat produced in the EU is not exported to third countries, with only 8-10% of beef leaving the bloc, for example (Vinci, 2022). There may be a corollary between declining consumption and production within the EU, although it is also possible that EU production will remain the same or even increase to meet higher global demand (hence the proportion of exports could increase in future as EU demand falls). For further discussion of this topic, which is continued in the Future Developments section, refer to FORENV 2018-2019 cycle Issue 3 (European Commission Directorate General for Environment et al., 2019) **Water governance tensions** Water governance can create tensions between the need for food production and biodiversity. Drinking water production and cooling for energy-generating plants and shipping are other competitors. This will likely be exacerbated in future, particularly in the face of a European biodiversity crisis (European Environment Agency, 2023a), and increasing water scarcity. For example, large irrigation projects to support drought-affected farmers can have negative consequences for biodiversity by allocating water to agriculture at the expense of the wider rural and natural landscape. This can provoke tensions between drought-affected farmers and environmental campaigners, as occurred in violent demonstrations in western France in 2023 over the health of the Poitevin marshland in Nouvelle Aquitaine, France's second largest wetland (Gill, 2023). (See also Issue 4: Emerging challenges for the governance and equality of access and use of water at the local level for further discussion of such issues.) Substantial tensions can also arise between the supply of water for agriculture and demands generally from industry, household use, power generation, and biodiversity needs. In arid and semi-arid regions, where water scarcity and water governance challenges are already heightened, a substantial anthropological literature exists on these historic and ongoing tensions.
How might the issue develop in future?	**Climate change and food production** In future, the increase in frequency and intensity of heat stress and droughts may force changes in what can be profitably produced in certain regions. For certain crops, suitable growing conditions may shift to other regions within or outside the EU. Studies in the Philippines, for example, show a likely loss in suitable areas for corn production (Salvacion and

Artemio, 2016). Climate change may exacerbate seasonal shortages in certain food and result in higher food prices for consumers.

Production and consumption

The total EU agricultural area is projected to remain stable, while pasture areas and arable land are expected to decline marginally (European Commission, 2022). Indeed, EU meat consumption is expected to fall by 1.6 kg per capita by 2032, to 66kg per capita (European Commission, 2022).

There is also a substantial trade interdependency with non-European countries. Indeed, imports increased from 100 billion USD in 2008 to 196 billion USD in 2022 (Eurostat, 2022). Many of these countries are located in climate regions that will be even more dramatically affected by global warming in future years. This will create issues in terms of water scarcity for them but also food security risk in Europe.

Sustainable farming

Sustainable farming in the EU, which incorporates agro-ecology and organic farming, is expected to increase in the immediate future, as well as over the next few decades. Sustainable farming fulfils many of the ambitions outlined in the EU's environmental plans, due to its alignment with promoting soil health, carbon sequestration, and biodiversity conservation, as well as sustainable water use. The future direction of these approaches is indicated by the number of EU programs promoting them and the EU Regulation on Organic Farming. This issue was explored in detail in the 2020-2021 cycle of FORENV, Issue 4 on sustainable farming. In addition to the policy and financial support via the CAP, already discussed in the Drivers section, there is also a growing market amongst retailers and consumers for sustainably produced food. A survey of over 1,800 companies in France, Germany, Italy, and the Netherlands, conducted by the International Trade Commission, found there is growing demand for sustainably sourced products in these countries (Morrison, 2019). If demand for sustainably sourced food becomes more widespread, opportunities could increase for conventional farmers to learn about these practices through knowledge-sharing networks. This will be supported by the EU's platforms for agricultural knowledge, including the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI) and the European Network for Rural Development (ENRD). However, ultimately, the adoption of sustainable farming practices may be inhibited by demands on food production in Europe, as yields can be lower than in industrial farming (at least for some crops) – although this could be compensated for by increasing imports of foodstuffs that the EU is deficient in from third countries.

New methods for sustainable approaches to agriculture are also being trialled, and these can have further benefits for improving soil structure and mitigating against the effects of drought. Research has shown that no-till production, which minimises soil damage, can also be used to reduce the application of herbicides (Summers et al., 2021) that can harm microorganisms and soil organic matter, both of which positively influence soil structure.

New technologies

Even though most research into the genetic modification of crops is not concerned with traits for water efficiency, there is ongoing research aimed at improving the water sustainability of arable crops. Genetic modifications – such as for wheat that grows longer roots (and hence access water deeper in the ground, increasing resilience) and the use of CRISPR gene editing technology for improved tolerance to drought or poor water quality – could both emerge into mainstream practice in Europe in the medium term (10-20 years), given current legislative constraints and the societal acceptability of GMO crops. Conventional breeding and hybridisation can also produce plant varieties that are more resistant to water stress, but it will take time for effective varieties to be developed and to progress from laboratory to market-ready stages.

In China, scientists have developed a strain of rice that can be grown in salt water (Bloomberg News, 2022). The Mediterranean region of Europe currently produces 2.8 million tonnes of paddy rice per year (European Commission, n. d.). In a future of increased water scarcity for southerly regions with access to the sea, this solution may provide opportunities to continue producing rice but with minimal freshwater use. However, saltwater irrigation should only ever be applied in naturally saline soils, and these are relatively scarce in Europe (Negacz et al., 2022). If it were to be effective and accepted in other world regions, while considering current legislative constraints for GMO, social acceptability, and the need for wholescale infrastructural and land-use change, there is potential for growing this strain of rice in the EU in the medium to long term.

Kelp – which grows in salt water – is increasingly being farmed and used as a commercial food product. Indeed, the European seaweed industry could become one of the key aquaculture sectors of the future. According to some estimates, the growth of the industry is enough to create 115,000 new jobs by 2030 (European Commission, 2023). The increased adoption of kelp in European diets may displace other, more freshwater-intensive foods.

Finally, the research field of space mutagenesis – the process of observing how space-induced mutations may reveal useful genetic traits – could yield results useful for drought resistance and water efficiency in crops (Mohanta et al., 2021) in the medium to long term.

In agriculture, the Internet of Things (IoT) could be scaled up to enable more precise irrigation of crops, utilising remote sensing and automated technologies to integrate weather data, nutrient loads, and other information. However, these systems are expensive in their current form. Whilst access will likely become democratised as technology becomes more affordable, potential solutions to overcome this in the short to medium term include pricing models that remove the initial investment burden and allow farmers to opt out at any time (Goedde et al., 2020).

In the future, urban farming may become more widespread with advances in technologies relevant to water sustainability, such as closed system hydroponic farming. The value of the indoor vertical farming industry alone is expected to more than double by 2030 in Europe, reaching a value of €21.4bn (VynZ Research, 2023). However, as discussed, indoor farming requires large amounts of energy and chemical inputs. Given the need to reduce energy consumption to meet net zero targets, this is a significant barrier to its future development (European Environment Agency, 2023b). The current energy crisis in Europe also shows how unstable the global energy market is and how subject it is to geopolitical instability. This has influenced future energy policy in myriad ways, and it has likely disincentivised investment into sectors with very high energy consumption. Innovative sunlight distribution technologies may, however, go some way to reducing this consumption, particularly in regions receiving more sunlight (Dineen, 2023). Intermittent light exposure (known as disruptive cultivation protocols) may also have potential to increase yields whilst reducing power needs (Avgoustaki, Bartzanas and Xydis, 2021).

Livestock farming

Existing technological innovations like improved milk tank cleaning technologies and water recirculation in cheese making have the potential to be scaled up and made more accessible to farmers and food processors.

In the future, cultured or plant-based alternatives to meat, lab-grown meat, or protein from edible insects could replace traditional meat for consumption, with substantial savings in water possible; see FORENV Cycle 1 (2018-19) Issue 3 (European Commission, Directorate General for Environment et al., 2019). Research has suggested that replacing animal-source foods with novel or plant-based foods in European diets can reduce water use by over 80% (Mazac et al., 2022). Globally, the meat substitute market is expected to grow by 42% annually until 2030 (Grand View Research, 2022). Europe – being amongst the world’s most economically developed regions – could be a leader in this development; however, there could be significant political and practical hurdles to such a transformation, given the importance of animal agriculture economically and culturally in

<table>
<tr><td></td><td colspan="2">many EU countries. The risks of transitions to plant-based diets, particularly those associated with cultured meat and plant-based alternatives, are discussed in the following section.

Land-use change

Water scarcity may in future become a more significant driver around decisions to de-intensify agricultural production in less productive areas, and conversely ramp up production in more highly productive or new areas. This would help ensure that less water is used irrigating land that produces relatively lower volumes of food, whilst preserving water for areas that produce more, typically those with better access to sustainable water sources (Beyer et al., 2022). In more northern latitudes, at least, agricultural land use change is mostly being driven by the need to meet climate and biodiversity goals, but in future, water resource scarcity may become a more significant factor. In semi-arid regions, for example in parts of Spain, this may already be a significant driver of change as farmers fear the feasibility of continuing to farm in drought-prone areas (Euronews Green, 2023).

Rising production costs in more economically well-developed countries could also further shift the production of certain foods like fruit and vegetables (including water-intensive crops like tomatoes, watermelons, and citrus) to southern Europe and North Africa (Anouar, 2022).

Aquaculture

More than half of seafood consumed today comes from fish farms and the sector is expected to grow in the future. The FAO estimates that over 60% of all fish will be farmed by 2030 (FAO, 2018). This could have potential benefits for water use. Freshwater aquaculture does impact water use directly, and both freshwater and marine impact it indirectly due to the water needed to produce feedstocks. However, even freshwater aquaculture generally consumes less freshwater than the production of terrestrial animals (Troell et al., 2014). As explored below, however, this could result in additional environmental risks.</td></tr>
<tr><td>Potential implications for water resilience, the wider environment and human health</td><td>Opportunities</td><td>Risks</td></tr>
<tr><td>There may be seasonal shortages in some water-intensive foods and/or prices may increase for water-intensive foods</td><td>• In the longer term, such shortages may provide opportunities to move to less water-intensive crops and practices. Policy could be used to support this transition.</td><td>• Typical consumers priced out of some foods, which comes with negative health implications, particularly if there are price increases for fruits and vegetables. However, reduced consumption of water-intensive foods like beef may be beneficial to dietary health, as well as greenhouse gas emissions.
• Economic losses for farmers as yields are reduced and some may be forced to stop farming altogether.
• Shocks can propagate through agricultural commodity markets.</td></tr>
<tr><td>The CAP may both support and hinder sustainable water use in agriculture</td><td>• Options to mitigate existing policy that may hinder sustainable water use in agriculture though the EU requesting justifications for exemptions to the WFD and tying CAP payments to</td><td>• Insufficient standards within the CAP, including minimal penalisation of water-intensive farming and grant availability for practices not conducive to sustainable water use, could mean water use in agriculture remains too high,</td></tr>
</table>

	compliance with environmental standards (European Court of Auditors, 2021).	leading to sectoral tensions and localised water scarcities.
Droughts increasing the need for adaptive monetary support packages for European farmers		• Monetary packages supplied by the EU to respond to drought-affected farmers in Europe are useful, but are likely insufficient to respond to the scale of a worsening climate. This is evidenced by the EU committing €430 million to support farmers across Europe in 2023, whilst Spain alone has needed to provide €2.2bn for its own farmers. • The amount of money required reduces the amount available for other uses, such as investment in social welfare and the green transition. • Subsidies can also create farmer dependence on subsidies rather than production and hinder the adoption of adaptative practices.
Increasing interest in genetic modification of crops for improved drought resistance and reduced water needs	• There are signs within the EU that New Genomic Techniques (NGTs) may be more acceptable for European citizens than historical GMOs. • While GMO research is not new there remains potential for developing new drought-resistant and water-efficient crop varieties through genetic engineering techniques.	• EU regulations set a high standard for the approval of GMOs in the EU, and levels of acceptability for GMO foods are low in some EU countries. • Safety concerns have been raised over the effects of GM crops on biodiversity, non-target organisms, and ecosystem functioning. The potential for gene flow for GM crops to wild relatives is a particular concern. • There are public health concerns with GMO, including allergic reactions and antibiotic resistance. • The majority of GMO research is not currently focused on drought resistance or water sustainability. • Risk of concentration of the seed sector, due to patent/intellectual property issues and the risk of market foreclosure. • Risk of increased uniformity of genetic diversity ultimately making agriculture less resilient to environmental stress. • Risk of diversion of investments and delay in the implementation of other structural changes.
GMO paddy rice that can be grown in saline conditions in coastal areas or river deltas could reduce water scarcity for Mediterranean	• Could enable scaling up of rice production in Mediterranean countries with significant economic benefits. • New employment opportunities in coastal regions.	• Overall area of suitable saline land in Europe is relatively scarce compared to places like China and East Asia, where this type of GMO rice is being developed. • Would require infrastructure overhaul and capital investment, converting the use of land previously unworkable for agriculture due to salinity.

rice-producing countries		• Traditional freshwater rice paddy farmers in southern latitudes could suffer impacts to their livelihoods. • Competitiveness with freshwater rice is uncertain due to current challenges associated with taste, nutritional quality, and the overall yield of salt tolerant rice. • Potential negative impacts on marine, river delta, and wetland biodiversity.
Modern irrigation technologies, including drip irrigation and remote sensing are expensive for many farmers	• Technologies should become less expensive in future. • Agri-tech companies can provide innovative pricing models to overcome financial constraints.	• Modernising irrigation does not always improve water sustainability (e.g. due to altered cropping systems and poor decision making). • Realised increases in efficiency can also incentivise expansion into previously unfarmable land, increasing water scarcity issues in those regions.
Water governance can create tensions between the need for food production and biodiversity, as well as industry and households, as water is diverted to feed crops	• Tensions can be mitigated through agroecological land management strategies that combine habitat provision with food production.	• Water extraction in the regions surrounding protected areas may reduce the water required by freshwater ecosystems that depend on both groundwater and surface water. • Will create additional strains on meeting European biodiversity goals and halting biodiversity decline on the Continent. • Could have negative consequences for the mental health of farmers and other people concerned with the health of the environment.
The commercialisation of satellite technology has created a relatively inexpensive method of monitoring water use for farmers	• Improved monitoring data can assist farmers in using water more efficiently. • Improved monitoring can assist governments in monitoring farmer compliance with water.	• Can be subject to significant uncertainties in accuracy. Measurement errors create welfare losses for farmers. • Upfront costs for farmers can still be high, and it requires technological expertise and training.
Falling meat consumption could reduce meat production in Europe	• Opportunities for farmers to diversify agricultural practices or for land to be converted to nature. • Reduced meat consumption should be focused on intensively reared livestock.	• May be compensated by other protein-rich foods that are also water-intensive (e.g. milk and nuts). • Loss of income for farmers. • Risk of abandonment of lands, especially in marginal areas (e.g. mountain areas) with possible negative impacts on biodiversity. Can also increase wildfire risk. • Risk of acceleration of depopulation of some rural areas. • Some plant-based meat substitutes are ultra-processed food (UPFs), consumption of which should be

		limited according to WHO (World Health Organisation, 2021); increased consumption may have negative health implications for the European population.
Indoor farming, which requires less water, is on the rise in Europe	• Reduced water consumption can be further accelerated through water re-use and rainwater harvesting. • Improved access to locally sourced food and food security. • Reduced transport costs and associated emissions due to urban proximity. • Reduced need for pesticide use. • Partly dependant on chemical fertilisers, especially with hydroponics. • Year-round cultivation and efficient land use with reduced reliance on arable land. • Enables precise control over environmental conditions, resulting in crop consistency as well as protection against variable environmental conditions. • Can result in yields many times greater than outdoor farming. • Provides opportunities for using disused urban spaces, including old factories, shipping containers, warehouses, and office space.	• The potential is limited to mostly vegetables which are already partly produced in glasshouses or closed systems. • Controlled environment farming tends to involve higher energy costs. Growth will be undermined by the increasing need to reach net zero and future unforeseen energy crises. • High initial investment costs may be a barrier to many farmers or start-ups looking to start their own indoor farms. • Equipment failure of sophisticated technology is a risk. • Power shortages and blackouts are a threat to the food supply.
A growth in sustainable agro-ecological farming practices across Europe could increase sustainable water use	• Funding to support sustainable farming empowers farmers to implement practices that improve soil structure and thus water retention. • Provides multiple holistic benefits, including nature recovery and climate adaptation and recovery.	• Limits on the amount of food, for livestock in particular, that can feasibly be produced without increasing land use.
In future, farming may need to cease on unproductive land due to water scarcity	• More efficient use of land (i.e. scaled up production on productive land). • Opportunity for nature to recover, with potential boost to sectors like nature-based tourism.	• Farmers' loss of income. • Cultural decline of rural areas and loss of skills and knowledge. • Rewilded or abandoned lands can become more prone to fire risk and land degradation in some cases, whilst nature-based tourism also consumes water. • Loss of livelihoods will increase unemployment and may entail population displacement to more

		northerly latitudes.
Increasing reliance on food imported to Europe		• In countries where climate change will be a greater threat to water scarcity due to more arid conditions, this could increase European food security risks and worsen water scarcity issues for non-European producer countries.
Both the marine and freshwater fish farming markets are expected to grow	• Presents an opportunity for water scarcity (and fish stocks), as freshwater use requirements – even for freshwater farms – tend to be lower than for terrestrial livestock. However, the opportunity relies on fish consumption replacing meat consumption, not adding to it.	• Fish farming, both marine and freshwater, presents environmental issues, including water pollution and habitat destruction.
Rising production costs in northern Europe may further shift fruit and vegetable production to water-scarce countries further south	• Could bring short-term economic and employment benefits through expanding production in these countries, although this could be offset by the longer-term negative implications (see Risks).	• Could increase water scarcity, not only for countries in southern Europe, but also in places like North Africa. • Could lead to challenges for and a decline in relevant food production systems.
Timeframe of emergence	This issue is one that is already evident (in the short term) but is expected to strengthen in the medium to long term. It is already of pressing significance, as evidenced by the wide-scale damage to croplands due to drought across Europe in 2018, 2022, and 2023 and the unprecedented support packages that have had to be introduced to mitigate them. The issue will intensify progressively over the next few decades at least, in line with predicted increases in the intensity and frequency of droughts as climate change advances (Toreti et al., 2019; Mathiesen et al., 2021) Many of the solutions for sustainable water use in agriculture are available now. However, their integration into mainstream food production in Europe will take time given the current barriers associated with their economic feasibility, associated skill requirements, and various other challenges specific to individual solutions (e.g. the high energy requirements of vertical farming). Timelines for various aspects of the issue will vary geographically. For example, in western and central Europe, water scarcity may in future be a significant driver of changes in land use; with more frequent droughts projected in a 2ºC increase scenario by 2050, agricultural land in less productive regions may be turned to nature and agriculture may intensify in more productive regions (Intergovernmental Panel on Climate Change, 2023). However, in the short to medium term, drivers such as climate and biodiversity goals are likely to be far more powerful (Balmford, 2021). This is less true for countries further south, where water scarcity may already be the main driver.	
Uncertainties	The major uncertainty associated with this issue is whether the progressive reductions in water use in agriculture that have occurred in recent decades will a) continue, and b) be sufficient to keep pace with both increasing demand for water from other sectors and the effects of climate change. In addition, there are several more specific uncertainties relevant to different topics within the wider issue. It is well recognised within the EU that improvements in irrigation	

	infrastructure and technologies have the *potential* to bring significant improvements in water efficiency, but it should not be assumed that simply modernising irrigation systems will increase water efficiency. The impacts of modern irrigation systems are complex, and they can have the opposite effect to that intended if farmers' altered cropping and water application decisions aggravate water scarcity (Pérez-Blanco et al., 2021). Spain, in particular, provides evidence of increased water consumption after the adoption of modern irrigation technologies (Berbel et al., 2019; EPRS, 2019). Other studies have found that the Spanish modernisation programme reduced the amount of water applied significantly, but in the long run it led to consistent consumption patterns due to the increase in the irrigated area of land (Garriga, 2022). If technological interventions such as drip irrigation and remote sensing monitoring are to be adopted on a large scale, it is likely that funding mechanisms beyond that provided by the CAP will be required. For example, the EU IRRICLIME Climate Smart Irrigation Tool, a web-based program for farmers, is seeking venture capital investors to scale up the service and promote business development (European Commission, 2023b). Whilst investment in these technologies is likely to continue, the pace of adoption will likely vary across the EU, with factors including infrastructure, affordability, and awareness influencing the pace of adoption. It is therefore uncertain how quickly and comprehensively such technologies will be integrated across the EU. Genetically modified crops may provide many solutions to reduced water availability in agriculture, but there are uncertainties around their potential effects on natural ecosystem functioning and biodiversity, in particular the potential for transgene flow to wild relatives (Ryffel, 2014). They also have potential effects on human health (e.g., allergic effects and their precise nutritional compositions) (Bawa and Anilakumar, 2013). Controlled environment farming (such as vertical farming) holds great promise, but the major barrier to its wide-scale implementation is its high energy demands. The war in Ukraine and associated energy crisis has shown the instability of the global energy market. This is an example of the kind of event that can act as a barrier to investment in the sector. How the future of energy provision in the EU plays out, including the speed of technological advances and the transition to a green economy, other future potential energy crises, and changes in energy consumption patterns globally, will all influence the future feasibility of indoor farming. All these aspects are subject to considerable uncertainty. Whilst projected forecasts of a decline in meat consumption in Europe *could* mean an associated reduction in livestock production in the bloc, this is not necessarily the case. Increased demand for meat globally (Stewart et al., 2021) could feasibly result in sustained production levels in Europe to accommodate third country consumption. The benefits of sustainable farming methods may be increasingly recognised at policy and farm level in Europe, but their successful implementation at scale will rely on the provision of predictable and long-term agri-environmental support to farmers, as well as support for sustainable transformation initiatives (European Academies Science Advisory Council, 2022). Whilst the revised CAP provides improved opportunities to support sustainable agriculture, according to the European Academies Science Advisory Council, it is not clear whether it will be sufficient to enable the transformative approach necessary for long-term agricultural sustainability and resource management, or whether additional areas of intervention will be necessary (European Academies Science Advisory Council, 2022).
Additional research or evidence that may be needed	As the impacts of climate change accelerate, including increasingly frequent and intense droughts and heatwaves, as well as changes in water quality, there will be an accelerated need for further research to understand crop water requirements in terms of both quantity and quality under varying climatic conditions. It will also be necessary to determine optimal irrigation scheduling and irrigation methods for different crops and regions (Lorite et al., 2018). Additional research into climate modelling and

	scenario analysis (including agro-economic models) will also be necessary to help policymakers and farmers anticipate and plan for potential water scarcity challenges. Whilst satellite monitoring has been heralded as a low-cost solution to fill gaps in the monitoring of agricultural water use, the accuracy of water-use estimates is subject to significant uncertainty, with measurement errors potentially creating welfare losses for farmers (Foster, Mieno and Brozović, 2020). Further research is therefore required into understanding to reduce these uncertainties and make systems more accurate. This may need to be coupled with improved training opportunities for farmers. To ensure their safety, a variety of research avenues in genetically modified crops will need to be further developed. Further funding is therefore required for environmental impact assessments, environmental monitoring, gene flow and containment, food safety assessments, allergenicity studies, and nutritional content. Indoor vertical farming can provide a range of environmental benefits, but may be undermined by its high energy costs. Further research is required into how this barrier may be minimised, building on advances in sunlight re-distribution and innovations like highly controlled light exposure (see Future Development Section).
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Issue 8. Use of digital technologies to improve water management	
Emerging issue description	The increase in global water demand and challenges inherent in maintaining ageing water assets and infrastructure, compounded by the impact of climate change and environmental degradation, is driving interest in "digital water management", a term used to describe the rapid digital transformation in the water sector (Sarni et al., 2019). Digital technologies such as artificial intelligence/machine learning, Internet of Things (IoT) (i.e. connected) sensors, mobile technology, open software, augmented reality, cloud computing, and data analytics are providing real-time and actionable information on water for better quality control as well as remote asset management and responsible water use (Ramos et al., 2019; Antzoulatos et al., 2020; Li et al., 2020; Digital-Water City, 2022). The uptake of digital technologies and their integration into water services has been described by the International Water Association as a paradigm shift to the "next generation of water systems, beyond traditional water and sewage infrastructure", where we are seeing (IWA, n.d.): • new services for water management, which include the adoption of digital approaches that integrate operational siloes and provide more dynamic and sustainable real-time decision-making; • a systems approach that recognises the interconnectedness of water across sectors and the benefit of more integrated decisions that acknowledge differences in stakeholder interest/priorities and the need for benefit sharing; and • the adoption of decentralised or distributed systems that maximise resource recovery and address population trends and urbanisation to reduce risks related to failures, particularly infrastructure failure. The water sector is increasingly challenged by water systems and infrastructure that are obsolete, as well as, in many cases, incomplete information on water consumption and losses that occur in the distribution networks due to leaks or cracks (Barton et al., 2019). 'Digital water' consists of sensors and analytical software to digitise and understand water use, quality, and risks and thus improve efficiency, leak prevention, and safety. Digital water management could improve water supply reliability, encourage water conservation, and build resilience through operational efficiencies (Kerr, n.d.). The digital transformation could foster more efficient monitoring, control, optimisation, and forecasting of water consumption and pollution; it could therefore play a role in achieving sustainable development goals related to the safe management of water and sanitation (SDG 6) and the prudent use of natural resources (SDG 12) (Mondejar et al., 2021). Digital technologies are already helping utilities and local municipalities to better understand water supply and demand patterns and identify efficiencies and opportunities to optimise water use and reduce losses. For example, digital twins and augmented and virtual reality technologies are allowing utilities to visualise and model situational scenarios to identify data-driven solutions, "enabling rapid response to water management issues and emergencies and tracking where and when water is needed and at what quality" (Aboelnga et al., 2023). Digital platforms, apps, and tools can increase transparency and accountability in water management, allowing stakeholders (e.g. utilities, consumers) to access and analyse data and make more informed decisions. These tools can also increase engagement between utilities and communities and improve trust in the water sector (Banerjee et al., 2022). While digital technologies have a lot of promise, their upscaling will be challenging due to several factors, including a lack of experienced digitally skilled workers, ageing infrastructure, and the slow adoption of new technologies. A digitalised water sector will require adaptation of traditional risk management approaches to address environmental challenges emerging from the increase in electrical and electronic waste, as well as safety and security protocols to identify cybersecurity threats and safeguard digital infrastructure (e.g. sensors, intelligent

<table>
<tr><td></td><td>management systems) (Germano, 2019). Such protocols should also ensure digital privacy and the protection of consumer data in relation to the deployment of smart water meters (Salomonos et al., 2020).</td></tr>
<tr><td>Key drivers: what is driving the emergence of this issue?</td><td>Ageing and overly stressed water infrastructure

Ageing infrastructure causes water leakage and has posed a significant challenge for water management in cities. It carries risks in terms of potential failure and environmental impact (Ram, 2018). For example, water leakage leads to waste and the overconsumption of resources and is particularly problematic in water treatment facilities that consume a lot of energy and water and must compensate for these losses (Deloitte, 2016). Utilities, however, struggle to evaluate the risks and prioritise strategies, given the technical complexity and financial needs for infrastructure rehabilitation, repair, or replacement (e.g. water mains, pipelines); retrofitting existing and ageing infrastructure; and planning and building adequate water and wastewater treatment in cities (Ram, 2018; Deloitte, 2016). These challenges create opportunities for technological transformation, establishing new data-driven solutions for effective asset management, more efficient operations and remote system management, and low operational costs. This transformation requires integration of the right combination of technologies (e.g. digital sensors, communications, and data analytics) to drive intelligence-based decisions in utility operations, maintenance, and infrastructure investments (Deloitte, 2016; Aboelnga et al. 2023). New and existing infrastructure may also benefit from the adoption of digital twins that enable scenario-planning to optimise performance and the design of future assets (Aboelnga et al., 2023). Digital twins are simulations of smart water grids or cyber-physical systems involving engines, sensors, and processors in continuous communication; they enable more effective control of water management systems. These simulations can improve and continually update data on system components, thereby facilitating greater efficiencies and more proactive maintenance and system performance (Ramos et al., 2023).

Climate change, urbanisation, and population growth driving the adoption of smart systems

A number of challenges – including a changing and uncertain future climate, rapid population growth driving increased social and economic development, globalisation, and urbanisation (Cosgrove et al., 2015) – are increasing pressure on water supply and distribution networks. They are driving the water industry (utilities in particular) to adapt to meet emerging demands of “a dynamic, highly deregulated and competitive environment” against the backdrop of a changing climate (Aboelnga et al., 2023).

Population growth and rapid increase in urbanisation (linked to Issue 6 – Water resilient cities) are accelerating water scarcity in cities, leading to significant water shortages and imbalances at municipal, industrial, and household levels (Aivazidou et al., 2021). These challenges emphasise the need for urban water stewardship and are driving the adoption of more sustainable actions, policies, and technologies. Digital technologies are being adopted to tackle water security challenges in urban landscapes (Liu et al., 2021) and industrial facilities (Su et al., 2020) and the market is shifting to digitalised business models that provide novel services to society at reduced costs (Liu et al., 2021). These disruptive interventions are facilitating real-time monitoring, optimisation, and forecasting of water consumption and pollution (Boudhaouia and Wira, 2021). To maintain delivery of essential services, water utilities are adopting smart systems to address urban sustainability challenges such as excessive water use, flood, drought, and water pollution.

Accelerating climate change is adding further stress to the global water cycle, altering average patterns of water availability and increasing the magnitude and frequency of water-related extremes in different parts of Europe (EEA, 2021). However, there remains much uncertainty about these changes and a lack of understanding among utilities on how to</td></tr>
</table>

	respond to them. As climate change increases, uncertainty over projections of water supply and demand will increase, as well as uncertainty over the feasibility and economic performance assessment of water infrastructure (Fletcher et al., 2019). Weather data has historically guided water infrastructure development, while concurrently presenting water as a timeless and unadulterated natural element (Morgan, 2019). However, future-proofing water management operations against a changing and uncertain future climate will require utilities to better prepare for the impacts of extreme weather before they occur. This implies that relying solely on outdated statistics will prove limiting; establishing new evidence bases for investments is imperative for decision-making when considering infrastructure renewal (Pot, 2023). Water managers are adopting innovations such as predictive modelling approaches that combine operational, meteorological, and climate data to generate insights and improve operational resilience (Banerjee et al., 2022). For example, digital twins could be adopted to predict what might happen in a smart water network and model how the system might react to extreme precipitation events or to monitor real-time water use during periods of drought. These tools have the potential to improve utilities' capability to anticipate disruption and better understand the impacts (i.e. predict and model what may occur and how the system might react), thereby increasing their ability to act early and adapt to disruptive events (IWA, 2021). **Innovation in the water sector** Digitalisation has been identified as an important and necessary innovation in water management with scope for improving the efficiency of distributing water resources across different uses (Sarni et al., 2019). While the global supply of available freshwater is more than adequate to meet current and foreseeable water demands, its spatial and temporal distributions are inadequate (Cosgrove et al., 2015), creating a demand gap. Digital technology has the potential to transform water systems, allowing utilities to become more resilient, imaginative, and efficient while also adopting more cost-effective approaches (Kapadia, 2022). In this context, digitalisation can be seen as a way to maintain and innovate the services provided, increasing business opportunities and connections to other municipal services. The digital vision of Water Europe specifically encompasses business, innovation, and career opportunities, fostering a landscape that is rich with potential for socio-technical growth and progress (Water Europe, 2017). According to estimations, the global utility sector was projected to witness a substantial increase in expenditure on data analytics. Specifically, this expenditure was anticipated to increase dramatically from £700 million in 2012 to 3.8 billion by 2020. This significant growth is already observed across all regions of the world, encompassing gas, electricity, and water suppliers' investments. A new digital ecosystem is being created by integrating smart and IoT-enabled home appliances, smart utility meters, and predictive analytics, based on historical price data from utilities, to accelerate problem-solving and innovate for the benefit of both utilities and customers (Md Eshrat et al., 2023). However, the success of digital transformation in the water sector is reliant on technology development, as well as the connectivity and digital maturity of utilities and their willingness to digitise systems. The demand pull, including regulatory requirements, economics, and efficiency, are key drivers for technology development (Liu et al., 2021).
How might the issue develop in future?	**Digital solutions at municipal, industrial and household level** *Smart water cities* Urbanisation creates a major challenge in urban water management, with specific issues including the inadequate provision of drinking water, poor water quality, and ageing or inadequate infrastructure. The concept of a smart city is becoming prominent as a response to challenges associated with city expansion. A Smart Water City (SWC) is "a sustainable city with contactless, intelligent water and wastewater

management systems" (IWA, 2021). AI-enabled and smart management systems are widely adopted in smart cities, as they enable the efficient use of resources and optimisation of water usage.

The adoption of smart technologies in water management and service provision has increased over the past decade (Leflaive et al., 2020). For example, in the USA, digital technologies have been employed in city planning and urban expansion to restore the natural water cycle. In Kenya, digital platforms are employed to engage residents to identify and scope local water management challenges (e.g. water quality and sanitation issues), facilitating a more localised approach to defining solutions. In Costa Rica, digital technologies are being employed to monitor water quality, collect water sediments, and identify poor drinking water status. A smart city initiative in Spain is facilitating the development of national and regional regulatory frameworks to regulate the use of smart water technology in the treatment and reuse of reclaimed urban waters. The digital management of data can also contribute to human health monitoring and surveillance, as seen in the recent COVID pandemic, or in illicit drug use (Causanilles et al., 2018).

The main challenge associated with SWC is the requirement for significant investment in hardware, software, and personnel. There are also concerns related to the high data requirement (to assure functionality) and the need to protect and secure individual privacy and the confidentiality of personal data (Frackiewicz, 2023). A digitally enabled water sector requires staff with multiple skill sets (e.g. AI/machine learning, sensing, cybersecurity) who are flexible enough to adapt to a rapidly evolving water environment. A World Economic Forum report on the Future of Jobs stated that 50% of global employees will need reskilling by 2025, as the adoption of digital technology grows in multiple sectors (WEF, 2020). Equally, the digital transformation will need to be inclusive in its approach to ensure equitable and sustainable development (IWA, 2021). The ramifications of the digital divide – a phenomenon frequently associated with the perpetuation of poverty in underprivileged nations and the exacerbation of socio-economic disparities in prosperous ones – as a persistent challenge need to be addressed.

Digital waste management is already being integrated in wider visions, such as the Water-Smart Society model introduced by Water Europe (2023) to encourage social system-level reflection in the context of smart water cities. The model emphasises the importance of water as a fundamental human right with a crucial social role across various objectives (ability to withstand impacts of climate change, ensure the safety of water resources, promote sustainability) and innovation concepts related to the objectives (circularity, usage, infrastructure considerations, governance for inclusive water, and digital waste management). The debate over water's status as a basic human right brings to light the reality that the privatisation of water systems is a critical problem that calls for increased conversation and consideration on its own (SCHEER, 2023). See Issue 4 for further information.

Digital water utilities

Globally, water and wastewater utility sector expenditure on digital solutions is forecast to grow 8.8% annually, from $25.9 billion in 2021 to $55.2 billion in 2030 (IWA, 2021). Challenges for water utilities are expected to intensify as a result of climate change and increased water demand due to population growth (Larsen et al., 2016). Digital technologies have proven effective in achieving resilience and efficiency in water utility operations dealing with challenges such as leakage in pipelines, water shortages, and growing non-revenue water costs (Beal & Flynn, 2015). In the UK, satellite technology company Utilis conducted trials with three utility companies using satellite imagery and advanced algorithmic analysis to detect underground water leaks from pipelines within a 100m radius. Results from the study showed the number of leaks found per site inspected was approximately 0.75, equivalent to about three leaks for every four sites investigated. Advances in satellite

	RADAR capabilities and analysis algorithms are expected to improve leak detection capabilities (Aqua Tech, 2018). The uptake of digital technologies in the water sector was initially relatively slow compared to others (e.g. manufacturing, energy, healthcare) (Mutchek & Williams, 2014). Future policy outlooks and water management strategies are focused on rapid change, with the aim of addressing climate change and water security challenges using digital technologies (Nadkarni & Prügl, 2021). Digital technologies are expected to help water utilities become operationally efficient, more inclusive, and digitally integrated with customers and society (Arnell et al., 2023). Employees in utilities will require new skills to manage digital systems (hardware and software) and integrated systems for operations and maintenance (e.g. operational risks and cybersecurity plans). Operational areas such as instruments and sensors, data management, infrastructure, and cybersecurity will grow in size and importance as the sector's digital transformation accelerates (Hassanzadeh et al., 2020; Arnell et al., 2023; Simic and Nedelko, 2019). Given the growing utilisation of digital technologies in government, business, and infrastructure, there might be shared characteristics that could potentially enable the transfer of experience and lessons learned, especially to the water sector. However, issues around data sharing and the training of algorithms are major challenges. Therefore, regulations should be developed and satisfactorily implemented, and cybersecurity measures should be fortified to support this (SCHEER, 2023). *Smart irrigation (link to Issue 8)* The Food and Agricultural Organisation (FAO) forecasts a more than 50% increase in irrigated food production by 2050; this will require a 10% increase in water abstracted for agriculture, providing there are reductions in water use and greater efficiencies in farm water management operations (FAO, 2020). Irrigation scheduling is crucial to reduce high water consumption by matching supplies to crop needs and avoiding losses. Drones, AI, and IoT systems are used to optimise water schedules, automate the frequency of irrigation, and make adjustments to meet specific landscape needs (Blanco et al., 2020; Nui et al., 2020; Duangsuwan et al., 2020). Garcia et al. (2020) have proved that farmers who rely on heuristic methods of scheduling, such as manual, time-based, and volume-based irrigation, registered significant water losses. Implementing an optimised irrigation schedule through a smart irrigation system can reduce losses. For example, Meeks et al. (2020) reported a 10% reduction in irrigation water used through irrigation scheduling in cotton production. Smart irrigation requires sensors to monitor soil, plant, and weather conditions. This is then complemented by irrigation control, which allocates inputs and makes necessary adjustments according to the crop response to save irrigation water, while mitigating the effects of disturbances and uncertainties (Abioye et al., 2020a; Zazueta et al., 2008). Typical commercial sensors for agricultural irrigation systems are expensive, making it difficult for small-hold farmers to implement this type of system (Garcia et al., 2020). *Smart water metering and dynamic pricing* Smart metering and monitoring, introduced in Mexico, have enhanced operation and maintenance programmes with greater operational efficiencies, thereby reducing non-revenue water and extracting less water from existing sources (McKinsey Global Institute, 2018). Smart meters help manage water demand by moving from time-invariant to time-varying volumetric prices, referred to as dynamic pricing. The adoption of smart water meters in Spain, when compared with prior constant volumetric rates, showed that urban consumption reduced by 18% in the driest years, lowering the basin-wide cost by 34% (Lopez-Nicolas et al., 2018). Smart metering could facilitate water conservation by dynamically changing prices to reflect water scarcity and supply cost variability. However, there are uncertainties around water consumers' acceptance

of short-term price changes – a fundamental determinant of the effectiveness of dynamic water pricing (Marzano et al., 2020). The barriers to the diffusion and adoption of dynamic pricing include political resistance to time-varying prices and the unavailability of cheap associated technologies. These barriers are heightened in the water sector, where time-varying prices could be considered an infringement on the essential right to water (Dutta and Mitra, 2017).

Smart meters reduce water losses and support the management of water demand. In 2019, Singapore's National Water Agency reported reduced water losses of 5% due to early leak detection and the adoption of water-saving habits. Brears (2019) reported that Singapore's Public Utilities Board (PUB) planned to introduce smart meters in new and existing residential, commercial, and industrial premises by 2023. The PUB has deployed autonomous Beyond Visual Line of Sight (BVLOS) drones to manage aquatic plant growth and monitor reservoir activities. Overall, 7,200 hours of staff time are normally used per annum to undertake these tasks. Using the BVLOS drones saved around 5,000 hours of staff time, allowing the utility to redirect its staff to other tasks (Brears, 2021).

Decentralised and distributed water management systems

Centralised water systems are challenged by increasing water costs and water delivery and security issues, particularly for underserved populations. Centralised systems currently face multiple challenges, both on the supply and the demand sides (Bouziotas et al., 2019). These systems are capital-intensive and have high negative environmental impacts. Centralised water management systems have increasingly been vulnerable to floods, fires, and droughts. It is anticipated that these challenges will be addressed by decentralising water management using novel technologies, institutions, and practices (Xu et al., 2020). Modern innovations have already been used in the waste and energy sectors through decentralised systems and this is likely to happen in the water sector as well.

Interest is growing in the use of decentralised and distributed water infrastructure to improve water resilience in communities. Distributed practices have the potential to reduce costs and risks associated with the failure of old infrastructure and ultimately improve water resilience in communities. However, challenges associated with the spatial integration of decentralised or distributed systems, their high energy consumption, and their social, economic, and environmental viability cannot be ignored. The decentralisation of urban water will not come easily: it brings a higher degree of system complexity and requires cooperation from multiple sectoral bodies, including water utilities, communities, and entrepreneurs (e.g. start-ups), to collaborate and co-design efficient systems. The decentralised system has other challenges, such as the use of diverse water sources (e.g. rainwater, grey water), and faces significant resistance from the public. Legislation to guide the implementation of decentralised and hybrid systems is critical to facilitating their adoption and uptake (Xu et al., 2020).

Digital platforms, apps, and tools to improve consumer access to data on water resource management

Several digital solutions have been developed for monitoring water, with successes reported for commercial systems that have achieved enhanced efficiency compared to older technologies (Ahmed et al., 2020). Sensor devices within smart buildings are enabling smart water consumption management and monitoring. Smart meters transmit data to a centralised system that stores water consumption information, draws conclusions about water use (e.g. high consumption, possible leaks), and sends data to the user or for further data processing (e.g. use of machine learning algorithms to anticipate future consumption patterns).

In smart buildings, for example, consumers can monitor their consumption through easy access to data and billing information. Mobile apps and digital devices can deliver timely and targeted prompts to help

	citizens keep track of water use. An unusually hot weather spell, for example, can trigger smart ideas for keeping the garden watered. For those households on smart water meters, a higher-than-normal bill could trigger water saving advice along with examples of how much money can be saved on the next bill, delivered right at the point of billing via social media and app channels (Weller, 2019). In the UK, a major water utility (Thames Water) has launched a new online community platform that will make it easy for customers to engage with the company and each other. The data from these conversations will be used to improve the service provided. According to ForeSee's 2018 Utilities CX Insights report, 80% of customers would forego the call centre if provided with an ideal online experience. Digital self-service can make organisations more cost-efficient and give customers more control of their spending. Companies like United Utilities are making life easier for customers with an app that lets them make payments, submit meter readings, and view their payment history (Weller, 2019). **Predictive modelling and analytics to build operational resilience** *Use of AI and data analytics for more informed water management decisions* Artificial intelligence, sensing techniques, and data analytics are being employed in the water sector to optimise the design and control of water and wastewater treatment systems. Data-driven technologies and sensing techniques (e.g. IoT sensors and AI) are employed to generate deeper insight around plant malfunctioning (e.g. fault scenarios, demand prediction) to prevent system failure, and improve operational efficiencies (e.g. leaks, water quality). For example, Sydney Water in Australia established a digital pilot programme in 2017 to proactively reduce leaks and breaks in the water network using acoustic technology (Brears, 2020). Acoustic sensors were deployed across Sydney's water main network to gather data in real time. Sydney Water estimates that the programme will help reduce 50% of water main leaks and breaks in the future, enabling more proactive maintenance that will reduce interruption to customers and operational costs (Brears, 2020). Furthermore, evidence from the European Commission and the Executive Agency for Small and Medium-sized Enterprises (2021) suggests that recent research is exploring innovative technologies that are both efficient and economical for monitoring water quantity and quality. Examples include the DIGITAL-WATER.city (DWC) project, which seeks to leverage the potential of smart digital technologies to improve, inter-alia, human health outcomes through real-time bacterial monitoring, and SCOREwater, which focuses on real-time water level monitoring. Findings like these indicate that predictive water maintenance and monitoring at city level could be used instead of manual inspection for maintaining wastewater infrastructure. A case study in Gothenburg estimated that this investment could make up around 10% of the annual maintenance cost. A digital twin of the sewer networks in two Swedish cities (Gothenburg and Helsingborg) was developed to identify a solution to combined sewer overflows that led to 3 billion litres per year (2% of total flow) of untreated wastewater being discharged to the environment. The digital twin was adopted as a decision support system with online prediction and suggestions for control strategies. Simulation of real-time control strategies increased the operator's confidence to make decisions as the effects of changing strategies were visualised. The next stage of development focuses on implementing a fully predictive control model. However, a significant challenge is the slow speed of computations for both current operation and model comparison functions, which restrict scenario evaluation and predictions (IWA, 2021). Ageing infrastructure in the water sector is paving the way for data-driven tools. For example, real-time water quality audits at critical points could help identify where decentralised water treatment may be required to ensure good water quality (Mondejar et al., 2021). The integration of data-driven approaches and modular on/off treatment

systems could improve water quality in European countries. Such integrated approaches represent a step-change in water management practice, creating a platform for the better integration of sustainable development goals in water management strategies (Richard et al., 2020). To accelerate the transition, the sector requires investment in infrastructure that will support digital technologies (or the ability to deploy smart infrastructure) and digital skills training to enhance capacity and develop the skills needed to effectively use and manage these technologies. Equally, the benefits of the digital transformation should be accessible across society and the cost (often transferred to consumers) could mean that poorer communities are further disadvantaged (H2O Global News, 2021). There are also increasing societal concerns around the development and (mis)use of AI technology, which points to the need for responsible innovation as a pillar of digital futures (SCHEER, 2023).

Analytical tools to support better water resource planning and management in large river basins

Large river basins have historical challenges for water resource planning and management, given that they span multiple jurisdictions (e.g. transboundary basins). Significant challenges arise from the need to integrate data across large areas, consider multi-stakeholder perspectives to inform coordinated decisions, and secure large infrastructure investments. Digital technologies are proving useful to gather real-time data (e.g. via in-situ and IoT sensor networks) and to acquire increasingly powerful Earth observations from satellites, drones, and other unmanned aerial vehicles to survey large water bodies (Harshadeep and Young, 2020). Analytical tools (e.g. scenarios, forecasts) are useful for producing a digital replica (such as a digital twin) of river basins to facilitate analysis (e.g. estimates of water status at any point along the basin); these can provide insights for tactical operations and support strategic planning (Harshadeep and Young, 2020). The integration of data mining and machine learning/AI can integrate perspectives and support the development of integrated basin and aquifer plans, based on both analytical and stakeholder input (Harshadeep and Young, 2020). Crowd and other open / sharing platforms (e.g. fintech, assets sharing systems) have applications for water management in large basins to support learning and constructive exchange among different stakeholders. The effective deployment of these tools will depend on the governance structures within countries bordering water bodies and the extent to which digital technology enhances or hinders processes of stakeholder participation and empowerment (Flores and Crompvoets, 2020).

Cybersecurity, digital privacy, and data protection

The digital transformation of the water sector has increased cybersecurity risks to the operation of water systems. For example, a water treatment plant in Florida in 2022 was subject to a cyberattack in which the amount of lye added to the water was changed to dangerous levels. However, the lye content was adjusted by the plant operator before any significant harm was done (Bushwick, 2021). Attacks of this nature pose a threat to public health and safety as well as national security.

Digital water systems utilising IoT networks (e.g., LoRaWAN communication protocols) are particularly vulnerable to cyberattack, where perpetrators can gain deep insights into water operations and management processes and manipulate data and algorithms to create major faults or system failure. Attacks can cause contamination, operational malfunction, and service outages that could generate serious environmental and public health impacts (e.g. illness, causalities), resulting in costly recovery and remediation efforts and national security issues (Germano, 2019). Increasingly, water companies are finding that they need better risk assessment and IT systems to protect customer privacy and sensitive personal information (e.g. employee records,

<table>
<tr><td></td><td colspan="2">customer usage data and billing information) that is also attractive to cybercriminals.

The legislative framework in the European Union (e.g. General Data Protection Regulation, the Network and Information Systems Directive and the Cybersecurity Act) has established regulatory measures that have improved the security regime for critical services such as energy, health, and water supply. For example, drinking water providers are required to implement cybersecurity measures that ensure operation in an emergency, and they have a responsibility to report cyberattacks to national regulators (Markopoulou et al., 2019). However, greater organisational responsibility and accountability (e.g. municipalities, utilities) are needed to ensure physical installations are safeguarded and appropriate security and data management systems are installed to protect the confidentiality, integrity, and privacy of information systems. The challenges for utilities are multifaceted (e.g. public health, environmental protection and security), with governance and oversight from multiple authorities (e.g. local /regional municipalities, national agencies, European authorities) overseeing the management of water and wastewater systems. Utilities in some cities are also embedded in municipalities, with shared infrastructure with varying levels of risks, and a legacy system (e.g. aged infrastructure) that increases the challenge of managing cyber risks demonstrated by a lack of cybersecurity and/or data protection plans (Cali et al., 2023). Examples include the risk of access breaches in the drinking water system, including the supply and distribution network, and an increased risk of cross-border cyber-attacks (SCHEER, 2023). More proactive management of cyber risks will require utilities to establish new standards for risk assessment planning and responses to identify cybersecurity threats, safeguard digital infrastructure, and protect the confidentiality, integrity, and privacy of information systems (Cali et al., 2023; Markopoulou et al., 2019).

Environmental impact of digital futures

The effects of digitalisation on water resources are complex. Research conducted in emerging domains (e.g., data anthropology, media infrastructure) challenge technology-centric perspectives associated with the Fourth Industrial Revolution (IR 4.0). Cloud infrastructure, as explained by Ortar et al. (2022), relies on data centres to provide digital societies with apps, software, and computing resources via the cloud. Data centres, as engines of digital worlds, store, process, and transfer huge volumes of daily data from internet-connected devices, using a lot of energy to operate and cool their computing equipment – so much that in recent years they have become a major worldwide consumer of electricity (1% according to Al Kez et al., 2022). One example of the risk they pose is straining local energy supply and generating energy shortages in neighbouring communities.

Conflicts have emerged in regions where water scarcity is a pressing issue, partly due to the substantial water usage of data centres. As reported by Mytton (2021), these data hubs consume water through direct means, such as cooling processes, with up to 57% being sourced from potable water or through indirect generation of power. According to the same source, controversy exists around the public disclosure of large data hubs’ (like Google and Microsoft) water usage. Recent research indicates the need to shift the process of digitising industry towards environmentally friendly data centres, called green data centres. These are based on principles of adopting green and renewable solutions, including green power, water reclamation, and zero-water cooling systems; recycling and waste management practices; and avoiding outdated systems such as inactive or overused servers (Sovacool et al., 2022). By embracing newer and more efficient technologies and practices, these data centres could promote sustainability.</td></tr>
<tr><td>**Potential implications**</td><td>**Opportunities**</td><td>**Risks**</td></tr>
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for water resilience, the wider environment and human health		
Smart water cities, use of digital tools to enhance city planning and water management	• Smart water city approach (e.g. in Spain) has embedded a national and regional framework to regulate the use of smart water technology in the treatment and reuse of reclaimed urban waters. • Digital technologies employed in city planning and urban expansion to restore the natural water cycle. • Digital platforms engage residents in scoping local water challenges, facilitating a more localised approach to water management. • Forecasts and predictive models of water demand used to monitor water quality and optimise water management and service provision (e.g. enhance quality). • Facilitating the development of national and regional regulatory framework to regulate the use of smart water technology.	• Accelerating the uptake of digital technologies in the water sector requires significant investment in hardware, software, and personnel. • Training institutions are needed to adapt existing skills and ways of working across the sector. • Concerns exist around the high data requirement (to assure the functionality of digital systems) and the need to protect and secure individual privacy and the confidentiality of personal data. • Inherent unpredictability of socio-technical maturity in the management of sensors for water applications (e.g., sensitive parts and components drive up costs, reliance on human skills and management, reliance on progress in other areas which is also unpredictable) (SCHEER, 2023).
Digital water utilities; use of digital tools to optimise water management operations and services	• Digital technologies help water utilities become operationally efficient, more inclusive, and digitally integrated with customers and society. • Digitally enabled leak detection systems allow the detection of underground water leaks from pipelines – for example, by using satellite imagery and advance algorithmic analysis. as in the UK.	• Relatively slow uptake of digital technologies in the water sector compared to others (e.g. manufacturing, energy, healthcare). • Utilities employees require new skills to manage digital systems (hardware and software) and integrated systems for operations and maintenance (e.g. operational risks and cybersecurity plans). • Lack of data protocols (e.g., standardization of data and metadata from different sources) (SCHEER, 2023). • Advances in satellite RADAR capabilities and analysis algorithms needed to improve leak detection capabilities at utilities.
Smart irrigation	• Irrigation scheduling is crucial to reduce high water consumption. Drones, AI, and IoT systems are used to optimise water schedules and automate frequency, making adjustments to meet specific landscape needs.	• Commercial sensors for irrigation systems are expensive, possibly barring access to smallholder farmers.
Smart water metering and	• Can reduce non-revenue water by extracting less water from	• High investment cost.

monitoring	existing water sources. • Useful in managing water demand.	• Reduced labour demand.
Dynamic water pricing	• Allows for conserving water by dynamically changing prices to reflect water scarcity and supply cost variability. • Saves staff time and effort.	• Effectiveness and consumer acceptability of dynamic water pricing uncertain. • Political resistance to time-varying prices. • High cost of associated technologies.
Decentralised and distributed water management systems	• Distributed practices have the potential to reduce costs and risks associated with the failure of old infrastructure and ultimately improve water resilience in communities.	• Higher degree of complexity due to the need for spatial integration of decentralised systems and high energy consumption, along with social, economic, and environmental viability. • Requires cooperation from multiple stakeholders (e.g. water utilities, communities, and entrepreneurs) to collaborate and co-design these systems. • Legislation to guide decentralised and hybrid systems is critical. • Faces significant resistance from the public.
Improving consumer access to data on water resource management	• Mobile apps and digital devices can deliver timely and targeted prompts to help citizens keep track of water use. • Customers have more control of their spending, with easy access to water use data and billing information.	• Increasing cyberattacks targeting consumer data and personal information pose high risk to privacy and data security. • Lack of engagement in digital apps (e.g. among older population or those with limited access to IT resources).

Data-driven tools (e.g. AI, sensing) that enhance water management decisions	• Integrated data tools and sensing techniques (e.g. IoT sensors and AI) generate deeper insight into the operation of water treatment plants to predict faults and system failure. • Real-time water quality audits at critical points could help identify where decentralised water treatment may be required to ensure good water quality. • Drones/unmanned aerial vehicles improve surveillance of river basins, generating real-time actionable data (e.g. water flow, quality). • A digital twin of a river basin could be used to estimate water status at any point along it, providing insights for tactical operations and long-term planning. • Crowd and other open / sharing platforms (e.g. fintech, assets sharing systems) have applications for water management in large basins to support learning and constructive exchange among different stakeholders.	• Poor digital skills and capacity to effectively implement and manage digital technologies. • Lack of investment in infrastructure to support digital technologies. • Lack of demonstration projects that illustrate the capabilities of digital technologies in supporting decision-making, e.g. fully predictive digital twin model (IWA, 2021). • Governance structures within countries bordering water bodies could hinder the extent to which digital tech enhances the processes of stakeholder participation and empowerment.
Cybersecurity, digital privacy and data protection	• New standards for risk assessment planning and responses to identify cybersecurity threats will improve the accountability of utilities and municipalities.	• Lack of digital skills and cybersecurity training of water sector employees, along with a lack of appropriate security and data protection plans, are increasing vulnerability to cyberattack. • Governance and oversight on water and wastewater management issues (e.g. public health, environmental protection, and security) are provided by multiple authorities and lack an integrated, holistic approach.
Timeframe of emergence	The adoption of digital technologies is already occurring in the water sector, but progress is slow and patchy compared to other sectors (e.g. manufacturing, energy, healthcare). Challenges related to high investment costs and a lack of digital skills are impeding progress in some European countries, who lag with lower operational and service delivery efficiencies compared to more technologically progressive countries. The digital transition will depend on organisational culture and will and access to the skills needed to adopt digital technologies, alongside regulations and compliance requirements that may impede adoption and access to markets. Pressures to innovate may accelerate the transition in the short to medium term as rising operation and maintenance costs and ageing infrastructure, compounded by urbanisation and climate change, prompt rapid uptake of digital technologies to help balance flow, monitor leakages, and manage capacity. The digital management of water could continue to contribute to human health monitoring and surveillance systems, as in wastewater monitoring for COVID (SCHEER, 2023).	

Uncertainties	The current digitalisation agenda is propelling the use of digital tools to optimise water management. However, the slow adoption of digital technologies compared to the energy sector, for example, and the lack of studies do not allow a full assessment of the potential for digital water management to address the current challenges. Similar uncertainties remain around the use of some of the more promising digital tools (e.g., predictive capabilities, real-time monitoring, and decision support through digital twins). The effectiveness of predictive models (based on digital twin applications) hinges on the availability of historical data and the acquisition of real-time data, coupled with computational capability (e.g. IT hardware and software, algorithmic analysis). Current evidence suggests that the application of digital twins in the water sector could be challenged by the slow speed of computations for both current operation and model comparison functions, which restrict scenario evaluation and predictions (IWA, 2021).
Additional research or evidence that may be needed	Additional research or evidence to further understand the emerging issue: • A better understanding of techno-economic, social, and environmental challenges inherent in adopting digital technologies in the water sector (Aivazidou et al., 2021). • Guidance and integration of operational risk and digital security as the water sector transitions away from traditional approaches to risk assessment, mitigation, and contingency planning (Taormina et al., 2018). • Complex social and political aspects of digital water management (e.g. dynamic pricing) (Sharmina et al., 2019). • Technical skills to develop digital capabilities (e.g., learning algorithms, predictive modelling) are in the hands of a small, relatively homogenous community of experts and the inherent diversity within communities is not well represented (Criado Perez, 2019; Thylstrup & Veel, 2017).
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Issue 9: The need for co-transitions to avoid unintended consequences for water resilience	
Emerging issue description	Distinct but interrelated transitions are currently taking place in Europe, for example the green and digital transitions. Transition processes are highly unpredictable, open-ended, complex, and non-linear processes that often produce unintended consequences and surprises. Due to interlinkages between societal systems, governance interventions to alter one part of a system are likely to produce costs and benefits elsewhere (EEA, 2019). Given the shared reliance of production and consumption systems (e.g. energy, food, mobility, and the built environment) on natural resources (including water) and the scale of the changes envisaged for these transitions, they are likely to have both synergies with and impacts on water (EEA, 2022), including competition and conflict over water usage and overall demand. For example, some new technologies needed to achieve net-zero greenhouse gas emissions, such as carbon capture and storage and hydrogen production, are particularly water-intensive, putting further pressure on scarce water resources (Weston, 2022). At the same time, the digital transition may exacerbate pre-existing water shortages due to additional demand for water use in, for example, micro-chip production, extractive industries, recycling, and the cooling of data centres (see also Issue 8 on Digital technologies for water management). As transitions in energy, digitalisation, and the green economy gain momentum, they might inadvertently exert greater pressure on Europe's water resources. At the same time, transitions have the potential to enhance water use efficiency, offsetting the additional consumption of water. It is expected that the energy transition overall will reduce the impact of the energy sector on freshwater resources (European Commission, 2020a). The energy transition is driving a shift towards new energy sources (e.g. renewables) and the emergence of a hydrogen economy is also possible, especially in some sectors. Some low-carbon technologies, such as wind and solar PV, require very little water; others – such as biofuels, concentrating solar power (CSP), carbon capture, utilisation, and storage, or nuclear power – are relatively water-intensive (IEA, n.d.). However, their potential water demands are not generally being considered as a priority. Consideration must be given to the ability of co-transitions to counteract or reinforce each other, as well potential cumulative and unintended consequences on water resources. To strengthen EU policy coherence and minimise unintended pressures on water and other natural resources, the challenges and opportunities associated with simultaneous transitions need to be analysed from a systematic lens (EEA, 2022).
Key drivers: what is driving the emergence of this issue?	**EU policy and long-term strategic goals** The principal ambition of the European Green Deal is to reconfigure production and consumption systems such as energy, food, mobility, and the built environment towards sustainability (EEA, 2022). Both the green and digital transitions are political priorities of the European Commission that will shape the EU's future in the long term (European Commission, 2022). A proactive and integrated approach to managing this twin transition is necessary to ensure that they successfully reinforce each other to deliver a sustainable, fair, and competitive future for Europe (Muench et al., 2022). The EU Climate Law laid down the EU's commitment to be climate-neutral by 2050 – an economy with net-zero greenhouse gas (GHG) emissions. This commitment is at the heart of the European Green Deal and in line with the EU's commitment to global climate action under the Paris Agreement (European Commission, n.d.(a)). As part of this plan, the Commission has proposed (as part of the 2050 long-term strategy) to cut GHG emissions by at least 55% by 2030 (European Commission, 2020b). The Net-Zero Industry Act has also been announced as part of the Green Deal Industrial Plan. The Act aims to scale up manufacturing of clean technologies in the EU and make sure the Union is well-equipped for the clean energy transition (European Commission, 2023a).

Industry demonstrating the potential of increased water

It is estimated that industry is responsible for approximately half of the total water consumption in Europe; it is thus both a heavy consumer and a key catalyst in mitigating water challenges sustainably and efficiently. In January 2023, some leading industry partners issued a joint statement on how and why Europe must develop an integrated approach to water resource management, water reuse, and wastewater discharge. This goes from the Water Framework Directive directly to the Industrial Emissions Directive, supported by the Green Taxonomy and ESG reporting as well as the rules on the treatment of urban wastewater (State of Green, 2023). In Denmark, companies like Grundfos, AVK, Rambøll, NIRAS, Carlsberg Group, and FLSmidth have all shown how solutions such as metering, pumps, valves, and temperature control can produce goods with lower impact on water resources (State of Green, 2023).

A renewed focus on EU energy security

Russia's war in Ukraine is reinforcing the need to improve EU energy security by increasing the bloc's independence and ensuring the safety of critical energy infrastructure (Muench et al., 2022). The EU therefore has an ambition to end imports of Russian fossil fuels in the next few years (DG ENER, 2023; Taylor, 2022). In response to the hardships and global energy market disruption caused by the Russian war of aggression against Ukraine, the European Commission has announced its RePowerEU Plan. This aims to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition, inter alia, by setting groundwork for a dramatic acceleration of renewables in the European Union (European Commission, 2022a; S&P Global, 2023).

This supports the shift in focus towards clean energy technologies (i.e., renewables, energy storage, hydrogen, carbon sequestration) playing a central role – not only as enablers of a low-carbon economy but also as pivotal drivers to increasing energy security, independence, and power systems' resilience (S&P Global, 2023).

EU investment in new and alternative energy sources (e.g. sustainable hydrogen production)

The Commission has set out new plans to stimulate and support investment in sustainable (green) hydrogen production through a European Hydrogen Bank (EHB), a €3 billion investment vehicle (DG ENER, 2023; Hernandez, 2022). This initiative is aimed at accelerating investment and bridging the investment gap to help the EU to reach its ambitious REPowerEU targets of producing domestically 10 million tonnes (mt) of renewable hydrogen by 2030, coupled with 10 mt of imports (DG ENER, 2023).

The Commission has already proposed a fully-fledged legislative framework for the production, consumption, infrastructure development, and market design for hydrogen; this includes binding targets for renewable hydrogen consumption in industry and transport under the revised Renewable Energy Directive (DG ENER, 2023). The EU has also launched and promotes several industrial, funding, and research and innovation initiatives on hydrogen, including the Clean Hydrogen Partnership, the European Clean Hydrogen Alliance, and the Hydrogen Public Funding Compass (European Commission, n.d.(b)). In the case of hydrogen, in response to the impact of the Covid pandemic on the Commission's Green Deal plans, the Commission has prioritised hydrogen as a key potential solution (Hernandez, 2022).

EU investment in micro-chip production

Recent global semiconductor shortages made more evident the extreme global dependency of the semiconductor value chain on a very limited number of actors in a complex geopolitical context (European Commission, n.d.(C)). The findings of the Chips Survey, launched by the European Commission, highlighted that industry expects demand for chips to double by 2030. This reflects the growing importance of semiconductors for use in European industry and society (European Commission, n.d.(c)). The European Chips Act aims to address semiconductor shortages and

	strengthen Europe's technological leadership by mobilising more than €43 billion of policy-driven investments (European Commission, n.d.(c)).
How might the issue develop in future?	**Green and digital transition may increasingly put unintended pressure on European water resources (but conversely also drive water efficiency)** Net-zero and decarbonisation are at the forefront of political and corporate agendas. Among the EU's green and digital transition goals are the electrification of mobility, the transition from fossil-based energy production to renewable energy sources, and the development of new technologies and techniques for storing and distributing clean energy (Press Release: Europe and its green and digital transition: where and how to get the necessary critical raw materials?, 2022). As industry gears up for decarbonisation, water supply is likely to be the "twin challenge" that companies face in achieving their carbon goals (Foresight Events, n.d.). This is partly because water is critical for some key decarbonisation solutions (e.g. micro chip production, carbon capture and storage (CCS), hydrogen production, nuclear power, hydropower), therefore putting further pressure on scarce water resources (Alsford, 2022; Weston, 2022). In Europe, industry represents nearly 50% of total water use and some industry leaders are already pushing for increased water efficiency in European industries (State of Green, 2023). The highly integrated nature of water in the energy transition (water-energy-nexus) may mean that decarbonisation is a key driver (and in some places, a precondition) of improved water efficiency across industry in coming decades (Foresight Events, n.d.; Weston, 2022). Alternatively, scarce water resources could become a key barrier and challenge to achieving the green energy transition. Similarly, the digital revolution brings its own water challenges; for example, more data centres will need more and more water for cooling (Foresight Events, n.d.) until less water-intensive cooling technologies are extensively adopted (e.g., liquid cooling). Interventions to increase industry access to water may require investment in expensive technology, such as desalination (Alsford, 2022) (see also Issue 2 on new and alternative sources of water). As noted in Issue 2 and explored in Issue 3 on whether a circular economy will enhance water resilience, the parallel demand for water efficiency and decarbonisation could also lead to novel approaches, such as the use of sewage wastewater heat in district heating systems (DG ENV, n.d.). The twin digital and green transition could also create opportunities for the use of digital technology to improve water management – for example, greater integration of ICT in water grids and the emergence of smart water grids. The widespread roll-out of smart meters in EU countries could also provide a range of opportunities for more efficient water consumption and management (Msamadya et al., 2022). (See Issue 8 on how digital technologies could improve water management.) Likewise, hydropower can contribute to water management (flood prevention, drought impact mitigation, irrigation control, water distribution, and wastewater control), if managed sustainably – for example, by addressing the impacts on biodiversity. **The energy transition may increasingly impact on water resources: example of the potential emergence of a hydrogen economy** Hydrogen is expected to be a key instrument for meeting the EU Green Deal's main objective: climate neutrality by 2050 (Arrigoni and Bravo Diaz, 2022). The European Commission adopted an EU Hydrogen Strategy in July 2020 and it now estimates that the share of hydrogen in the EU's energy mix could reach 13-20% in 2050 (Huet, 2022). In a speech made in April 2022, Executive Vice President (2019-2023) Frans Timmermans has also said that he strongly believes in hydrogen "as the driving force of our energy system of the future" (Taylor, 2022). The EU Hydrogen Strategy foresees expanding production of blue hydrogen (although the Strategy does not use this term) over the next decade to displace natural gas and also for use in hard-to-electrify sectors like heavy

transport and steel and cement production (Hernandez, 2021). Blue hydrogen refers to hydrogen produced from natural gas, in which the resulting GHGs are captured using carbon capture and storage (CCS). The strategy also relies on cleaner but more expensive green hydrogen, made from water and renewable electricity, eventually becoming available in larger quantities (Hernandez, 2021). The REPowerEU strategy, released in early 2022, proposes reducing the EU's reliance on Russian oil and gas by not only making its own hydrogen, but also by importing 10 million more tons by 2030 from "reliable suppliers" across the globe (European Commission, 2022b; Hernandez, 2022). However, there is some doubt about whether hydrogen, which is supposed to decarbonise industrial processes as well as shipping and aviation, will deliver what it promises (Kurmayer, 2022) (see Implications).

Rolling out hydrogen capacity also requires access to plentiful water for cooling purposes (blue hydrogen) and electrolysis (green hydrogen) (Alsford, 2022). The growing demand for hydrogen could therefore impact water scarcity: globally it has been estimated that 60% of hydrogen energy projects will be located in water-scarce regions (Alsford, 2022).

As the transition accelerates, there may be potential cumulative impacts on water resources

Europe is currently undergoing multiple transitions in line with the transition policy agenda (see Drivers). Interlinkages between complex societal systems mean that governance interventions to alter one part of the system will likely generate unintended changes in other parts, or feedbacks that undermine sustainability improvements (EEA, 2019). Although some consideration has been given to coordinating these transitions (e.g. twinning the green and digital transitions), transition pathways are effectively laid out for each individual industrial ecosystem (e.g. energy, mobility, tourism, food etc) independently (European Commission, n.d.(d)). The ability of different transitions (and transition pathways) to counteract or reinforce each other, as well as the potential cumulative and unintended consequences (e.g. on water resources), deserves closer scrutiny.

Ideally, the green and digital transitions reinforce each other. However, sometimes the two transitions can also clash (JRC, 2022). One example is the increased disposal of electronic waste by data centres (Ghoshal, 2023). Another example is the increased energy supplied to data centres; however, to correctly assess the total impact, the energy saved by the increased digitalisation should be factored in.

Given that the different transitions each have implications for water resources (as outlined above), the cumulative impacts are likely to be significant. A coordinated approach to ensure the twin transitions successfully reinforce each other to deliver a sustainable, fair, and competitive future for Europe must consider the impacts on (and challenges presented by) European water scarcity.

Mitigating climate change and adapting to its impacts could intensify economic, social, and environmental inequalities (Akgüç et al., 2022). The Just Transition Mechanism and the proposed Social Climate Fund, an element of the Fit for 55 climate policy package, are some of the main EU measures intended to mitigate the impact of the transition on the most affected regions, vulnerable individuals, and businesses. The efforts toward a just transition are clearly genuine; however, realising it in practice will be challenging. For example, one trade union body in the EU has argued that efforts to date at EU level to ensure that the transition is just or fair may not be sufficient to fully address the social challenges ahead if Europe is to become a net-zero carbon economy (Akgüç et al., 2022). Addressing equality of access to and use of water may be a key future policy tool for facilitating a just transition, especially in cities. For example, some recent research has shown that the swimming pools, well-watered gardens, and clean cars of the rich are driving water crises in some cities (especially those in already water-stressed regions) at least as much as the climate emergency or population growth (Carrington, 2023; Savelli et al., 2023).

Potential implications for water resilience, the wider environment and human health	**Opportunities**	**Risks**
Higher levels of electrification, solar and wind power investments, and more electric vehicles will lead to significantly higher copper demand; this will put further pressure on water supplies as its mining is a water-intensive process (Alsford, 2022). The Copper mining (like many mining activities) is also becoming increasingly water intensive as ore grades decline. Any intervention to provide greater industry access to water while reducing pressure on fresh water could employ alternative solutions such as investment in expensive technology – for example, desalination (Alsford, 2022).	• Increased electrification and the transition away from fossil fuels to renewable energy will contribute to reducing GHG emissions and is among the goals of the EU Green Deal.	• The gap between global demand and supplies of fresh water is expected to reach 40% by 2030. The transition to clean energy may increase that deficit further (Alsford, 2022).
So far net zero water targets have received less attention than net zero carbon or net zero waste, however it is possible that the private sector may increasingly be aiming to be net-zero water in coming decades. Some companies who are large water users, and in particular those companies whose operations are based in drought-prone areas, are putting in place net zero water targets	• The ambition to reach net zero water would be a stretch target for industry and could provide a real focus for water conservation and reuse efforts. However, it is not always evident how the net zero target will be achieved, and it is important that companies outline concrete and tangible steps on their journey to net zero.	• Some solutions to reducing emissions, reaching net zero, or becoming net zero waste require approaches and technologies that are water intensive (e.g. recycling technologies). Shifting the focus to net zero water may then make some of these decarbonisation or recycling approaches unfeasible.

(e.g. CocaCola)(CocaCola, 2021).		
The planning of new battery factories is likely to become more prevalent in Europe as demand for zero (tailpipe) emission (i.e. electric) vehicles grows. Some EU countries (e.g. Hungary) are already taking steps to meet this demand by planning the development of new battery factories (Debreceni Nap, 2023).	-	• There are concerns about the environmental impacts of “water-polluting and environmentally destructive” battery factories. For example, Debrecen in Hungary is already struggling with a lack of rainfall, and this will increase in the future as the summers get hotter (Debreceni Nap, 2023). This example indicates the potential risk if environmental aspects are not well assessed when developing new factories to meet growing battery demand. One of the critical aspects of new battery factories is their water demand, especially in areas where water is already scarce.
The twin digital and green transition could see the adoption of digital technologies to improve the environmental impacts of the water sector – for example, the use of digital twins to improve water management (also discussed in FORENV 2019-2020 cycle Issue 8: Digital twins as a driver of large-scale circular transformation).	• Advocates of digital twins for water use suggest they can be used to monitor and assess live water supply situations and to test and explore scenarios – for example, around different water use cases –to improve efficiency and identify potential problems. • Benefits could include improved and more resilient water management and supply (through, for example, testing new ideas and system changes virtually before roll-out), as well as improved efficiency by enabling a more holistic view that can facilitate optimisation of, for example, pumping schedules, etc.	• Digital twins are vulnerable to cybersecurity threats (e.g. hacks and data breaches) and need to be protected (Pratt, 2023; Svilpa, 2022). The water sector deals with critical infrastructure on which millions of people rely; failure to protect those assets could leave the system exposed to domestic and international threats (Svilpa, 2022).
Shift from a fossil-fuel economy to a hydrogen economy in some sectors.	• Studies have shown that replacing conventional fuels with green hydrogen will help decarbonise the energy system and reduce its water consumption (Newborough and Cooley, 2021). • Hydrogen only releases water vapour when burned, prompting optimism about the new gas as a way of tackling climate change. • Experts have agreed that a hydrogen economy could reduce the global warming impact compared to a fossil fuel economy (Arrigoni and	• The production, storage, and transport of green hydrogen are not without risks and impacts on the environment and people. • For example, one of the main environmental risks associated with green hydrogen is the potential for water scarcity. Its production requires a significant amount of water and, in some areas where water is already scarce, this increase in demand could exacerbate existing water shortages.

	Bravo Diaz, 2022). In the longer term, if it mitigates climate change, this will have a positive impact through reducing climate drivers of scarcity (e.g. drought, changed precipitation).	
Digitalisation of the economy and (micro) chip production	• Chips are strategic assets for key industrial value chains. With the digital transformation, new products and markets for the chip industry are emerging – for example, highly automated cars, cloud, Internet of Things, connectivity, space, defence, and supercomputers (European Commission, n.d.).	• Semiconductor manufacturing needs a lot of water (as much as 264 billion gallons per year), primarily to produce ultrapure water for the process itself (Jones and Vacuum, 2022).
New energy and GHG efficient desalination may be an increasingly necessary part of Europe's water supply, especially in water-scarce regions.	• There is an opportunity for the use of solar energy as a means of efficient evaporation (steam generation) from seawater to create useable water for human consumption without resorting to fossil fuel-based desalination systems that create significant GHGs and wastewater pollution (Zhu et al., 2022).	• While the use of deionized water produced by desalination plants may reduce freshwater demand, it generates a need to discharge a stream of brine into water sources and soils (Hurwitz et al., 2023).

Timeframe of emergence	The green and digital transitions are already happening in Europe, and thus already changing the way many (if not all) industries operate. Therefore, this issue is likely to emerge in the short to medium term. However, the timeframe of emergence for some aspects of the issue (e.g. the hydrogen economy) is uncertain and will likely be medium/longer-term. Uncertainties outlined below will influence the reality of the EU reaching the driving targets set out in the policies and strategies outlined in the Drivers section of this report. The digital transition plays a pivotal role in making the energy transition more feasible. For example, digital devices can monitor and adjust energy consumption in real time, and data collected about energy use can drive efficiency. However, as highlighted below, there are still uncertainties about the reality of the two transitions complementing each other in a way that benefits water resource use. As highlighted in Issue 8 (Use of digital technologies to improve water management), the adoption of digital technologies in the water sector is slow and patchy compared to other sectors such as energy.
Uncertainties	The intersections of the twin transitions are complex, and their implications for water resource management have yet to be fully explored; therefore, many uncertainties exist. Uncertainties exist around whether the green and digital transitions can successfully complement each other and their potential cumulative impacts on water resources. Digital technologies (e.g. smart grids) are being adopted by the energy sector to optimise the distribution of energy. However, the adoption of such technologies for water management is slower and their potential has not been fully assessed (see Issue 8). Considerable uncertainties exist around the emergence of a hydrogen economy, the timescale of this emergence, and the environmental (including water) and social impacts. For example, the Hydrogen Strategy is based on a rapid expansion of blue hydrogen production over the next decade and an increase in the availability of green hydrogen. The European Commission has proposed producing 10 million tonnes of renewable hydrogen and importing 10 million tonnes by 2030 (European Commission, n.d.). However, in 2022, hydrogen accounted for less than 2% of Europe's

	energy consumption, while 96% of hydrogen in Europe is still produced using fossil fuels (European Commission, n.d.; Jagdale, 2022). Furthermore, there is criticism around the potential of hydrogen use to achieve climate goals (see Implications). Certain operational hurdles must be overcome in the short term for the successful and speedy integration of renewable energy into Europe's national energy systems. For example, energy storage technologies and grid enhancements will be necessary – currently grid constraints are seen as a major barrier to renewables in the power sector (S&P Global, 2023). The Fit for 55 climate policy package, launched by the European Commission in 2021, has put in place concrete actions to achieve the goals of the Green Deal. However, the social dimension of the European Green Deal remains significantly underdeveloped compared with the other hard-law Fit for 55 initiatives (Akgüç et al., 2022). Therefore, uncertainty exists about the realistic possibility of a just transition (Akgüç et al., 2022). Potential unintended consequences of the green and digital transition have the potential to further exacerbate social inequalities, specifically for people living in already water-scarce areas. The multidimensional nature of transition processes means that they are influenced, either positively or negatively, by policies in diverse domains. This creates significant risks or inconsistencies and incoherence (EEA, 2019). Governing sustainability transitions therefore requires horizontal policy coordination, aligning both sectoral and cross-cutting policies (EEA, 2019).
Additional research or evidence that may be needed	• There is a need for more research and debate about fossil-based hydrogen and whether it can truly help the EU achieve its climate targets (Hernandez, 2021). • Factors such as green hydrogen generation, hydrogen permeation and leakage management, efficient storage, risk assessment studies, blending, and techno-economic feasibility shall play a critical role in the socio-economic aspects of hydrogen energy research (Sharma et al., 2023). • More attention and evidence are needed on the unintended impacts of the green and digital transitions on water scarcity in Europe. Additional research and evidence are also needed on the interactions between the different transitions and their potential impacts on water scarcity. • Further work is needed to reconsider EU's uses of water with respect to the intended objectives Sufficiency considerations are key to achieving the objectives set out in the European Green Deal and in line with planetary boundaries (Stockholm Resilience Centre, n.d.). • Further research to understand the expected future gap between demand and supply of fresh water at the EU, national, and regional scales. • Further work to identify and understand existing policy misalignments that could lead to incoherence between sustainability transitions (EEA, 2019), particularly those that could have unexpected negative impacts on water resilience in Europe.
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Issue 10. Future water-related disputes and geopolitical conflicts drive transboundary cooperation on water	
Emerging issue description	Water is indispensable for social, economic, and political stability and related to many aspects of human prosperity (human consumption, agriculture, energy, industry etc). Water-related conflicts have mostly been associated with countries of the Global South affected by severe water shortages. However, such disputes and conflicts have occurred and continue to do so worldwide, including in Europe, such as the disputes between Spain and Portugal in 2019 and again in 2022 on water supply, the conflict between Armenia and Azerbaijan, and the Nagorno-Karabakh conflict over the control of water infrastructure, especially the Sarsang dam, in 2023 (van der Meer, 2022; UN, 2013). Europe has the highest number of shared river basins in the world, with many countries being interdependent on water resources. Water management-related issues have arisen over the years between countries sharing transboundary water resources. Even though water has rarely been the direct cause of conflicts, with little evidence of water wars, there have been incidents of direct confrontations over it and the weaponisation of water resources in existing conflicts, for example, in Ukraine (Landay, 2022; United Nations, 2023). Large-scale water infrastructure facilities may be destroyed, captured during wartime, or deliberately sabotaged to put pressure on governments and intimidate civilians. For example, the destruction of the Nova Kakhovka dam in Ukraine in June 2023 created huge consequences for the local population, the evacuation of thousands of people (migration), the flooding of agricultural land, and environmental concerns over the contamination of the river from industrial lubricants (BBC News, 2023). The significance of water in countries' interrelations has led to the deployment of diplomacy (the establishment and/or further development of diplomatic relations, e.g. treaties or agreements); using tailored tools for water-related issues (e.g. water diplomacy, water-mediation, etc.); and the establishment of advocacy hubs (e.g. Geneva Water Hub) and institutions (e.g. Water Conventions). These can facilitate the use of transboundary waters in a reasonable and equitable way, ensure their sustainable management, and thus prevent water-related conflicts and promote the peaceful and effective solution of existing ones (Geneva Water Hub, 2018; Keskien et al., 2021; UNECE, 2023a). In Europe, transboundary water conventions, such as in the Rhine, Danube, and Sava, have been pivotal in building peaceful cooperation between riparian countries in the aftermath of regional wars and tensions, exemplifying their value for conflict prevention. These tools are being utilised by numerous institutions, including the European Union (EU), the United Nations (UN), and the Organization for Security Cooperation in Europe (OSCE) to minimise or peacefully resolve water-related issues, whether concerning conflict, management, or cooperation. However, water-related conflicts still persist in many regions globally (Schmeier, 2018). Water security has been considered among the major risk factors in regions without established frameworks for transboundary water cooperation. The expected changes in water availability due to climate change impacts on the spatial and temporal distribution of water resources could make tensions over shared waters more likely in basins that lack formalised institutions for preventing and resolving issues between riparian states. There is uncertainty on the trajectory and likelihood of water-related disputes in the future, as the available evidence shows that they have been handled unevenly, with different outcomes in different geographical areas. Although water-related disputes are expected to rise, intensifying political tensions, it is more likely that the need for water sharing will boost cooperation between nations sharing transboundary basins rather than generate conflicts (Farinosi et al., 2018). This is evident in certain cases – such as realising the opportunity of mutual economic benefits through joint investments in water infrastructure or achieving shared environmental benefits from collaborative efforts to address similar environmental challenges. However, it is important to note that, while such potential for cooperation exists, it is not guaranteed and will depend on

	various geopolitical and contextual factors (e.g., historical context, geopolitical relations, leadership and decision making, legal and institutional frameworks, etc.).
Key drivers: what is driving the emergence of this issue?	**Climate change and water scarcity** The extreme weather conditions created by climate change exacerbate existing variability and challenges in transboundary basin management and water scarcity; they are thus an important driver for the emergence of water-related conflicts globally (Farinosi et al., 2018; UNECE, 2023b). Water resources are expected to diminish and droughts to intensify in the near future, potentially resulting in severe water-related disputes and conflicts between countries (Farinosi et al., 2018). In areas where disputes over water resources already exist, climate change works as an intensifier. One example is the resurfacing in 2022 of the 2019 dispute over the supply of water from Spain to Portugal due to extreme droughts, leading to new tensions between the two countries (Blumstein et al., 2016). Another example is the riparian system of the Tigris and Euphrates, shared between Turkey, Syria, and Iraq (with Iran comprising parts of Tigris basin). The two rivers have their source in Turkey, and since the 1960s, the country has constructed dams, hydropower, and irrigation infrastructure on a large scale, influencing the flow of water to Syria. Disputes intensified during a period of extended drought in 1975, coupled with variations in precipitation throughout seasons, inefficient irrigation systems, and the cultivation of water-intensive crops; these almost led to armed conflict, only prevented by the mediation of Saudi Arabia. Rainfall levels are projected to decline significantly (30%) after 2040 in the upper Tigris River basin, and this will significantly influence downstream water availability. Given the projected impacts of climate change and environmental degradation in the basin, along with the lack of official agreements or frameworks to support equitable sharing and sustainable management of water resources, future conflicts are possible (Climate Diplomacy, 2022). **Population growth, economic development, and water demand** The global population is expected to increase in the next 30 years, reaching up to 9.7 billion in 2050. This will lead to increased water demand (estimated by 1% annually) in terms of consumption (for potable water and agriculture, for example) and water utilisation in industry and economic and technological advancement (cross-sectoral), especially in the growing economies of middle- and lower-income countries (Geneva Water Hub, 2018). None of the Sustainable Development Goal (SDG) 6 (Ensure availability and sustainable management of water and sanitation for all) targets appear to be on track. As of 2022, 2.2 billion people were without access to safely managed drinking water. Four out of five people lacking at least basic drinking water services lived in rural areas. The situation with respect to safely managed sanitation remains dire, with 3.5 billion people lacking access to such services (UN Water, 2024). Globally, water demand will increase due to the shifting of water use patterns in three areas: municipalities (urbanisation, driven by the expansion of water supply); industries (the intensification of industrial use, led by water-intensive processes such as manufacturing and energy production); and agriculture (driven by irrigation) (Geneva Water Hub, 2018). Agricultural production depends on water access and availability. It is among the most vulnerable sectors to climate-related water risks, as it uses approximately 72% of the freshwater withdrawals globally (FAO, 2023). Energy production accounts for between 10 and 15% of global water withdrawals. Water is required in the extraction and conversion of coal, oil and gas (including fracking), and is extensively used for electricity generation, for hydropower and as cooling water for thermal and nuclear power stations. Conversely, considerable amounts of energy are used to pump, treat and transport water and wastewater, including for irrigation and industry. Desalination is very energy-intensive, accounting for one quarter of the energy used in the water sector globally (UN Water, 2024). Initiatives towards sustainable industry and agriculture, including those related to water efficiency, have already been implemented and are expected to develop further (see also Issues 7 and 8). Population growth and economic

development may become catalysts for transboundary cooperation on water resources and cross-sectoral partnerships to address water demand and associated water-related emerging disputes and conflicts (Geneva Water Hub, 2018).

Political and legal frameworks

Political and legal frameworks for water management and governance at national, regional, transnational, and international levels are key drivers for transboundary cooperation over water supplies. However, gaps in these frameworks, such as insufficient mechanisms for adapting to climate change impacts or engaging all riparian states, can allow water-related tensions between countries to emerge and potentially escalate over time. While treaties and institutions are intended to facilitate the joint management and equitable use of shared waters, existing arrangements are often inadequate for addressing water-related issues, especially as resource pressures mount.

Water management is highly politicised in many transboundary basins, with considerable impact on conflict prevention, regional stability, and environmental peace-making. In Europe, the EU Water Framework Directive has mandated cooperation for shared waters, leading to formal agreements or institutionalised collaboration for most major basins. Gaps remain for certain river basins shared with non-EU states where cooperative structures are less established. The need to further transboundary water cooperation has led to high-level calls in recent years. Repeated statements from the United Nations (UN) Secretary-General, heads of agencies and other high-level persons have urged countries to develop river, lake and aquifer arrangements and to support that endeavour by becoming a Party to the two United Nations global water conventions: the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention) which at present has been ratified by 47 parties, (46 states and the European Union), and the Convention on the Law of the Non-Navigational Uses of International Watercourses (Watercourses Convention). Transboundary agreements over water supply are often not enough to prevent conflicts due to the lack of robust conflict management mechanisms (such as rules to adapt to the long-term impact of climate change) and may not include all the involved parties (Pohl et al., 2013).

At an international level, the challenge of climate change has driven governments to cooperate globally and coordinate their actions through the adoption of voluntary international agreements (Kyoto Agreement, Paris Agreement, the Water Convention, etc.) for sustainable development and the protection of the natural environment, including water resources (e.g., Sustainable Development Goals (SDG) 6 and 17). However, these are considered soft agreements, with no financial or political repercussions if countries violate them and no international court or governing body to enforce compliance; they are already at risk of not reaching their targets, which can undermine common efforts (UNESCO, 2023; UNU-INWEH, 2023a; 2023b).

Moreover, certain institutions (e.g. Global Observatory for Water and Peace, UN-World Bank Global High-Level Panel on Water, Safe Space for the inter-sectoral and cross-border pre-negotiation) are encouraging cooperation on water bodies and the development frameworks (e.g. Convention on the Protection and Use of Transboundary Watercourses and International Lakes – the Water Convention, UN Watercourses Convention, etc.) to enable, support, and implement transboundary water cooperation under the principles of international law (Geneva Water Hub, 2018).

Political tensions and instability

Socio-economic and cultural characteristics, along with topographic factors, are a significant driver influencing hydro-political dynamics (Farinosi et al., 2018). Political tensions have grown worldwide, and water resources and water management infrastructure has been either the source of conflict and dispute or has been weaponised to gain leverage against opposing parties. The weaponisation of water by political actors could be via reducing the quality of water (contamination) or the supply of water (quantity) or restricting access to water. Examples include the 2023 Armenia – Azerbaijan conflict over the Sarsang dam in the Nagorno-Kabakh region for control of

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water resources; the destruction of the dam in Nova Kakhovka (2023), as part of the ongoing conflict between Russia and Ukraine (van der Meer, 2022; Kuyumjian, 2021); and the poisoning of wells by ISIS to systematically clear out towns and villages (Yedur and Emin, 2023). As political instability is threatening peace worldwide, international cooperation over water resources is increasingly necessary to preserve peace and political stability.

Transboundary water infrastructure and energy demand
Transboundary water resources necessitate cooperation between countries for water management. Increasing demands for water, along with increased reliance on water for energy supply, are met mainly through water infrastructure (e.g., dams, hydropower plants). Infrastructure facilitating hydropower and irrigation are generally designed to provide energy and water security for the countries which have constructed it (rather than neighbouring or upstream / downstream countries. Additionally, as nuclear and hydrogen power are promoted as low-carbon energy sources, demand for water to facilitate these will increase and could have significant impact on water resources (due to clean water demand and water discharges) (Herald, 2016; Facini, 2023; Kohler, 2018; Zeitoun and Warner, 2006; Hodgkinson, 2022)

Moreover, in the case of conflicts or disputes between nations, water infrastructure can be used to inflict severe economic and humanitarian damage to an opposing country (Facini, 2023; Kohler, 2018; Zeitoun and Warner, 2006) and thus can be used as a bargaining tool in transnational political discussions. In the case of the Turkey-Syria dispute in 1987, Turkey brokered an agreement to release 500 cubic meters per second of water to Syria in return for Syria's withdrawal of support for the Kurdistan Workers' Party (PKK) (Climate Diplomacy, 2022);

Water quality changes driving tensions
The interrelationship between water quality and quantity is discussed in Issue 1. Globally, water quality is projected to deteriorate rapidly over the next decades, increasing the risks to human health, economic development, and ecosystems.

In Europe, overall water quality is projected to improve due to the enhancement of water infrastructure. However, extreme weather conditions caused by climate change will have severe consequences, including damage to water supply and sewage infrastructure, degradation of catchments and water quality, spillages of human waste to the environment, contamination of water supplies, and changes to water consumption (European Aluminium, 2018; UNECE, 2022; European Environment Agency, 2023). It is estimated that approximately 35% of the area of the EU will be under high water stress by the 2070s, affecting 16-44 million people. In areas of stress, this could result in the use of unsafe water sources that will increase exposure to pathogens and harmful chemicals. These impacts are already apparent in some countries; for example, the Netherlands is facing significant challenges to ensuring water supply and Spain is having problems managing water flow during severe droughts (Didde, 2022; UNECE, 2022).

In regions where the quality of water decreases, conflicts over water resources are likely to be exacerbated. This in turn will create the potential for conflicts over transboundary water resources, as well as surface and groundwater resources (for example, where deterioration in surface water in an upstream country increases pressure on groundwater in a downstream country).
</td></tr>
<tr><td>How might the issue develop in future?</td><td>
Development of international common policies on water management
International cooperation over water resources can offer significant opportunities for states sharing them by helping to minimise the impact of water use between countries and maximise the overall benefit for all basin countries (Pohl et al., 2017).

The political framework to address water-related issues at international level (outside the EU) is developing in particular with the above mentioned 2 Water Conventions in place, the first UN Water Conferences in 2023 and the upcoming UN Water Conferences in 2026 and 2028. This presents an opportunity to reduce potential destabilisation of political relations due to
</td></tr>
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water related issues. In the EU, such issues can be resolved by implementing EU legislation, but reduced water availability and exacerbated water stress conditions might destabilise political relations between countries at the global level.

In the future, treaties already in place between states may need to be strengthened due to changes in environmental and socio-economic conditions (e.g., water scarcity). In some cases, treaties already in place may be put in question, as occurred in the case of regimes governing diversions of water from the Meuse to feed navigation canals and irrigation channels between the Netherlands and Belgium. The two countries' economic ambitions have led to disputes about these interventions to the canals and to demands to cease development from both sides. Ultimately, the Netherlands initiated procedures in the Court by means of a unilateral application. The Court decided that the Treaty does not forbid either state to undertake works on the river, provided that neither the discharge of water through the feeder nor the volume of the water is affected (International Water Law Project, 2023).

Increasingly, limited regional and international cooperation and the threat of water-related disputes and geopolitical conflicts globally may highlight the urgency to strengthen international conventions, frameworks, policies and processes to foster peace and cooperation over transboundary water, as witnessed by the increasing efforts at a global level to govern natural water resources

Increasing levels and importance of water diplomacy

The need for international and regional collaboration is amplified by global challenges, such as climate change and the increasing scarcity of natural resources along with a growing disregard for international agreements and the enhanced role of geopolitics. Together, these challenges can create increasingly complex foreign policy relations that will require the development of new types of diplomacy (Keskien et al., 2021).

The use and allocation of transboundary water resources are often political and have led to the establishment of transboundary water cooperation agreements, building on the potential joint benefits for all involved parties, with a strong institutional basis (Keskien et al., 2021). The challenges of climate change will pose risks to society and the economic activities of all countries, including risks to existing infrastructure, the development of sectors (e.g. energy, agriculture, tourism), and low-lying coastal settlements. These challenges may bring forth unresolved disputes or put pressure on fragile cooperation with the potential to lead to future conflict globally (IPCC, 2022).

Tackling these different challenges will depend on and require all parties (governments, private sector, civil society) to work for closer transboundary cooperation to enhance cross-national and cross-sectoral synergies and water-related technical and economic opportunities. This inherent necessity may strengthen political efforts globally to improve water-related crisis responses, develop conflict resolution mechanisms, and enhance transboundary governance through foreign policy. These in turn may lead to the resolution of other longstanding, currently stagnant political issues and disputes and to progress on crucial foreign policy issues and greater regional integration. As such, foreign policy will be closely linked with water diplomacy, with new approaches deployed to drive countries' cooperation on water resources (IPCC, 2022).

Existing tools such as water diplomacy are expected to be further developed to ensure the efficient and sustainable use of water resources, linking foreign policy and diplomacy with shared waters.

Increased weaponisation of water resources

The resolution of conflicts through water diplomacy may foster peace and political stability overall, but it may also result in a (real or perceived) loss of sovereignty for some countries. Water and the control of water resources can be weaponised by countries to achieve their political agendas. Countries with advantages (such as greater economic wealth) might increasingly use water investments and water resources or infrastructure as tools in negotiations with lower-income countries (Facini, 2023; Kohler, 2018; Zeitoun and

Warner, 2006).

Water as a tool in improved international security and reduced migration flows

Water can become an additional factor in conflict and migration flows due to its impacts on political stability at an international level. In recent years, water-related political tensions have grown worldwide (for example, in Syria and Afghanistan and between Armenia and Azerbaijan) and become a factor (alongside political, economic, and wider environmental issues) in the migration of large numbers of people to other countries or regions in search of a safer future.

Global migration flows are at perhaps their highest ever level, with an estimated 258 million international migrants (3.3% of world's population) living outside their home country in 2018 (IOM, 2023). This number has risen since 2018, with the UN estimating 281 million international migrants globally (3.6% of the world's population) in 2020 (McAuliffe and Triandafylidou, 2021). These migration flows result from a range of interrelated economic, social, and environmental factors. Some migration is clearly linked to natural resource and water scarcity, with water deficits associated with 10% of the rise in global migration (IOM, 2023). If this trend continues, it may make water resource governance an increasingly important consideration for regional, national, and international policy frameworks on migration (IOM, 2023).

The displacement of people due to water-related factors such as drought and high temperatures, along with floods, storms, and earthquakes, has been linked to increased migration flows to Europe (European Commission, 2021; IOM, 2023). Preserving and sustaining urban resources and water infrastructure can help manage the growing demands of urban populations and increased pressures on water resources; this in turn can help protect and improve people's livelihoods, enhance urban water resilience (World Bank, 2021). If this is achieved, then related migration flows may decrease.

Creating water infrastructure that meets international standards for efficient and sustainable water use could improve local and national water management and resilience and also help safeguard international security. Complemented by the efforts of foreign policy, this could improve people's wellbeing and prevent the evacuation of water-stressed areas (Pohl et al., 2013).

Water as a tool to enable cooperation for transnational water investments

Achieving common political approaches on an international and regional level, along with political stability between countries in relation to transboundary waters and water scarcity, will necessitate the establishment of efficient water infrastructure. Establishing such infrastructure may increasingly require (and potentially enable) international and transboundary cooperation between governments, private sector, and civil society, to reduce risks and facilitate equity, justice, decision-making, and investments. It may also foster closer cross-sectoral synergies in terms of resource management, with joint plans of actions for water management to increase resilience under future water-stressed conditions (IPCC, 2022).

For this to transpire, however, riparian countries must cooperate by sharing data and information on water resources to inform and accelerate the decision-making process. This will most likely occur in countries that have good overall diplomatic relations (for example, as in the Netherlands and Belgium over the Meuse river), but it may be more challenging for countries with socio-economic differences and territorial conflicts (e.g., Turkey with Syria or Iraq, Armenia with Azerbaijan). Some European transboundary basins like the Danube and Rhine already demonstrate moves in this direction through joint infrastructure planning and climate adaptation strategies (European Commission, 2019a).

Water for food and energy security

Climate change directly affects water and food security. Water is also key factor for energy security. Agriculture alone requires large quantities of water for irrigation, with an estimated 70% of global freshwater appropriated for its

	use (FAO UN, 2017). As water stresses intensify, it is most likely that human lives and livelihoods, economic prosperity, and peace and security around the world will be affected. The same applies to energy security, given increasing energy demand and the reliance of energy infrastructure on water resources (Herald, 2016; Facini, 2023; Kohler, 2018; Zeitoun and Warner, 2006). Therefore, it is likely that water scarcity could lead to instability and eventually conflicts over the government and management of water resources, especially in vulnerable states (Kenney, 2017).	
Potential implications for water resilience, the wider environment and human health	**Opportunities**	**Risks**
Development of common policies over water management	• Common policies/approaches to water management – homogenous. • Cooperation of countries for new investments on water infrastructure. • Enhance cross-national and cross-sectoral synergies to prevent and resolve conflicts.	• Might be rejected by many countries/industries/citizens due to restrictions to their water usage, socio-economic and political legacies between entailed countries. • Difficulty in implementing and monitoring socio-economic and political legacies. • Lack of trust in institutions may lead to the failure of policies to reconstruct national water institutions.
Integration of water diplomacy on foreign diplomacy	• Empower water-related crisis response and develop conflict resolution mechanisms (Pohl et al., 2013). • Improve transboundary governance through foreign policy (Pohl et al., 2013). • Resolution of non-water related political issues and disputes stagnated for years, hampering progress on crucial foreign policy interests (Pohl et al., 2013). • Achieve greater regional integration (Pohl et al., 2013; IPCC, 2022). • Drive investments between countries over water-related infrastructure and create economic activities between countries. • Enable exchange of knowledge, training, and capacity building on a shared basis between countries that strengthen cooperation.	• It might not be possible to overcome socio-economic and political legacies between countries. • Failure to recognise and manage trade-off between short- and long-term measures to respond in immediate water needs and long-term measures may undermine water security prospects for the forcibly displaces and their host communities (World Bank, 2021).
Establishment of transboundary water governance as mandated by the UN Water Convention	• Establishment of transboundary institutions that will regulate and govern water resources. • Transboundary treaties and agreements to be formally established and met. • Opportunity to avoid future water conflicts and disputes over countries	• Might not be accepted by all states. • Might be inequity issues between nations (high-income countries versus low-income countries).
Increase investments to water	• Create socio-economic relationships between riparian countries	• High cost of construction may not allow wider investments, especially for low- and middle-

infrastructures built and maintenance	• Ensure the efficiency of water infrastructure and enhance urban water resilience (World Bank, 2021). • Limit water leakages from insufficient infrastructure and increase the efficiency of water use (World Bank, 2021). • Improve water use efficiency and better protect water resources from pollution or mismanagement. • Limit migration flows by improving water access and quality in potential migrants' countries of origin.	income countries (World Bank, 2021).

Timeframe of emergence	This issue is already emerging and will accelerate in the short to medium term, especially outside Europe. In Europe as elsewhere, institutional structures for transboundary water cooperation will need to be reviewed and strengthened to adapt to the current and future consequences of climate change. Due to the inherent influence of climate and environmental change on water resources, this issue will continue to emerge and evolve in the long term. As water scarcity is one of the main drivers of the issue, and this is not expected to improve in the long term, efforts to improve transboundary cooperation over water resources will likely always be required (and, conversely, tensions will continue).
Uncertainties	Efforts to reduce the risk of future water-related and geopolitical conflicts between countries globally (through effective political leadership and strong governance mechanisms, which facilitate and regulate such cooperation) could drive transboundary cooperation over water resources. They could also strengthen existing transboundary agreements in Europe, leading to significant outcomes for efficient water management and the prevention, and even resolution, of water (and wider) conflicts. All positive outcomes are based on the assumption that countries will agree on a common approach over water management. However, history suggests this might not be achievable at a global or even regional or transnational level. Within the EU and other regions where countries have established governance structures, international institutions could be strengthened to develop, oversee, and monitor water management through common policies and political approaches, thus possibly avoiding future conflicts. However, this might not be possible for conflict-afflicted countries and regions outside the EU with significant socio-economic and long-term differences and conflicts (e.g. the Armenia and Azerbaijan conflict) (van der Meer, 2022; Kuyumjian, 2021). Furthermore, even between countries with existing diplomatic relations, there is uncertainty over accepting and abiding with set agreements when water stress and associated political pressures increase due to the impacts of climate change. In the case in 2022 between Spain and Portugal (European Commission, 2019b), the problem was resolved peacefully due to successful bilateral EU diplomacy and in line with the rules of the Albufeira Agreement, but it is not certain that future disagreements will see peaceful resolution. Finally, water – although it intensifies existing disputes and geopolitical conflicts – has not so far been the immediate trigger for their emergence, nor has it been explicitly stated as the reason for such conflicts. Water-related conflicts are mostly complementary to existing disputes arising from socio-economic and political legacies; as such, it is not certain that geopolitical conflicts will be resolved through transboundary cooperations on water. The conflict between Armenia and Azerbaijan in 2020 may have included disputes over water flow; however, that was not the main cause, and the conflict arose despite an existing agreement over water flow (van der Meer, 2022; Kuyumjian, 2021).
Additional research or	Additional research or evidence to further understand the emerging issue: • Additional research would be required on the integration of water

evidence that may be needed	diplomacy with foreign diplomacy. Although there is extensive research on the reasons for integrating these concepts and the entailed benefits, there is little if any on how this should materialise. • It is important to further explore existing water-related treaties and disputes within Europe and the potential impacts of climate change and water scarcity on them; this would generate an in-depth understanding of the implications and the solutions to imminent conflicts between water-sharing countries. • In addition, the institutions working to resolve water-related-conflicts, the approaches they use, and their impact should be explored to better understand areas of improvement in establishing international and transnational institutions. • Finally, further research is needed into how transboundary cooperation on water could affect disputes and geopolitical conflicts in Europe as well as internationally and if investments in water infrastructure in developing countries would affect migration flows to Europe.
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APPENDIX B VALIDATION OF ISSUES BY SCIENTIFIC COMMITTEES

This Appendix summarises the key findings of peer-reviews by members of the European Environment Agency (EEA) Scientific Committee and the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER) of the 10 priority issues identified in relation to the ability to achieve a water-resilient Europe by 2050.

The issues were divided between the two Scientific Committees for review based on the relevance of each issue to the Committees areas of expertise.

On this basis the SCHEER reviewed and validated issues 1, 2, 3, 7 and 8; and the EEA Scientific Committee issues 4, 5, 6, 9 and 10. A summary of the review is presented below. In addition, some additional in-text comments and edits were provided my members of the Committees to the text of issues 1, 5, 6 and 9.

Where possible, the opinions of the Scientific Committees have been incorporated into the issue characterisations (listed in full in Appendix A), including edits (provided in form of tracked-changes), in-text comments and suggested additional and/or alternative references.

In some cases particular suggestions and comments were not included, including in particular:

- Requests that would change the focus or scope of particular issues, beyond that which was collectively agreed through the FORENV process (in particular sense-making workshops). For example, the review of Issue 7 proposed widening the issue scope to include a focus on the loss of agricultural land due to increased rain and flooding, and associated soil erosion. While these suggestions are both valuable and relevant, the scope of this cycle of FORENV was explicitly on water resilience in the context of availability of water (and its scarcity), and not on the issue of too much water (i.e. rain and flooding). However, such comments were considered in the overall characterisations to ensure that such scoping considerations are clearly stated and explained.
- Requests to re-write issues to be informed by more comprehensive literature and evidence reviews (e.g. see EEA review comments on Issue 4, Issue 10) and to be written and researched in a more comprehensive way in order to place each issue in a more systemic (showing connections to other sectors etc.) and dynamic manner exploring interlinkages more systematically. These comments were understood and accepted as valid, however the design of the FORENV approach is that issues are characterised based on the outcomes of scanning and sensemaking, and the intention is that issues are selective and thus inevitably limited, incomplete and partial in terms of evidence. Their aim is to spark discussion and thinking rather than to attempt a complete assessment of literature in relation to the topics identified. Furthermore, the clustering and identification of emerging themes together with uncertainties and question for policy are intended, in part at least, to address the valid comment about interconnections and interlinkages between 'trends and crises' as this process is based on reading-across all the issues and identifying thematic trends and pressures. As noted in previous cycles, the FORENV emerging issue descriptions are intended to be a selective, exploratory assessment of emerging evidence to identify plausible future risks and opportunities rather than comprehensive evidence reviews. The aim none-the-less is that the issues are as balanced as possible, and the views and comments from both SCHEER and EEA scientific committees are invaluable in ensuring this.
- Requests to more explicitly consider and discuss time-frames of emergence of each issue and the risks and opportunities defined (e.g. EEA review of Issue 4). The FORENV process seeks to give an overview of the expected timeframe of emergence (defined as short, medium or long-term), however the nature of the evidence base and the breadth of each issue as described means that identifying specific timeframes for e.g. the

emergence of each risk and opportunity is considered both not possible, but also likely to lead to a situation where the results are presented as being more certain than is possible. Where research used in the characterisations refer to specific dates (e.g. in context of scenarios and outlooks) these are included (for example outlooks for water scarcity), but in their absence it has been decided that it is better not to attempt to assign specific time-frames. The hope is that providing a broad outline of emergence this can help guide potential discussions and follow up work to those issues and topics that are most urgent.

It should also be noted that one reviewer from the EEA Scientific Committee made a number of more strategic as well as somewhat critical and fundamental comments regarding FORENV (see comments on Issues 4 and 10). It is the view of the FORENV secretariat that these comments reflect an acknowledged tension in the FORENV process: between providing insight into a wide range of issues, while providing sufficient depth of evidence to support plausible and useful findings. It is not possible in the context of FORENV (nor was it intended in the methodology for FORENV) to provide comprehensive evidence reviews or scenarios for each issue. It is accepted that this does mean that the characterisation of some issues may appear to be quite 'selective' in evidence used, and at the same time the process (which takes signals and outcomes from expert discussion) inevitably leads to some subjective judgement on the future direction and implications of issues. We acknowledge that these weaknesses in the process exist, but also note that the process has the primary aim of sparking discussion and providing insight into possible future challenges and opportunities. None-the-less, in forthcoming FORENV cycles it is the intention of the Secretariat to consider revisions to the characterisation process to enhance the accessibility and utility of the issue descriptions.

Summary of review by the SCHEER

This section presents verbatim the comments provided by the SCHEER on Issues 1, 2, 3, 7 and 8.

Issue 1: Interrelated challenge of water scarcity and water quality

General comments

The issue is one of the most concerning global problems related to climate change. Water scarcity may be defined as a persistent reduction of water availability, has intensified in many regions in the last few decades and it is likely that it will continue over this century due to increasing human population, accelerated economic activity and land-use changes (Stocker *et al.*, 2013, Herrera-Pantoja and Hiscock, 2015). Arid and semi-arid regions occupy more than one third of the planet's land surface and host about 30% of the world population (Safriel *et al.*, 2005).

While the issue description briefly mentions the interaction between water scarcity and water quality, however, the interdependence of the two factors is not clearly described and some more details on the consequences of water quality deterioration should be provided. In particular, the reduced amount of water in freshwater bodies (lakes, rivers, wetlands, etc.) with an almost constant level of pollutant emissions would lead to deterioration of water quality. Water flow reduction also produces a reduction of the habitat, affecting the general status of the aquatic ecosystem. According to the Water Framework Directive (WFD), the "status" of a water body is defined as a function of chemical, ecological and hydromorphological characteristics (i.e., quality and quantity of water). A more explicit reference to the WFD would have been appropriate in describing environmental effects.

Moreover, the issue description does not clearly address the implications that decreased water quantity and worsened water quality (also related to water reuse issues) would have on human health and food safety (this topic is mentioned in the list of potential risks).

Urban growth may reallocate water demand (requiring an increased demand for efficiency of water distribution systems, see also issue 8) and wastewater emissions, increasing the problems of water quantity and quality in certain areas. However, increasing demand for water may not be solely attributed to population growth in Europe, as described in the Issue. Very few countries in the European Union are growing in population, including larger countries. It should rather be interpreted as a combination of multiple factors, such as urbanization, economic growth and geographical concentration of financial capital.

Climate change does not only produce increased temperature and decreased rainfall in some areas. The increased frequency and intensity of extreme weather events, after dry periods (tropicalisation), substantially alter the water cycle. Traditional water resources (lakes, reservoirs, river flow and groundwater) are dramatically altered. The SCHEER notes that benefitting from increased rainfall in other areas can improve or combat water scarcity by developing more/better reservoirs and distribution systems (water ducts for long distance transport, cf. Romans). Heavy rain events due to climate change can be a potential source for collecting and storing water which requires new technological development. As well as storing water in extreme events, the increase in and improvement of water storage systems will contribute to the efficiency needed in water use. However, the effects of potential disruptions to the water cycle (surface and groundwater) must be evaluated.

The reduction of water availability and the deterioration of quality is not only a risk for human and environmental health but also entails economic, social and political problems, particularly in poorer countries and regions, e.g. effects include desertification, food shortage, and increased migration.

Answers to mandate questions

Question 1: Is the emerging issue identified likely to have the risks and/or opportunities described, or also additional ones? And if so, which ones?

It is the opinion of the SCHEER that very few opportunities may be envisaged from the emerging issue. Indeed, most of the opportunities listed in the FORENV document are just attempts to counteract the risks and the damages produced by a substantial decrease of quantity and quality of freshwater resources. So, they are not real “opportunities” but actions that are necessary to mitigate the adverse effects of a very concerning process that already affects many regions in Europe and in the world, and for which effective solutions seems not realistic in reasonably short time. In this frame, additional actions may be an improved land use management, the development of new technologies for agricultural practices, including drought resistant crops (see Issue 7), for alternative water sources (see Issue 2), for advanced water management (see issue 8).

An opportunity could be the increasing awareness of people and the political will of decision makers, particularly toward the more rational and efficient use of natural resources and their sustainability. Similarly, the minimisation of water losses in engineered and managed systems is an essential part of the solution.

Among the risks, it is the opinion of the SCHEER that, although the loss of biodiversity is mentioned, the complete, or almost complete, disruption of several freshwater ecosystems is not stressed sufficiently. In arid or semiarid regions, many rivers may be completely dry for large parts of the year. In the last few decades, many rivers previously “permanent” (i.e., with water flowing throughout the year) have become “intermittent” (i.e., completely dry during several months) with dramatic changes on the aquatic communities and ecosystems (see, for example, Arenas-Sanchez *et al.*, 2016; 2021) and relevant effects on the terrestrial ecosystems.

In terms of quality, in some rivers, the water flow downstream of large cities may be represented almost totally by wastewater (e.g., Manzanares River downstream Madrid is about

90% wastewater for several months of the year (Paredes *et al.*, 2010). So, structure and functioning of the ecosystem are completely modified.

Drought should be interpreted as a hazard, rather than a risk, as otherwise the vulnerability to this hazard is not properly addressed.

The increase of wildfire frequency due to drought and the decreased capacity to contain the fires due to water scarcity is also not highlighted (Bracewell *et al,* 2023, Vale O, 2023). This represents a sequence of cascading hazards, including the runoff of soil nutrients and ash from wildfires after heavy rainfall, the loss of soil, the filling of reservoirs with washed soil, and the coverage of estuarine and coastal ecosystems with these deposits.

The aggregated value of mixing and dilution of pollutants, and self-purification should be interpreted in terms of ecosystem services provided by riverine systems as "mechanical and chemical capacity of abiotic soil, soil biota and vegetation to trap and 'convert' sediments, nutrients, pollutants or pathogens" (La Notte *et al.*, 2017).

The proliferation of the microalgae *Ostreopsis ovata* is supported by a non-academic reference when there are many scientific examples of evidence and identified earlier than the example provided (e.g., David *et al.*, 2012a, 2012b). Remediation measures to counteract such developments is not highlighted.

Question 2: In your view, are there additional long-term development/s related to the issue that the issue description currently omits? If so, please describe them briefly. Do these development/s pose additional risks and/or opportunities?

The most important long-term development to mitigate the effects of the issue is related to the global strategies to counteract climate change (e.g., decarbonisation). Indeed, these strategies are the only ones capable to reverse the present trend of increasing severe drought events. This is mentioned in the issue description but not explicitly stated. The SCHEER also has the view that efficiency of water use, and in particular the reduction of the significant losses (e.g. in urban pipe systems) is not fully addressed and should be highlighted.

The contribution of urbanization and of certain patterns of urban growth (sprawl city) is not sufficiently examined in terms of the use of natural resources, or in terms of the involved impacts, of land use change, from natural or farmland to residential and industrial uses, extending the area of impervious surfaces (e.g. stimulation of citizens and companies to cope with heavy rainfall and make sure that such water is collected in reservoirs/soil rather than spilled in sewers).

There is an emphasis on the impact on recreational uses of water, which is relevant among other socioeconomic impacts (Berdalet *et al.*, 2022) but more emphasis should be placed on the health impacts in using poor quality bathing water.

The issue refers to the impact of droughts on wetlands, but this impact is particularly more important on Mediterranean wetlands (Convention on Wetlands, 2021).

Examples of water conflicts, metaphorically identified as water wars, are not provided. Some examples in Europe and elsewhere can be found in the literature (Barraqué, 2010; Graham *et al.*, 2013).

Soil, and soil moisture, is neglected as a relevant environment that is affected by drought (Berg and Sheffield, 2018; Samaniego *et al.*, 2018). Despite representing a small percentage of total water in the cycle, soil provides important ecosystem services, such as water retention and is determinant for farming productivity. There is also no mention of groundwater contribution which is a key element of the complete hydrological cycle.

Question 3: Are the described expected implications (positive or negative) for the environment and human health plausible, including the expected time-frame of emergence?

The expected implications, including the time-frame, are plausible. However, the SCHEER note that while climate change impacts are by their nature uncertain, the increasing frequency of severe drought events in Europe in the last few years is at the limit of the plausible climate scenarios which had been predicted.

Furthermore, since in many countries the waterways are major transport channels for goods, water scarcity may as well have impacts on the ability to transport goods.

The issue states that "More research needed on the links between the increase in wildfires and the decline in water quality", however there is much scientific evidence relating to the dual nature of wildfires as the result of drought –among other factors-, and as drivers of pollution of surface waters as the result from runoff and transportation of ash (Hallema *et al.*, 2018; Smith *et al.*, 2011; Mansilha *et al.*, 2019).

Question 4: Can you assess each identified emerging issue on the basis of their potential or likely environmental and human health impact, by assigning an assessment of their impact as being: High; Medium; or Low?

See Assessment of Impact section below.

Issue 2: New and alternative sources of water

General comments

The alternative technologies put forward by FORENV relied mostly on developments of existing ones, for example, desalination with advances in membrane technology leading to improved efficiency in reverse osmosis desalination and/or new innovative seawater desalination methods. In spite of the need for advancements in membrane technology in desalination applications, the SCHEER considers that reverse-osmosis remains a high energy- water demand process, SCHEER also considers that higher EU investment in new and more sustainable energy sources, in conjunction with the advancement in seawater desalination methods will result in the future in more cost-effective processes and hopefully in more water availability in arid and semi-arid areas. Consideration around the handling and disposal of sludges on the membrane filters is not discussed.

The SCHEER considers that there is a need to increase water sources and water accessibility by introducing new and alternative technologies in the medium-term, with the necessary risk mitigation measures, but there is also an emerging need to create new technologies (or expand existing ones) in order to upgrade water savings, e.g., in agriculture, and retention techniques at home or small scale, home-based solutions e.g. 'rainwater harvesting architecture', 'rain barrel ideas' (Joyner, 2023) ("low technology solutions").

Reducing losses in water distribution systems would provide a practical partial solution to the challenge of water scarcity. In some countries the inefficiency of old distribution systems leads to more than 50% losses (Farley and Trow, 2005). The recovery of water losses may represent one of the most relevant "new sources" of water. Technologies to make the water transportation system highly efficient and over long distances should be promoted and financed. The topic is also discussed in Issue 8.

It is the opinion of the SCHEER that in the description of the issue an evaluation of the costs and the energy requirements of the proposed technologies is completely missing. It would be very useful for an evaluation of the practical suitability and sustainability of the proposals.

The issue also proposes the acequia as a solution. However, the acequia operates as an open surface conduction for water, to be distributed for irrigation, but it is not a source of water. Having said that, there is a traditional solution associated with the acequia that has been used in mountain areas as a groundwater recharging system, known as *acequia de careo* (Martos-Rosillo *et al*., 2019), that catches snowmelt water in situ and conducts it underground.

Answers to mandate questions

Question 1: Is the emerging issue identified likely to have the risks and/or opportunities described, or also additional ones? And if so, which ones?

It is the opinion of the SCHEER that risks and opportunities are adequately identified and described in a clear way, based on references. There is one additional opportunity that SCHEER considers may be worth considering which is the potential of re-use of large volumes of treated ballast water. The SCHEER notes that there is limited discussion of the energy needs of many of the technologies discussed and on the disposal of membrane filter sludges

Question 2: In your view, are there additional long-term development/s related to the issue that the issue description currently omits? If so, please describe them briefly. Do these development/s pose additional risks and/or opportunities?

The long-term developments related to implementation of new and alternative water sources are well described. In particular, SCHEER concurs with the approach taken by FORENV in terms of considering that there is a potential risk of putting the access/use of a public resource like water under private scrutiny, as a result of company financing. The SCHEER considers that upscaling the innovative technologies should adhere to regulatory requirements, in terms of safety for human and ecosystem health. There is also the consideration of social acceptability of some of the solutions proposed, as well as their sustainability in the long-term perspective.

Question 3: Are the described expected implications (positive or negative) for the environment and human health plausible, including the expected time-frame of emergence?

The SCHEER considers that the expected implications of introducing new and alternative technologies for water sources are sufficiently covered and well explained. Besides the desalinization process which represents already an existing technology, some of the emerging technologies are still at the stage of prototyping, therefore, it is not easy to anticipate the real impacts for human health and ecosystems.

Question 4: Can you assess each identified emerging issue on the basis of their potential or likely environmental and human health impact, by assigning an assessment of their impact as being: High; Medium; or Low?

See Assessment of Impact section below.

Issue 3: Will the circular economy drive water resilience?

General comments

Water quality criteria are an essential part of any water reuse and are required to protect the environment and ecosystems, and both directly and indirectly public health. Confidence in the criteria are important for public acceptability of the re-use, and the rigour of the criteria can also impact the economic viability of water reuse projects. “Currently no uniform criteria exist, but they diverge, often greatly, between countries and states” (Paranychianakis, *et al*, 2015).

The issue involves several very complex aspects: both the reduction in total consumption of water, with an emphasis on water reuse- so touching on water quality and fit for purpose, as well as the extraction of resources from, e.g., wastewater. There is a distinction between water re-use and wastewater re-use. In addition, the CE of water also touches on the processing of wastewater and the re-capture of other ‘scarce’ materials such as nutrients. As in other issues, there is very little discussion of how the first step in circularity is also in the reduction of losses which are known to be substantial.

However, some of the innovations described in the FORENV are still quite small scale- such as smaller decentralised water reuse systems, advancements in small-scale innovative technologies (e.g., membrane filtration, advanced oxidation processes, and adsorption).

Therefore, their scalability is not yet demonstrated. It must be considered that reused wastewater can now meet 40% of Singapore's water demand[21]

There is also mention of the commodification of water (also touched in Issue 8) and which the SCHEER has expressed concerns over.

The FORENV document also clearly makes the connections to co-transitions in the green, digital, and energy transitions which will all have implications for water availability in Europe (as outlined in Issues 8 and 9). Water is required for energy production, while energy is needed to purify, deliver, heat or cool water, and also to treat water/wastewater which is a key component in achieving circularity of water systems as discussed previously. Therefore, more renewable energy contributing to increased water/wastewater recycling and reuse should provide future benefits for water security in Europe. The SCHEER agrees more research is required to optimise treatment systems for renewable energy sources.

Animal –intensive and combined intensive/extensive- farming is already applying the principles of circular economy to water and nutrient management. They are primary big users of water, together with irrigation farming. However, they use farm slurry (liquid manure) to fertilize pastureland or cropland, recycling both water and nutrients, particularly Nitrogen, but also Phosphorous and Potassium. However, there are environmental concerns, such as the spread of pathogens and excess nutrients through runoff to water courses, or the concentration of antibiotics –used for animal treatment- in water and soils.

Centralized solutions of energy recovery from liquid manure where there is a high spatial concentration of animal farming is a viable option that does not have high requirements of transportation –energy sources close to energy plant-, simplifies the individual farm management of liquid manure, and would help managing some of the environmental challenges of the decentralised management of farm slurry, particularly the health problem associated to pathogens.

Timeframe is described as medium to long term, which, in the opinion of the SCHEER, underestimates the urgency.

Answers to mandate questions

Question 1: Is the emerging issue identified likely to have the risks and/or opportunities described, or also additional ones? And if so, which ones?

It is the opinion of the SCHEER that risks and opportunities are adequately described and generally a well written issue. The relationship to existing legislation and strategies is quite clear, but also quite complex.

However, it is the opinion of the SCHEER that some topics could have been better discussed. For example, the problem of minimum quality requirements for the reuse of wastewater and the levels of protection against environmental risks ensured by current regulations are not adequately addressed. The issue was already discussed in a previous SCHEER opinion (SCHEER, 2017; Rizzo *et al*., 2018).

The connection to nutrients and recovery of those is an important aspect, but there may also be others.

This issue is very strongly linked to issue 1, and also new sources of water (issue 2).

Governance of resource recovery from wastewater is not discussed, despite some critical issues being involved. A stringent regulatory framework is required to prevent diversion of these extracted resources for non-authorised uses or transportation to countries where regulation is

[21] https://www.voanews.com/a/east-asia-pacific_singapore-turns-sewage-clean-drinkable-water-meeting-40- demand/6209374.html

less stringent. New institutions or new mandates for existing institutions (water boards) are to be established, particularly relating to monitoring, control and penalization.

Water commodification may drive social and spatial inequalities in the access to water, socially, between those social groups that can pay the real costs and those who do not, and between urban areas, that secure their water supply and rural areas that do not have the political support –as they are less populated- needed to secure their access and cannot compete in the same way.

Question 2: In your view, are there additional long-term development/s related to the issue that the issue description currently omits? If so, please describe them briefly. Do these development/s pose additional risks and/or opportunities?

The SCHEER takes the view that there is insufficient discussion around changing perceptions regarding the re-use of water in the FORENV discussion and on the necessary criteria for water reuse. There should also be more discussion given to the ecological impacts of some of the proposed opportunities e.g. of large-scale rainwater harvesting for surface water and groundwater.

The human health aspects are not discussed in any detail at all.

Question 3: Are the described expected implications (positive or negative) for the environment and human health plausible, including the expected time-frame of emergence?

The SCHEER takes the view that the issues raised here are more urgent than the expressed timescale.

Question 4: Can you assess each identified emerging issue on the basis of their potential or likely environmental and human health impact, by assigning an assessment of their impact as being: High; Medium; or Low?

See Assessment of impact section below

Issue 7: Rethinking agriculture for a water resilient EU

General comments

Similar to other issues analysed in this FORENV cycle, this issue is driven by global climate change. All the measures outlined in the analysis are therefore only partial solutions and must be analysed in the context of global efforts for climate change mitigation.

The issue involves several complex aspects, such as agricultural practices and technologies, land use, economic, social and political issues, environmental protection, human health, food habits and animal welfare without pretending to list all. It is connected to other issues of this FORENV Cycle (e.g., Issue 1), as well as to previous FORENV Cycles (e.g., Cycle 1, Issue 3; Cycle 3, Issue 4). The SCHEER recommends to explicitly acknowledge those links in the text. In particular the issue of changing food habits with a shift toward a reduction of meat consumption has multiple benefits, which was extensively discussed in a previous FORENV Cycle (see FORENV Cycle 1, Issue 3; SCHEER, 2019). Further the potential change in which crops are produced is one that could be highlighted.

In the summer of 2023 many countries, particularly in southern Europe, suffered from extreme drought with enormous damages to agriculture. Based on the prognosis by the IPCC and other climate models, it is highly likely that this will be a re-occurring pattern in the future. Therefore, it is the opinion of the SCHEER that, in addition to the long-term solutions that currently take up a major part of the text, there is also an urgent need for fast, short- term tested solutions. It might even be advisable to provide at least rough timelines for the different issues.

Climate change and the resulting changes in the water cycle do not only cause droughts, but also lead to high rainfall events. The latter drive soil erosion, cause flooding and detrimentally impact harvests in general as crops lose their anchorage, nutrients are washed out of the soil and roots suffer from lack of oxygen in waterlogged soils. Both consequences of changing water cycles will pose massive challenges for European agriculture in the near future. The SCHEER therefore suggests to either discuss both issues in the text, or to change the topic of the analysis to "Rethinking Agriculture for a Drought Resilient EU".

Drought as well as high rainfall both lead to an increase in soil erosion and loss in soil fertility. Either in the form of wind-driven erosion as a consequence of drought, and/or as water-driven erosion resulting from heavy rainfall and flooding. Soil erosion, the need to counteract it and the methods that are available (now or in the foreseeable future) should be included in the analysis.

In this context, the issue of no-till farming might warrant a deeper analysis, from the perspective of increasing drought resilience as well as increasing resilience to water-driven erosion. The SCHEER recommends in particular to identify the development of new methods for no-till farming that do not rely on pesticides (glyphosate) as a research and development need.

The issue does not consider the different challenges in term of water demand and impacts between crops, and crop farming versus animal farming, between extensive and intensive crop farming, and between extensive and intensive animal farming.

The SCHEER also recommends considering the likely changes in agrochemicals (especially fungicides) use, as a consequence of the aforementioned changes in water cycles.

The analysis of goal conflicts in water governance is currently too limited. The text focuses almost exclusively on the potential conflicts between biodiversity protection and agriculture. However, there will also be substantial conflicts between the water demands from agriculture and the water demands from various industries (chemical industry, energy production, tourism) and drinking water supply to the general population.

The SCHEER agrees that animal farming (production of dairy products, meat production) is a key issue. However, it is unclear why changing export patterns are relevant for the issue at hand (it should be irrelevant with respect to water consumption whether the dairy products or meat that are produced in the EU are consumed or exported). Although technical developments, as discussed in the section "Technological innovation" might be highly relevant for lowering the water footprint of dairy and meat production, the provided examples remain somewhat piecemeal and rely heavily on marketing materials.

The term "sustainable agriculture", as used in the text is somewhat problematic, as every farmer would claim that he/she works sustainably. Whether organic farming, with its lower yields per hectare for several crops, leads to an increase or a decrease in total water use per ton of harvested crop is a critical issue, and no solid arguments are provided in the current text. The argument that decreased yields can be compensated by imports is not convincing, given that other countries are experiencing similar or even higher levels of water stress, as currently seen in the drop of global rice production which caused several Asian countries to ban exports.

Furthermore, it is the opinion of the SCHEER that the use of NGTs and GMOs is a key issue and should be carefully considered. In the last few decades, the public concern with GMOs has led to an almost complete stop of public research in the field of GMOs in Europe. As mentioned in the FORENV document, recent research on GMOs (usually supported by private investments) was not focused on the development of crops that would make European agriculture more resilient, such as the development of drought resistant crops or crops capable of growing in marginal and extreme conditions. Most GMO-crops were designed to be resistant to specific products, leading to an increased use of these chemicals, beneficial mainly to the chemical industry, and potentially even resulting in an increased dependence of farmers on the agro-industry.

A properly oriented progress of NGTs, with careful control on human and environmental safety issues, may be extremely useful not only for Europe but also at the global scale.

This will need an adequate information of the public to reduce the negative position against GMO that has been developed in recent years.

There may be other eustressors (physical or chemical, non-biological) to increase drought resistance (Vázquez-Hernández *et al*., 2019).

Lenience of Member Countries in permitting water abstraction is attributed to outdated data or uncertainties relating the modelling of impacts of climate change but does not consider relevant factors such as vote gaining. See for example the water wars in the Doñana Protected Area, as warned by the European Commission (Camacho *et al*., 2022).

The statement "Other studies have found that the Spanish modernisation programme reduced water applied significantly, but in the long run led to increased consumption due to changes in cropping patterns, as well as the adoption of more water demanding crops (Perry, Steduto and Karajeh, 2017)" is not fully supported by evidence, as the increase in efficiency of water irrigation has meant an increase of the irrigated area in Spain, the final outcome being that the volume of water consumed by farming remained almost constant over the years[22]

The reference to "European Parliament Research Centre" should be replaced by the correct reference to the European Parliamentary Research Service (EPRS).

Answers to mandate questions

Question 1: Is the emerging issue identified likely to have the risks and/or opportunities described, or also additional ones? And if so, which ones?

It is the opinion of the SCHEER that risks and opportunities of the different issues that might jeopardize the resilience of European agriculture are not always adequately described (see detailed comments above).The SCHEER identified the following issues that warrant attention but are either not taken up in the current FORENV text or that are not taken up with a sufficient level of detail: (1) loss of agricultural land due to an increased frequency of heavy rain / flood events, (2) increased soil erosion due to flood events and droughts, (3) use of GMO techniques for increasing the resilience of agricultural crops, (4) competing demands with various industrial sectors, including tourism, chemical and energy industry, (5) increased used of fertilizers and pesticides, with an increasing risk of water pollution.

Question 2: In your view, are there additional long-term development/s related to the issue that the issue description currently omits? If so, please describe them briefly. Do these development/s pose additional risks and/or opportunities?

The issue describes several possibilities that may be developed "in future" like developing resistant crops, changing land use and food habits, etc.

However, it is the opinion of the SCHEER that the problem is extremely urgent.

In the last summer (2023) many countries, particularly in south Europe, suffered from extreme drought with enormous damages to agriculture. Considering the trend of the last few years, it is very likely that this will happen in the near future.

Therefore, it is the opinion of the SCHEER that, besides long-term solutions (that may be very important), there is urgent need for short-term solutions.

European trade with agricultural produce has continuously increased during previous years (import as well as export increased from 100 billion USD 2008 to 196 billion USD (import) and 223 billion USD (export) in 2022, Eurostat)[23]. This interdependency with non-European countries, many of which many are located in climate regions that will be even more dramatically affected by global warming, is a potential Achilles heel for food security in Europe and elsewhere, depending on the types of agricultural products being traded.

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[22] https://www.caixabankresearch.com/es/analisis-sectorial/agroalimentario/uso-del-agua-agricultura-avanzando- modernizacion-del-regadio-y

[23] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Extra-EU_trade_in_agricultural_goods

Farming is not only a source of food, but increasingly also used to fuel a bioeconomy that is supposed to reduce reliance on fossil fuels. Plants are increasingly used for energy production and as feedstock for chemical synthesis. This will lead to goal conflicts with food production in the future. This new and developing role of agriculture also requires specific attention while discussing measures to increase resilience of European agriculture, due to the different demands of the crops involved.

A new development is land based aquaculture that relates to any operation producing or maintaining aquatic livestock within facilities operating on land. This can be cultures with both marine and freshwater (Zhang *et al*., 2022), and include both indoor and outdoor farming (The Economist, 2021;Land-Based Aquaculture in Zeeland - Impuls Zeeland helpt jou als ondernemer met innoveren, investeren en internationaliseren).

Question 3: Are the described expected implications (positive or negative) for the environment and human health plausible, including the expected time-frame of emergence?

As for other issues of this FORENV Cycle, the solutions are strictly related to the control or mitigation of the effects of climate changes and, therefore, in the medium/long term, it is reasonable to predict that the outlined problems and challenges will get more severe. Even if implemented, the measures discussed will only be able to mitigate some of the consequences, as part of an adaptation strategy to a world that is inevitably changing.

All measures discussed may only try to mitigate the consequences, adapting the strategies to a world that is inescapably changing.

In this frame, the FORENV document is quite realistic, considering the barriers associated with the practical and economic feasibility of the possible solutions.

The differences between arid and semi-arid southern countries and the water richest countries of central and northern Europe are also highlighted, as well as other uncertainties.

Considering all these uncertainties, the anticipated time-frame for implementing the different possible measures is not clearly indicated in the FORENV document.

The SCHEER agrees with these difficulties and uncertainties and considers the indication of a precise time-frame unfeasible. However, the SCHEER recommends to provide an indicative timeframe (in terms of decades) in which the different risk mitigation measures need to be implemented in order to avoid the worst consequences of global warming for European farming and food security.

Question 4: Can you assess each identified emerging issue on the basis of their potential or likely environmental and human health impact, by assigning an assessment of their impact as being: High; Medium; or Low?

See Assessment of impact section below.

Issue 8: Use of digital technologies to improve water management

General comments

The issue involves several very complex aspects: as well as environmental, there are cyber security, governance and privacy aspects. Within the issue, the emphasis tends to be on water quantity, feeding through into floods and droughts and very little on water quality. Management when dealing with a resource for which there are competing uses (and also there are commercial aspects, since many water companies are privatised) is not well described. Privatisation of water supplies is a key problem that should be better discussed (probably it could merit a specific FORENV Issue). Some important questions are: May a fundamental good like water be privatised? Is it acceptable making profit from water? What can be done at European level?

In the issue description, the problem of water losses in distribution systems is highlighted (see also Issue 3). Possible solutions are mentioned but should be better clarified. Increasingly water companies are making use of digital technology for the early detection of leaks. The use of digital technology for monitoring quality, not only quantity, is described very briefly in this Issue.

The increasing use of digital technologies in many areas of government and business, and infrastructure generally has common features, so there are experiences and lessons that can be learned / transferred across.

Availability of data and training of algorithms are major challenges, especially considering the need for new technology (e.g. new sensors for novel contaminants) and increasing use of earth observation. Data sharing is a common challenge, and some of the issues associated with digital water could easily be cross-boundary and cross-jurisdiction, therefore regulation and cybersecurity aspects should be ensured.

Digital skills may be required of consumers when smart (and remotely controlled) meters and automated communication are implemented by water companies / suppliers for e.g., administrative purpose.

Answers to mandate questions

Question 1: Is the emerging issue identified likely to have the risks and/or opportunities described, or also additional ones? And if so, which ones?

It is the opinion of the SCHEER that risks and opportunities are adequately described but very much focussed on water quantity and not on quality. There is very limited discussion about responsible innovation, or about the major societal challenge around data sharing, GDPR and privacy and security.

Question 2: In your view, are there additional long-term development/s related to the issue that the issue description currently omits? If so, please describe them briefly. Do these development/s pose additional risks and/or opportunities?

As the SCHEER have indicated, this issue does not cover water quality in detail and the technological developments that are ongoing around smart sensors for water quality, development of early warning systems (e.g. for harmful algal blooms). Security and privacy while mentioned are insufficiently emphasised.

Question 3: Are the described expected implications (positive or negative) for the environment and human health plausible, including the expected time-frame of emergence?

The digital revolution and evolution is happening now and accelerating, so that these issues are current and likely to rapidly develop. The SCHEER considers that the digital management of water data could contribute to the human health monitoring and surveillance systems, as we have seen in wastewater monitoring for Covid. There is also no mention of the 'digital divide'.

Question 4: Can you assess each identified emerging issue on the basis of their potential or likely environmental and human health impact, by assigning an assessment of their impact as being: High; Medium; or Low?

See Assessment of impact section below.

Assessment of the impact

To answer the fourth question in the Term of Reference about assessing the impact of each issue on environment and human health, the SCHEER followed the procedure of classifying the issues into three categories of high, moderate and low impact on environment and human health. All members of the SCHEER were asked to classify the five issues, then a score was given to the individual classifications (3 for high impact, 2 for moderate, 1 for low). The 13 scores provided were summed to give a total score and the mean score calculated, rounded to the nearest whole number and reported in Table 1.

Table 1: Classification of the 5 issues into the three impact classes (1: Low, 2: Moderate, 3: High) for the environment and human health, made by the SCHEER members.

Issue	Environment (mean score)	Human health (mean score)
Issue 1:	3	3
Issue 2:	2	2
Issue 3:	2	2
Issue 7:	3	2
Issue 8:	2	1

Dominating the scoring of the issues was issue 1, which was a general issue on water scarcity and quality. The impact of water scarcity on human society and the environment can barely be overstated and is directly connected to the other issues considered in this opinion. The SCHEER consider that the topic of water resilience is one of the most urgent and challenging issues facing society. The remaining issues are considered to have moderate impact affecting environment and human health equally (only issue 8 deviates slightly from this assessment).

Summary of review by the EEA Scientific Committee

This section presents verbatim the comments by the EEA Scientific Committee on issues 4, 5, 9 and 10. For issue 6 only in-text comments and edits were provided, and as noted in the introduction to this section these were addressed as far as possible in the final versions presented in this report.

Issue 4: Emerging challenges for the governance and equality of access and use of water at the local and regional level

Is the emerging issue identified likely to have the risks and/or opportunities described, or also additional ones? And if so, which ones?

The opportunities described are obvious and sometimes nice to have, but the risks column is more relevant. I would have started with the risks and then see how they can be dealt with, through trade-offs, finding synergies, and through other means (legislation, participation, incentives: examples from the three basic governance styles (hierarchical, network and market governance). Now the column of opportunities comes across as slightly naïve, and also very sectoral (siloed).

Where participation is considered as the panacea to solve all problems, there is no mentioning of concrete tools. An evident tool seems the mutual gains approach (MGA). Also, the future research suggestions seem like more of the same. Why is not mentioned how important peer learning between water authorities can be? The European Commission supports this also at local and regional level (through a dedicated programme within INTERREG).

In your view are there additional long-term development/s related to the issue that the issue description currently omits? If so, please describe them briefly. Do these developments pose additional risks and/or opportunities?

I still do not know what the emerging issue is, besides increasing water stress in its various forms. What I completely miss is the increasing complexity of water stress challenges because they are intertwined with other trends and crises. The paper pays no attention to these interlinkages. Pity because if the 2030 Agenda with its interlinked SDGs had been used as framework, this would have been clear from the start.

The paper also misses the potential impact of the cascading crises, on water systems, water governance, and on democratic governance as a whole. If the current trend continues that national governments continue using emergency legal short-cuts and centralising resources for crisis management, subnational authorities may suffer so much that there may be in the future less legal room, nor resources for participatory approaches. A scenario approach could have dealt with this!

Are the described expected implications (positive or negative) for the environment and human health plausible, including the expected timeframe of emergence?

I have not seen anything in the paper on time frames. The authors must have assumed that it was not the purpose of the paper to discuss possible future developments.

Can you assess each identified emerging issue on the basis of their potential or likely environmental and human health impact, by assigning an assessment of their impact as being: High; Medium; or, Low?

No, not possible. The discussion of the 'emerging issue' is so fuzzy that I cannot link that to environmental and health impacts.

Issue 5: Will societal change drive water resilience or will our shared ambition for water change society?

Is the emerging issue identified likely to have the risks and/or opportunities described, or also additional ones? And if so, which ones?

I understand that addressing societal change is a challenging subject due to the diversity of opinions and viewpoints on what defines such change and how it can be fostered. This could potentially serve as a starting point of the issue paper. Although the document contains well-formed arguments, it appears to struggle with the diversity of topics. Eventually, the document concentrates on specific topics, yet it provides limited justification for the rationale behind singling out these particular ones.

The most extensively developed part is devoted to the concept of Rights of Nature (RoN). This is an intriguing and relatively novel subject that, in my view, warrants being the sole focus of the issue paper. Other topics such as wastewater recycling, xeriscaping or water-neutral design are less elaborated and substantiated in comparison. In general, the issue paper shifts its focus towards conserving water resources in specific sectors, like domestic water use and the fashion industry (addressed only in the summary table), while omitting others such as agriculture. Granted, some of these topics have been covered in the previous forenv exercises and should not be repeated. To maintain a clear focus, the introduction could start by recognizing the intricate nature of societal change in the context of water conservation. Following this, it could explicitly state that the paper's emphasis lies on certain areas where social change has the potential to yield significant outcomes. Furthermore, all the selected approaches primarily focus on managing water quantity, while there is limited discussion about addressing water quality.

In your view are there additional long-term development/s related to the issue that the issue description currently omits? If so please describe them briefly. Do these development/s pose additional risks and/or opportunities? Are the described expected implications (positive or negative) for the environment and human health plausible, including the expected time-frame of emergence?

I found the presentation of the aforementioned solutions – Rights of Nature (RoN), wastewater recycling, xeriscaping, and water-neutral design – leaning towards highlighting potential positive outcomes, with less emphasis placed on addressing the associated challenges. As an example, the implementation of environmental or ecological flows (see for example https://doi.org/10.1088/1748-9326/acc196) may be a good starting point for the challenges of putting RoN in practice. The insights from the implementation of the Aarhus convention may also be useful to mentioned.

Arguably, one of the reasons supporting the promotion of behavioural nudges is the observation that residential water demand tends to be less shaped by economic incentives (inflexible water-price elasticities, see for example https://doi.org/10.1146/annurev-resource-110220-104549). This may be stressed more. Another aspect that receives less attention in the issue paper is the potential concerns these approaches might raise in terms of social justice. Additionally, the discussion regarding the risks linked to the slow fashion movement is not consistently easy to follow (see my in-text comments).

Can you assess each identified emerging issue on the basis of their potential or likely environmental and human health impact, by assigning an assessment of their impact as being: High; Medium; or, Low?

In this context, I interpret this question as inquiring about the effectiveness of the various solutions and the level of severity of potential adverse consequences they may bring about. I am of the opinion that the manner in which they are implemented will significantly influence their performance.

Issue 9: The need for co-transitions to avoid unintended consequences for water resilience

Is the emerging issue identified likely to have the risks and/or opportunities described, or also additional ones? And if so, which ones?

The twin transitions of digital and energy are significant drivers of global transformation, intersecting and complementing each other in myriad ways. The digital transition signifies a shift from traditional modes of operation in businesses, governance, and everyday life to a more connected, data-driven paradigm. This transition is characterized by the proliferation of digital devices, the ascent of big data, and the growing significance of artificial intelligence and machine learning. In parallel, the energy transition marks a move from fossil-based energy systems to renewable, cleaner, and more sustainable sources, complemented by innovations in energy storage and distribution.

The twin transitions reverberate across many sectors, including water use. The brief addresses the implications for water management, but it does so selectively, focusing primarily on technological solutions for water provision, notably desalination, while referring to issue 2 for other alternative water sources. The intersections of the two transitions are complex, and their implications for water resource management have yet to be fully explored. This makes the knowledge synthesis challenging.

The main shortcoming of the issue is that it focuses extensively, and somewhat redundantly, on explaining the EU energy and decarbonisation policy goals, while only briefly addressing the water implications. Agricultural water use and efficiency are left out, probably for a good reason but this is not explained in the issue. The issue could be strengthened by a clearer framework explaining what is covered and what is not, guiding the literature review and assessment.

The issue should reference the 'Strategic Foresight Report 2022', which delved into the twin transition across various sectors: energy, transport, industry, construction, and agriculture.

In your view are there additional long-term development/s related to the issue that the issue description currently omits? If so please describe them briefly. Do these development/s pose additional risks and/or opportunities? Are the described expected implications (positive or negative) for the environment and human health plausible, including the expected time-frame of emergence?

What I felt was missing in the issue were the second-order aspects. Digital transition plays a pivotal role in making the energy transition more feasible. Smart grids use digital technology to optimize the distribution of energy. Digital devices can monitor and adjust energy (and water) consumption in real-time. Predictive analytics can forecast energy demands or the best times to store or release energy (water). The data collected about the actual energy/water use can drive efficiency, reduce wastage, and lead to new innovative solutions. All this may impact the resource efficiency which should be at least mentioned, if not fully explored.

Can you assess each identified emerging issue on the basis of their potential or likely environmental and human health impact, by assigning an assessment of their impact as being: High; Medium; or, Low?

I do not have a definitive answer to this question.

Issue 10: Future water-related disputes and geopolitical conflicts drive transboundary cooperation on water

Is the emerging issue identified likely to have the risks and/or opportunities described, or also additional ones? And if so, which ones?

As I also commented on issue 5, it would have been more fruitful to start with the risks and then see how they can be dealt with, through trade-offs, finding synergies, and through other means (legislation, participation, incentives: examples from the three basic governance styles (hierarchical, network and market governance). Now the column of opportunities comes across as slightly naïve, and also very sectoral (siloed).

The 'opportunities' are all things that are already happening or have been tried. I see new mentioning of innovative approaches that have been piloted.

In your view are there additional long-term development/s related to the issue that the issue description currently omits? If so, please describe them briefly. Do these developments pose additional risks and/or opportunities?

What is absolutely missing is water-related spill-over effects of what happens in the EU countries, to other global regions. A good source is the OECD/JRC report on spill-over effects. [24] Although transboundary is not defined in the paper, it is used to mean cross-boundary (on neighbouring countries). Everything beyond that is absent in the report.

Under "Uncertainties" (p8), it is assumed that "a desire to reduce the risk…" "could help drive transboundary cooperation". What was the author thinking? Reducing the risk can be the result of more cooperation. A desire doesn't bring much. Political leadership and strong governance mechanisms to regulate and coordinate can indeed be useful. But that's not what is written here.

Are the described expected implications (positive or negative) for the environment and human health plausible, including the expected timeframe of emergence?

I have not seen anything in the paper on time frames.

Can you assess each identified emerging issue on the basis of their potential or likely environmental and human health impact, by assigning an assessment of their impact as being: High; Medium; or, Low?

No, not possible. The discussion of the 'emerging issue' is so fuzzy that I cannot link that to environmental and health impacts. It contains some pseudo causalities that are not underpinned, and is too naïve about real powers (political, private sector) and legal constraints (such as private ownership in riverbeds). It is not analytical in the sense that it develops based on facts and observations new insights about how water disputes and conflicts could develop (or not): a scenario approach is missing, which would have given a focus to the paper. Now it meanders.

In addition, some sentences are incomplete. Work to do!

[24] https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/report-offers-new-tools-address-spillover-and-transboundary-impacts-un-2030-agenda-2021-04-08_en

APPENDIX C KEY TO ICONS USED IN ISSUE CLUSTERS

APPENDIX D SOURCES FOR SECTION 2.1

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