Sciences Po Energy Review

Tides of Change: Navigating the Intersection of Energy and Water

Issue IV - March 2026

SciencesPo
EUROPEAN CHAIR FOR SUSTAINABLE DEVELOPMENT AND CLIMATE TRANSITION

About the Cover Photography

The cover photography was taken by Tom McCaughey, winner of the Review's Photo Competition. Tom was born in Dublin and grew up in Potsdam, Germany. He began photography as a serious hobby in 2021 when, after finishing school, he went to work on a farm in Iceland for seven months. He brought his dad's old camera and was deeply inspired by the breathtaking landscape. Since then, he has brought his camera on every trip he's taken. Besides photography, he studies Computer Science in Potsdam, used to be a rowing trainer, and enjoys travelling! He spent his last semester on Erasmus in Paris and thoroughly enjoyed the city's amazing culture. *"The photograph was taken on a day trip to Le Havre in October. It was a windy day with piercing sunlight, and the waves were crashing over the pier. I took quite a few shots before managing to capture this composition of the walker under the waves."* You can find more of his work at @tom.mccaughey and @shotsbytommy.

Contents

About 3

Foreword 4

Editor's Note 5

Annotated Bibliography 7

Interviews

Interview with Isabel Ruck 13

Interview with Giacomo Parrinello 18

Case Studies

Brownfield Blues, Water Legacies and the Touro Mine: Local Frictions in Europe's Push for Energy Independence 26

A Shared Path to Green Hydrogen? Water, Infrastructure, and Policy Lessons from France and Namibia 28

Managing Trade-offs in the Water-Intensive Semiconductor Industry 35

District Heat & Data Centres: Barriers to Large Scale Implementation 37

Decarbonising Desalination: A Comparative Case Study of Fossil and Renewable-Powered Plants 40

Marine Carbon Dioxide Removal: A Blind Spot for Science and a Moral Hazard for Policy? 45

Water and Energy as Weapons: The Insights from the Russia-Ukraine War 48

The Unequal Burdens of the Green Energy Transition: Water Extractivism in Atacama, Chile 52

Critical Essays

Behind the Cloud: Water, Power, and Digital Extraction 55

Desalination in Kazakhstan's Industrial Mangystau and Atyrau Regions: Lifeline or Liability? 61

Green Hydrogen Won't Flow Without Water: Rethinking EU Energy Security for Resilient Trade with Waterscarce Partners 67

Death in the Shadow of the Dam: A Critical Political Ecology Perspective on the Lesotho Highlands Water Projects 74

Addressing Africa's Energy–Water–Food Challenges Simultaneously with an Agrivoltaics Nexus Approach 81

About The Board

Clara Klint | Editor in Chief

Clara is a master's student in International Energy Transitions at Sciences Po. She holds a BSc in Political Science from the London School of Economics. She is passionate about industrial policy and energy economics. She has experience working on energy technology supply chains at the International Energy Agency and previous experience in foreign direct investment consultancy and energy market research.

Sophie Schut | Editorial Board Member

Sophie is a graduate student in Environmental Policy at Sciences Po. She graduated from University College Utrecht with a major in political science and human geography. She is currently writing her master's thesis on inland fisheries in Indonesian peatlands through the lens of political ecology. She is also is working in the water team of the Sciences Po Sufficiency Lab. She has had research internships at environmental NGOs, such as Tropenbos Indonesia and Indigenous Livelihood Enhancement Partners.

Michael Gillesberger | Editorial Board Member

Michael is a graduate student in International Economic Policy at Sciences Po. He holds degrees in Economics from the Vienna University of Economics and Business and the Queensland University of Technology in Australia. He has worked at the intersection of economics, climate and policy, including at the Austrian Ministry for Climate Action and the applied research institute EcoAustria. Besides his studies, he is working as a Research Assistant at his home university. He is also a member of the Global Shapers, a worldwide community of young leaders under the auspices of the World Economic Forum.

Laila García Ferrer| Editorial Board Member

Laila is a graduate student in International Energy Transitions at Sciences Po. She holds a bachelor's degree in International Relations from El Colegio de México, where she wrote her thesis on geothermal energy development in Mexico. Beyond energy, she is interested in biodiversity conservation and restoration. She has experience as a Research Assistant at an NGO specialized in reforestation projects in the Los Tuxtlas region, Veracruz, Mexico, and as an intern at GIZ in the Mexican-German Energy Partnership team.

Maxim Mouret| Editorial Board Member

Maxim is a graduate student in International Energy Transitions at Sciences Po. He holds a bachelor's degree in International Relations and Political Science from the University of Sydney, where he wrote a thesis investigating community opposition to large-scale renewable projects. He has previous experience in the NGO and public sectors, working with a leading conservation agency and electoral commission in his home state of NSW, Australia. His primary interests include energy justice and the environmental impacts of energy developments.

Introduction

About the Sciences Po Energy Review

The Sciences Po Energy Review is a graduate student-led publication to advance dialogue about energy. Motivated by the pressing global need for energy transitions, the journal primarily employs a social scientific approach without being constrained by any single discipline, featuring graduate student writing and expert analyses. By placing contributors in conversation with peers and experts, the publication seeks to strengthen existing debates and research about energy at Sciences Po and beyond, and welcomes submissions from all around the world. The Sciences Po Energy Review is hosted by the European Chair for Sustainable Development and Climate Transition. The Review was founded by Gabriele Romeo and Ernest Lee (Promotion 2024).

About the European Chair for Sustainable Development and Climate Transition

The mission of the Chair is to advance education, innovation and public dialogue for the design and practice of policies for sustainable development and climate transition, within and outside of Europe. Challenges of climate change adaptation, decarbonisation, safeguarding planetary boundaries, green financing, biodiversity depletion and geopolitical environmental risks need to be understood and overcome in order to advance ambitions of the European Green Deal. The Chair's mission is to drive education, innovation, and public discourse in the development of sustainable policies and climate transition, both within Europe and globally. We are dedicated to addressing critical challenges such as decarbonization, climate change adaptation, implementing the energy transition, green finance and minimising environmental risks. Our ultimate goal is to support the European Green Deal's ambitious objectives. Our work centres on facilitating social and environmental transitions. We focus on analysing the content and governance of policies, partnerships, and actions needed to create transformative pathways for regions and cities. Our aim is to strike a balance between economic growth, social progress, and environmental protection. We are committed to establishing a broad network of actors who will contribute to research, education, and discussions on important topics such as regional well-being, just transition, climate mitigation and adaptation, energy transition, and climate-resilient infrastructure. Our approach embraces various perspectives, including economic, sociological and technological, overcoming traditional disciplinary boundaries. Hosted at the Paris School of International Affairs (PSIA) and the School of Public Affairs, the Chair is governed by two committees with the help of a team. The Chair is funded by: Hermès International, HSBC and the European Investment Bank (EIB).

Foreword

Marc Ringel | Scientific Advisor to the Sciences Po Energy Review

Dr. Marc Ringel is the Chairholder at the European Chair for Sustainable Development and Climate Transition at Sciences Po, Paris. Dr. Ringel is also professor at Nuertingen Geislingen University, Stuttgart, Germany. He is a senior associate researcher with the University of Brussels, Belgium (Vrije Universiteit Brussel) and an affiliated lecturer with Université d'Aix en Provence/Marseille, France. He leads multidisciplinary research on green transitions in the energy and climate field, focussing on the role of public governance.

The coupling of energy and water systems, the so-called energy-water nexus is a topic that allows for multifaceted research. Energy systems have always been water systems: rivers for hydropower, freshwater for cooling, and "hidden" volumes of water embedded in fuels and materials. What is new is how climate change, industrial reshoring and digitalisation are making water a binding constraint for decarbonisation choices. While we have known for years that a conflict between energy use and freshwater resources is likely to emerge, recent analyses show that we are entering into this conflict at a faster pace than previously anticipated.

Let me cite only a few examples that demonstrate the complexity of the energy-water nexus. Synthesis on hydropower stresses that climate change is disrupting inflows, sedimentation dynamics, and dam safety, with highly heterogeneous regional outcomes. Decarbonisation, on the other hand, can ease water pressures: the IEA notes that wind and solar PV require around one hundredth of the operational water used by fossil generation. Agrivoltaics shows a promising "triple dividend", especially in semiarid regions, and is yet another example of how win-win solutions can emerge if energy and water systems are intelligently designed and aligned.

Semiconductors and data centres bring industrial policy and digitalisation into the energy-water nexus, adding a further layer of complexity. As we increasingly witness, the energy transition is also a data transition. Already, large-scale data centres consume enormous amounts of water each day, and global data centre water consumption is projected to rise sharply, even under best-case scenarios of energy sector projections for 2030 and 2050. On the other hand, AI can drive considerable, wide-ranging energy savings and help optimise, and even reduce, water use. While these multi-faceted issues call for both deeper analysis and more comprehensive research, the policy questions are practical and will, in many cases, involve hard choices: How should basin level water stress be included in energy installation permitting and industrial siting? Which disclosure metrics should become mandatory? How can circular approaches (including water reuse rules and the identified potential for scaleup) reduce vulnerability without shifting burdens onto households and ecosystems? This issue of the Energy Review allows readers to dive into these often contradictory questions and gain an overview of the diverse challenges at the energy-water nexus.

I warmly thank the editorial board for their sustained engagement and rigorous guidance throughout this issue. With this, I wish you an enriching read, and hope it provides insights and inspirations for your own further research in this field. ■

Editor's Note

Energy and water supply are interlinked. Energy is used for extracting and delivering safe water sources. In turn, water supports every stage of energy production, from extraction to the cooling of power plants. With unsustainable use and climate change aggravating pressures, water management and tenure questions will create friction between different interests. As such, the management of water will increasingly shape the energy transition, both *within* and *across* borders. By thinking about energy and water questions together, we can start to develop more robust energy transition policies for all. This narrative-change won't come overnight. But we hope that this issue, which offers a broad spectrum of themes central to the energy-water nexus, can spark further debate.

One contribution to this issue that sits at the very heart of the energy-water nexus is Ivan Gligorov & Christopher Hegadorn's essay. They make a case for how co-location of agricultural production and solar PV can provide a solution for energy, water and food security across Africa - showing concretely how integrating all these dimensions can yield better solutions.

Another theme in this issue is water and industrial competitiveness. Nearly two years have passed since the Draghi-report spelled out the European Union's road to competitiveness in energy and digital technology. This issue features three pieces which closely examine water management in domestic technology supply chains. Evelyn Mang's case study homes in on the water-intensity of the semiconductor manufacturing industry – a pillar for the EU's tech ambitions. Clotilde Cerdán shows how speeding up new critical minerals mining by exploiting brownfields might not be a silver bullet for meeting the EU's critical minerals ambitions. In my case study, I touch on practical barriers to data centre waste heat reuse. Covering multiple steps of key supply chains, these case studies cover both the importance of public legitimacy, but also how Europe could become a breeding ground for sustainable water management practices.

Globalised technology supply chains place water burdens on countries that capture little of the economic gains. Marie-Alix Depuydt's brilliant essay *Behind the Cloud* examines how American tech giants set up thirsty datacentres in water-scarce regions in developing countries, perpetuating extractive colonial patterns. In her case study, Sophie Schut shows how mining companies in the Lithium Triangle, who are extracting lithium from brine, skirt environmental requirements.

In green hydrogen production, water leaves the hydrological cycle as the electrolyser splits water into hydrogen and oxygen. This makes water supply an important consideration in hydrogen production, particularly in arid regions. Julia Brahy's case study discusses strategic considerations at play, both for countries planning export-oriented hydrogen production and those with domestic use-cases, using Namibia and France as examples. Critically examining the EU's hydrogen import strategy, Manon Pituello engagingly explores how the EU's hydrogen import strategy fails to adequately account for water-scarcity and related socio-political risks in partner countries, thereby undermining key pillars of its energy security strategy.

Desalination, the process of removing minerals from seawater, is a primary technology for fresh water supply in the Middle East today, and its importance is growing fast. I am extremely pleased with the coverage of desalination from multiple angles in this issue. In rich technical detail, readers can learn more about different renewable and fossil desalination through Sofia García-Escribano's excellent case study of three desalination plants in the Middle East and Australia. Nargiz Shantayeva and Zhansulu Sagynysh and provide us with a thorough examination of how desalination impacts the Mangystau and Atyrau regions in Kazakhstan, illustrating the impacts across different time scales. These perspectives are complemented by Sophie Schut's and my interview with Isabel Ruck on desalination in the Middle East. She paints a vivid picture of how oil, water and state-power have interacted in the region, and how the growing importance of *produced* water is reshaping relations within the region.

Introduction

Editor’s Note

Hydropower dams are a source of baseload electricity – often important for balance intermittent renewables. But by controlling the flow of life-sustaining waterways, hydropower dams are also a source of conflict both *within* and *between* countries. The historical deep-dive provided through Laila García-Ferrer and Maxim Mouret’s interview with Giacomo Parrinelli contextualises challenges in river management, making it an ideal starting point to understand these issues. Galen Miller’s detail-rich essay on hydro dam construction in Lesotho depicts the different narratives at play in water transfer schemes and dam-construction – and voices shut out of the story. Additional readings on hydro dams in the annotated bibliography complement this analysis to understand both their physical impacts on societies and their symbolic charge. Oleksandra Pashkina’s piece on the destruction of hydropower and nuclear cooling infrastructure in Ukraine contributes further to the hydropower and conflict discourse by prompting us to think about the role of water infrastructure during times of war.

Finally, this issue will also shed some light at the water-energy nexus at sea. Lavanya Kapoor provides a timely case study on marine carbon dioxide removal, highlighting risks and dissecting its role in climate politics. The annotated bibliography also features a rich sample of readings exploring what happens to offshore energy infrastructure as they reach their end-of-life and highlights subsea mining developments.

I want to extend a warm thank you to everyone who contributed to this issue and made it possible. In particular, I want to thank the excellent editorial team for your dedication and passion – it has been an absolute delight working with you. ■

Clara Klint
Editor in Chief

Annotated Bibliography

Framing the debate.

The following section offers a series of short notes which summarises and reviews literature connected to the issue theme, offering a starting point for the discussion, as well as a complement to the contributions in this issue.

Hydropower, Resource Management, and Conflict

Bilgen, Arda, "'Concrete' steps toward modernization: Dam-, state-, and nation-building in southeastern Turkey." In *The Routledge Handbook on Contemporary Turkey*, edited by Joost Jongerden, 1st ed., 297–308. Routledge, 2023. ISBN 9781032023694.

Note by Clara Klint: An ever-fascinating topic to me is how collective stories of technology and progress shape state power. In a succinct format, this chapter by LSE Middle East Centre Scholar Dr. Arda Bilgen, shows how Turkish dam-building was intimately intertwined with both state- and nation-building. After WW2, and as a recipient under the Marshall plan, the republic was eager to demonstrate its ability for effective governance. Here, Bilgen shows convincingly how hydropower represented a central vehicle for this pursuit. Turkey set up new agencies based on US models, but staffed with top Turkish engineering talent. Managing a large, successful hydropower buildout would signal competence and legitimacy – both in the eyes of its own population and to Europeans onlookers. Dam projects also projected the strength of the republic in the Southeast, attempting to 'tie in' the Kurdish population through economic transformation. However, Bilgen also points out that legitimacy did not only rest on the promises of future economic prosperity. Nostalgia also played a role – large-scale hydro buildout was conceived as a continuation of the Mesopotamian mastery of water resources. Understanding the symbolic charge of hydropower, and its role in consolidating state power and nationhood, can help make sense of today's energy politics and mega projects.

Espeland, Wendy Nelson. *The Struggle for Water: Politics, Rationality, and Identity in the American Southwest*. (Chicago: University of Chicago Press, 1998).

Note by Sophie Schut: Espeland's analysis of how plans for the Ome Dam in the American South West were canceled in 1981, appealed to me as it showed the successful resistance against displacement. Simultaneously, she provides nuanced insights into water development networks, reflecting how this is a heterogenous group, with clashing epistemologies. She shows how the Bureau of Reclamation engineers, what she terms the Old Guard, seemed emotionally invested in the project, seeing beauty in the ability of big infrastructure to control water. On the other hand, the New Guard, consisting of social and environmental planners, aimed to translate harms into commensurables so that the Indigenous Fort McDowell Yavapai could be compensated. However, she argues that the substantive value of land was incommensurable to the Yavapai, due to a history of marginalisation and displacement, as well as ancestral burial grounds. Overall, I think she convincingly showed the limits of rational choice theory, making it an essential read for anyone interested in cost-benefit analyses.

Introduction

Annotated Bibliography

Matthews, Ron, and Vlado Vivoda. "'Water Wars': strategic implications of the grand Ethiopian Renaissance Dam." In Conflict, Security & Development vol. 23, no. 4 (2023).

Note by Maxim Mouret: Fair and equitable use of water has long been a point of contention amongst riparian countries worldwide, and one that is currently being exacerbated by the expansion of hydropower infrastructures. Emblematic of this is the Grand Ethiopian Renaissance Dam (GERD), which began operations in 2020, pitting Ethiopia's drive to increase their hydropower capacity against the need for water in downstream countries — most notably Egypt and Sudan. The majority of publications surrounding the GERD frame the project as a ticking time bomb, bound to spark inevitable conflict due to the divergent interests of upstream and downstream states. In this piece, Matter & Vivoda provide a far more nuanced, balanced, and potentially optimistic account that comes as a breath of fresh air. Highlighting the drawbacks the dam entails for Ethiopia (mass displacement, dependency on foreign funding, environmental damages…) and the potential benefits for Sudan and Egypt (less frequent flooding, more options for water management, etc…), the authors draw out a critical complexity and range of interests often left out of focus, and paint a far more optimistic picture regarding the possibilities for negotiation and compromise in the region. As water scarcity and resource conflicts propagate with the effects of climate change, it is critical that we develop solutions to such issues ahead of time.

Vishwanathan, Saritha S., Amit Garg, and Vineet Tiwari. ***Coal Transition in India: Assessing India's Energy Transition Options*****. Paris: IDDRI and Climate Strategies, 2018. [Report Link]**

Note by Isha Hiremath: The annual ritual of India's infamous coal-fired thermal power plants (TPP) restricting their operations during the air pollution season is widely discussed. However, India's coal- fired TPPs are also water-guzzling and many of them are located in water-stressed regions. In 2016, many TPPs across India were forced to pause their operations due to water scarcity issues. The issue persists to date, with water for energy in direct competition with municipal water supply (see for example, Reuters' recent coverage of Solapur city's problems with coal and water).[1] To dive deeper into the issue of India's coal-water nexus, I recommend Vishwanathan et.al's research paper *Coal Transition in India. Assessing India's Energy Transition Options.* The fourth section of this paper covers water scarcity challenges of India's coal-fired TPPs, and models the availability of water well into the 2040s, along with estimating the forced shutdowns due to water shortages. However, how such pressures will impact the coal sector's revenues at the backdrop of declining prices remains to be seen.

Innovation in the Energy and Water Nexus

"Top 10 Emerging Technologies of 2025.", World Economic Forum, last modified June 2025, [Report Link].

Note by Clara Klint: Imagine a technology that could not only offer a source of stable decarbonised baseload, but also has the potential to reinvent resource management. In 2025, the World Economic Forum's Report on Future Technology brought attention to the promise of osmotic power. The idea of exploiting the salinity difference where rivers meet the sea for large-scale electricity production has been around since the 1970s. But back then the technology was mothballed because the osmosis membranes of the time were deemed too inefficient. Today, nanotech breakthroughs may change that. What makes osmosis worth exploring is that it could provide steady electricity baseload around the clock. It also has global potential, with especially

[1] Jain, Mayank, and Saritha Rai. "India's $80 Billion Coal-Power Boom Is Running Short of Water." Reuters, June 9, 2025. https://www.reuters.com/sustainability/boards-policy-regulation/indias-80-bln-coal-power-boom-is-running-short-water-2025-06-09/

favourable prospects in high-salinity regions like the Middle East or Australia. It could be cost-competitive too. Osmosis-tech start-up Sweetech claims to be targeting €100/MWh by 2030 - which would bring it on par with other baseload options like nuclear. But this is not the only reason to be excited about an osmosis-fuelled future: In August 2025, Japan's first osmosis plant came online, and it is using the highly saline brine left over from a desalination plant – demonstrating how osmosis energy systems might help turning desalination waste into a resource.

Chang Wang, Siyuan Zhou, Xiaojie Shu and Huiling Song. "Deep-sea mining: a potential solution to secure critical energy minerals availability". Nature Partner Journals Ocean Sustainability vol 4, no. 1 (2025).

Note by Maxim Mouret: This brief literature review provides comprehensive insight into the current expansion and commercialisation of deep sea mining (DSM) activities. Acknowledging the recent maturation of long-term exploration contracts and the move towards mine development and commercialisation, this piece succinctly covers the emerging economic potential, geopolitical challenges, and environmental impacts of contemporary DSM. I find this topic both fascinating and critically relevant for a number of reasons. First, deep sea mining addresses one of the key complexities of renewable energy — the need for critical minerals, such as cobalt and nickel, and subsequent reliance on geopolitically-entwined and vulnerable supply chains. Heretofore states have been limited by the critical mineral reserves located within their own borders (along with those acquired through trade), however DSM opens new opportunities for countries with sufficient capacity to expand their operations outside their terrestrial borders and develop a notable advantage in contemporary and future renewable energy markets. On the other hand, the environmental impacts of DSM are significantly under-researched and bound to be dire. This balance between the need for critical minerals and maintaining the health of deep sea and surrounding ecosystems is quickly coming to a head. This article provides sobering evidence that, despite these trade-offs, we are likely to continue pursuing deep sea mining activities and must begin to anticipate its consequences.

Araújo, Kathleen M. "Icelandic Geothermal Energy: Shifting Ground." In *Low Carbon Energy Transitions*, 47–80. Oxford University Press, 2017.

Note by Laila García Ferrer: A trusted and long-standing technology that displays the water-energy nexus at heart is geothermal energy. Thinking about geothermal energy can quickly lead one to Iceland due to its high volcanic activity. Although it is true that two-thirds of Iceland's primary energy comes from geothermal, in her book chapter, Kathleen Araújo shows that the history of geothermal development in Iceland is not a straightforward story of just harnessing technical potential. Rather, it is a multifaceted trajectory shaped by diverse strategies and trade-offs among energy, environmental, and economic objectives to advance this inherently water-harnessing technology. I recommend this chapter to curious readers who wish to immerse themselves in decades of energy policy design and implementation aimed at advancing geothermal across its applications – power, heating, and cooling. As geothermal is receiving growing attention across regions due to recent technological innovations and investments – contributing to risk mitigation and increasing its harnessing potential beyond highly active volcanic zones – we might be seeing more geothermal development in the future. With this in mind, the Icelandic case offers a both sobering and inspiring account of what it takes to scale this low-carbon, versatile technology.

Annotated Bibliography

Matanzima, Joshua, Katharina Schramm, Hannah Uhrmann, et al. "Repurposing mines for renewable energy: Socio-environmental implications for local communities in Australia and Germany." ***Energy Research & Social Science*** **vol. 131, 2026, https://doi.org/10.1016/j.erss.2025.104508.**

Note by Sophie Schut: Having taken a course on critical mining, I have read various case studies on how mining closure is often not accounted for in the lifetime of a mine, which can have huge consequences for people. Hence, I was interested to learn more about the ways in which mining sites can be reused as sites for renewable energy production. Matanzima et al., analyse how water pumping infrastructure has been repurposed for closed-loop pumped hydroelectricity in Australia, by pumping water uphill and releasing it again to produce hydroelectric energy. However, they show how this is not an easy win-win solution, as it requires substantial water, can impact groundwater flows, and lead to aquifer contamination. Their second case study looked at the potential for mine-water geothermal energy in Germany. However, they argue that there is a general distrust, due to historical marginalisation and failed renewable energy projects. Based on these case studies, they recommend more thorough stakeholder consultations prior to the repurposing of mines, to account for non-transferable social licensing to operate. They also recommend more thorough hydrological studies and ensure mining sites are stable, before repurposing.

Below the Surface: Energy & Ecosystems

Stephen C.L., Szostek, C.L., Edwards-Jones, A. et al. "Assessing, monitoring and mitigating the effects of offshore wind farms on biodiversity." Nat. Rev. Biodivers. Vol. 1, (2025): 581–596. https://doi.org/10.1038/s44358-025-00074-5.

Note by Michael Gillesberger: When thinking about the energy-water nexus, one of the first images that comes to my mind is an offshore wind farm - tall circling blades off the coast providing renewable energy we so desperately need. But how does this image change when looking at it from another point of view - not from off the shore but from under the water? It is complex, and fascinating. The authors of this piece review the intricate biodiversity impacts of offshore wind farms across their entire life cycle - a perspective that is often missed in the discourse on offshore wind. On the one hand, turbine structures can support marine biodiversity by acting as artificial reefs, attracting fish, invertebrates and algae - although this effect varies by design and location. Typically, fishing is restricted or prohibited in the areas of installation. On the other hand, noise, particularly from construction, can lead to behavioral disturbances and stress for marine species. However, there are still significant knowledge gaps, especially with regards to the effects of floating wind farms and decommissioning. The article also discusses differing assessment, monitoring and mitigation strategies across projects. Stronger collaboration, shared data and smarter tools - including sensors, modelling and DNA-based monitoring are identified as key enablers to guide nature-positive offshore wind development. Therefore, making sure that offshore wind farms are located in the right places with the right mitigation strategies is key to safeguard biodiversity while accelerating the renewable transition.

Bull, Ann Scarborough, and Milton S. Love. "Worldwide Oil and Gas Platform Decommissioning: A Review of Practices and Reefing Options." ***Ocean & Coastal Management*** **168 (2019): 274–306. https://doi.org/10.1016/j.ocecoaman.2018.10.024**.

Note by Laila García Ferrer: What happens to oil and gas platforms after their productive life ends? Among decommissioning, abandonment and repurposing, converting them to artificial reefs is a possibility that transforms platform jackets into vibrant ecosystems. At the time of the article's publication, California was anticipating the decommission of a number of platforms. Because of state legislation's allowance to consider reefing them, the authors of the paper summarise the history, practices, regulations and science involved in

Rigs-to-Reefs (RtR) conversion programs in hopes of informing the public, policymakers and regulators about the upcoming Californian decisions. Californian or not, the provided review is a great place to understand the variety and challenges of reefing practices. Throughout the overview, I personally enjoyed learning about the reasons that originally inspired reefing conversions in different parts of the world. Perhaps unexpectedly, instead of environmental reasons, the fishing industry has been an important driver of RtR programs, mainly in the Gulf of Mexico, because of the associated replenishment of fish populations. The paper's intricate coverage of, mostly American, yet, also international RtR practices provides a myriad of interesting facts scattered throughout the historical account of their legislative regulation, implementation, and project results. Overall, the piece invites us to think about energy infrastructure's possibilities beyond its original function, in this case, its transition into lively underwater habitats.

Show, Pau Loke. "Global market and economic analysis of microalgae technology: Status and perspectives." ***Bioresource Technology*** **vol. 357, 2022.**

Note by Michael Gillesberger: Microalgae, microscopic marine plants, were among the first living organisms that fostered life on earth and have supplied about half of the atmospheric oxygen. As the demand for clean energy grows and water scarcity intensifies, these tiny 'biofactories' are increasingly seen - including by the WEF and the European Commission - as a scalable solution to address key challenges related to the energy-water nexus. This paper offers a great overview of the future potential and hurdles of cultivating these invisible plants. Microalgae can convert sunlight and carbon dioxide into biomass which can be transformed into biofuels, bioplastics, or protein-rich food. Because they do not require fertile land, they avoid many of the trade-offs associated with conventional bioenergy crops. Moreover, microalgae can grow in saltwater or wastewater, thereby absorbing nitrogen and phosphorus and contributing to water purification while generating biomass. What I particularly like about this article is that it explains the main use cases, and cultivation techniques of microalgae in a very accessible manner - showing the enormous prospects of microalgae biotechnology to contribute to major challenges such as deforestation, water scarcity and malnutrition. The author takes a global perspective and compares the development and approaches of microalgae industries in different world regions. In general, commercialization of microalgae remains challenging due to a lack of economies of scale and research funding. However, microalgae cultivation is a nexus technology that is recognised as one of the most promising components of the blue bioeconomy. These microscopic organisms therefore deserve far greater attention than they currently receive.

PART I

Interviews

Isabel Ruck on Desalination & the Politics of Scarcity in the Middle East

Isabel Ruck, Head of Research | CAREP

Isabel Ruck is a political scientist specialising in the Middle East and international relations. After earning a Master's degree in International Conflict Analysis from the Brussels School of International Studies (University of Kent) in 2010, she pursued doctoral research at Sciences Po Paris (CERI) under the supervision of Professor Bertrand Badie, initially focusing on the role of religion in politics. Currently the Head of Research and Scientific Coordination at CAREP Paris (Arab Center for Research and Political Studies), she oversees major research areas, including political ecology in the Arab world. She has also been a lecturer at Sciences Po Paris since 2012. Her time with the Forccast program of excellence (2018–2019) marked a turning point in her career: through her work on the "mapping of controversies," she developed an expertise in seawater desalination, a subject that remains at the heart of her research interest

In our interview with Isabel Ruck, we delve into the history of desalination, vividly exemplified with historical cases, where oil and water resources have intertwined with state-building. We also discuss how *produced* water is shaping politics around the region and the future for decarbonised desalination in the region.

Sophie: According to the Carboun Institute, the Gulf States are desalinating an annual volume equal to the flow of the Euphrates River, with Saudi Arabia alone accounting for 20% of total desalination globally.[2] Desalination almost seems to become the new normal for water supply within the region. Could you tell us a bit about how we got here?

The story of desalination is intrinsically linked to the socio-political and economic evolution in the region. To set the stage, we'll have to look at the late 19th - beginning of the 20th century, when the first desalination facility was built by the Ottoman authorities in 1907. The construction of this plant is explained both by the fear of a new cholera outbreak (since the region was struck by cholera in 1847-1948) and the history of pilgrimage of the Hajj. The Ottoman authorities considered that the city of Jeddah's water resources could no longer support the growing number of Hajj-pilgrims. They thus decided to invest in a British-built condenser, called *Al-Kindasa*. The condenser was the first water distillation unit in the Kingdom of Saudi Arabia under Ottoman rule. The arrival of colonial forces in the region later pursued this trend.

Modern large-scale seawater desalination in the Gulf dates back to the 1950s and is inextricably linked to the discovery of hydrocarbons. The nascent oil industry required vast quantities of water for drilling operations, while the water-scarce region relied on oil revenues to fund energy-intensive water production. This created a symbiotic, dual-extractive mindset, a defining characteristic of the Gulf's political economy that persists to this day.

A pioneer in the field, Kuwait adopted desalination technology as early as the 1950s and 60s, launching the first modern thermal-powered plant to utilize Multi-Stage Flash (MSF) distillation. This shift was driven by surging water demand from a nascent oil industry and a rapidly expanding migrant workforce. Before the advent of the 'desalination age,' Kuwait relied on traditional dhows, wooden sailing vessels, to transport fresh water from the Shatt al-Arab, hundreds of kilometres to the north. However, because this supply was contingent upon maintaining stable diplomatic relations with Iraq, desalination offered more than just a resource; it provided strategic water independence. This autonomy was essential for Kuwait to scale its oil

[2] Schwartzstein, Peter. "The Perils of 'Ghost Water.'" Carboun Institute, December 1, 2025. https://www.carboun.com/ghost-waters.

economy, which remains heavily dependent on water for drilling and extraction. Kuwait opened its first industrial desalination plant in 1951. The country's first venture into desalination was a small-scale plant at Mina Al Ahmadi, primarily serving the Kuwait Oil Company and its workforce. This was followed in 1953 by the inauguration of the first government-commissioned facility designed to serve the general public. Today, Kuwait operates eight major desalination plants, all strategically located along the coast of the Persian Gulf.

Saudi Arabia possesses an equally storied desalination history. In 1965, the Kingdom established a dedicated department for saltwater desalination within the Ministry of Environment, Water, and Agriculture. Its first large-scale facilities were commissioned in Al Wajh and Duba (1969), followed by Jeddah (1970) and Khobar (1973). As in Kuwait, the 'desalination turn' was inextricably linked to oil production and the broader project of state-building. King Abdulaziz (Ibn Saud) recognized that unifying a nation required the reliable distribution of water across his vast kingdom. To achieve this, he invited American geologists to map the country's subsurface for both water and hydrocarbons. The discovery of oil in Dammam in 1938 - following the 1933 concession - led to the formation of the Arabian American Oil Company (Aramco). While the Kingdom's first large-scale desalination plant was built as early as 1938, it was not until the 1970s, when soaring oil revenues made the energy-intensive process financially viable, that Saudi Arabia turned to mass-scale desalination to meet national demand. The quick urbanization and population growth in the 1970s onward, as well as the water-intensive agricultural policies of the 1960s, also explain the Kingdom's turn to desalination.

Sophie: There is intensive investment into desalination capacity to keep up with an increase in demand. Is desalination needed to meet SDG 6 - of "[ensuring] availability and sustainable management of water and sanitation for all"?

There is currently an intensive, perhaps excessive, investment in desalination capacity, with the market projected to expand at a compound annual growth rate (CAGR) of nearly 9% between 2025 and 2032. Globally, we desalinate the equivalent of 60,000 Olympic swimming pools daily. This massive scale carries significant environmental externalities, most notably brine discharge and high CO2 emissions. While these investments aim to satisfy rising demand, the core of the issue lies in the definition of that demand. In economic terms, 'demand' is a variable that can be managed or curtailed through policy and pricing. This stands in stark contrast to 'need,' which represents a fixed physiological and social requirement for human survival and dignity. Unlike our biological necessity for water, economically driven demand is not immutable; it can, and perhaps should, be scaled down.

"'demand' is a variable that can be managed or curtailed through policy and pricing. This stands in stark contrast to 'need,' which represents a fixed physiological and social requirement for human survival and dignity."

Turning to Sustainable Development Goal 6 (SDG 6): while water availability is framed as a universal mandate, we must critically examine for whom this security is established and at what social or ecological cost. In the Gulf, the vast majority of 'produced water' supports industrial sectors, such as power generation, oil refining, and hydrogen production, all of which are notoriously water-intensive. Domestic use is primarily diverted to flushing, showering, and district cooling; notably, only 2% to 3% is used for direct consumption, as bottled water remains the preferred source.

This raises a vital question: who defines these strategies, and who is marginalized by them? When a river is 'sustainably managed' to protect an industrial zone, it often becomes inaccessible to indigenous communities with ancestral claims. Consequently, 'sustainable management' can function as a narrative to justify dispossessing those labelled as 'inefficient,' reallocating resources toward export-oriented agribusiness under the guise of efficiency. Furthermore, SDG 6 assumes that the state is the primary arbiter of sustainability. This state-centric bias sidelines local actors and favours techno-centric solutions, such as dams and desalination plants, simply because they are more amenable to centralized monitoring and control.

Ultimately, while desalination may fulfil the 'availability' criteria of SDG 6 on paper, its energy-intensive nature and role in industrial prioritization suggest that it often addresses economic growth rather than the fundamental human right to water.

Clara: In the summer of 2025, Israeli and Emirati technology was deployed to drought-suffering Cyprus as a form of soft power. How does desalination and foreign policy intersect in the Middle East?

Desalination and foreign policy are increasingly intertwined in the region, giving rise to a form of ‘techno-diplomacy’: the extension of state interests through technological exports. In this context, technology is inherently politicized, serving as a vehicle for specific forms of power. The UAE’s deployment of 13 mobile desalination units to Cyprus is a quintessential example of this strategy. Similarly, Israel and specifically its national water company, Mekorot, which co-constructed in 2013 the Limassol plant, invest heavily in tech diplomacy to foster strategic interdependence. By positioning itself as a regional hydro-hegemon, Israel utilises water technology as a tool for normalisation, making its presence indispensable to its neighbours and European partners alike. Meanwhile, the UAE’s water diplomacy serves its broader post-oil economic diversification, as the nation seeks to transform itself into a global hub for knowledge-based industries and specialized expertise.

Sophie: Israel has tried to position itself as a key desalination power to stabilise relations in its region. Could you tell us a bit more about that?

Israel’s use of desalination has evolved from a tool for domestic survival into a cornerstone of its regional foreign policy. By effectively decoupling water security from erratic rainfall, Israel has established itself as a hydro-hegemon, leveraging a water surplus to anchor diplomatic agreements and stabilise its borders. This 'tech diplomacy' is most evident in the Abraham Accords, where firms like IDE Technologies and Netafim have entered the Gulf market to facilitate the transfer of technological knowledge, creating a framework of mutual, yet often asymmetric, dependency.

“Israel has established itself as a hydro-hegemon, leveraging a water surplus to anchor diplomatic agreements and stabilise its borders.”

However, this diplomacy is essentially an extension of Israel's long-standing hydro-hegemonic strategy. Desalination has granted Israel unprecedented autonomy from natural cycles; notably, the technological inversion of flows has allowed Israel to repurpose the Sea of Galilee into a strategic regional reservoir under its exclusive control. This consolidation of power has significant implications for downstream riparian actors like Jordan and the West Bank. Despite the 1994 Peace Treaty’s mandate for Israel to provide 50 million cubic meters (mcm) of water annually, Jordan remains precariously dependent on Israeli goodwill.

While Israel possesses a water surplus, it faces an increasing deficit in renewable energy to power its production. This vulnerability gave rise to 'Project Prosperity,' a UAE-brokered deal where a 600 MW solar plant in Jordan would supply Israel with green energy in exchange for up to 200 mcm of desalinated water. However, the project, which would have locked Jordan into a deep dependency on both Israel and the UAE, was rejected by Amman in 2023 following a heated public outcry. In a move to reclaim its sovereign water security, Jordan has since opted for a $5 billion Red Sea desalination project led by the French-led Meridiam consortium.

Clara: Desalination and fossil fuel have been intimately connected - often managed in the same government departments, potentially making them tricky to decouple. What is the outlook for clean desalination in ME?

While most Gulf countries historically relied on thermal desalination, there is a burgeoning effort to integrate renewable energy into production. This shift is driven by some of the world's highest solar irradiance levels, which have reduced solar power costs to a remarkable $0.02 per kWh. Currently, renewable energy accounts for 3–5% of the GCC's desalination capacity, with regional 'Vision' plans targeting 20–30% by 2030. Achieving this scale will require massive capital investment. A significant milestone in this transition is Saudi Arabia's Al-Khafji plant; commissioned in 2018, it remains the world's largest solar-powered Reverse Osmosis (RO) facility, producing 90,000 cubic meters of water daily, enough to support 450,000 people at a standard consumption rate of 200 liters per capita.

Beyond solar, geothermal energy is emerging as a 'new frontier' for desalination, valued for its ability to provide consistent, 24/7 baseload power. In Saudi Arabia, the King Abdullah University of Science and Technology has launched an experimental exploration project (K-GEP) in 2024 to tap into the high-heat 'hot spots' along the Red Sea coast. This research explores 'cascaded' energy use, where high-temperature steam generates electricity while residual heat is diverted directly into thermal desalination units. Similarly, in the UAE, the Masdar Institute has pioneered pilot studies on 'low-enthalpy' geothermal resources. Unlike the high-heat volcanic regions, these projects utilize lower-temperature underground heat, which is ideal for running Multiple Effect Distillation (MED) units more efficiently than traditional fossil-fuel-powered thermal plants. These experiments represent a strategic attempt to diversify the renewable mix and reduce the intermittency issues associated with solar power.

"It is a profound paradox that the world's most water-scarce region maintains the highest global consumption rates"

Finally, nuclear energy has also re-entered the debate as a potential path toward decarbonizing water production. While the UAE currently operates the region's only active nuclear facility (Barakah), Saudi Arabia is in advanced negotiations with the United States to establish a large-scale plant at Khor Duweihin. Meanwhile, on the opposite shore of the Arabian Gulf, Iran is working to couple its Bushehr nuclear power plant with a desalination unit, expected to go online in March 2026 with a capacity of 70,000 cubic meters per day. However, nuclear energy remains a contested solution due to its own environmental trade-offs, including high water intensity for cooling and the long-term challenges of nuclear waste storage.

Sophie: Are there alternative technologies and strategies that we are missing that could aid with the water shortage?

While technical alternatives exist, the fundamental question is whether we require more engineering fixes or a total reimagining of our relationship with water. It is a profound paradox that the world's most water-scarce region maintains the highest global consumption rates, averaging 450–500 litres per capita daily. In contrast, European consumption hovers around 200 litres, while the WHO defines the threshold for hygiene and dignity at just 50 litres. This discrepancy is fuelled by the 'mirage' of desalination, which has framed water as an infinite resource. Consequently, scarcity is largely absent from the environmental imaginary of many Gulf residents, replaced by a sense of manufactured abundance.

Addressing this requires more than just infrastructure; it demands demand-side management. Beyond curbing luxury uses like golf courses and swimming pools, addressing non-revenue water (NRW) and implementing tariff reforms are critical levers to provide a price signal for conservation. Furthermore, wastewater recycling, significantly less energy-intensive than desalination, emerges as an alternative. But we must acknowledge the externalities of reuse: producing water twice and diverting it from natural ecosystems risk further decoupling the human water cycle from its ecological origins.

Ultimately, it is a significant irony that the transition away from a hydrocarbon-based economy is likely to be even more water-intensive. Beyond the production of green hydrogen and mineral mining, the UAE's push to become a global AI powerhouse introduces a staggering new demand: hyperscale data centers. These facilities are water guzzlers by design; a single 100MW data center can consume up to 2.5 billion liters of water annually for cooling roughly the equivalent of the daily water needs of 80,000 people. As the UAE scales its digital infrastructure to serve as a regional 'brain', it is effectively trading its oil-dependency for a digital-water dependency, potentially deepening the region's reliance on energy-intensive desalination to keep its servers from overheating. ■

Giacomo Parrinello on the Water Crisis, Rivers Complexity and Dams' Ripple Effects Beyond Energy

Giacomo Parrinello, Associate Professor | Sciences Po Center for History

©Anne-Marie Filaire.

Giacomo Parrinello (Ph.D.) is an environmental historian and associate professor at the Sciences Po Centre for History. Specialising primarily in the interactions among rivers, state policy, and economic growth, Giacomo's research asks how modern societies have shaped and been shaped by natural systems and processes. His cross-cutting work bridges history with insights from various disciplines, including environmental science and geology, to better understand the past and present of rivers and society. He is the author of *The Work of Rivers*, a forthcoming book with Cambridge University Press on the history of river use and control in the Po Valley, Italy, from the late eighteenth to the early twenty-first century, and the editor of *Rivers on the Move*, an interdisciplinary collection of essays on rivers and society forthcoming with Duke University Press.

In our interview with Giacomo Parrinello, we discuss the pillars of the water crisis, with a particular focus on rivers as complex multifaceted systems. We also delve into hydro energy, its trade-offs and often unexpected or overlooked effects beyond power generation.

Laila: As an expert, what do you think are the most pressing elements of the water crisis?

First, let's try and get a sense of what we mean when we talk about the water crisis. The Global Commission on Water and Economics, for example, identifies three main elements: water scarcity (both global and local), water excess (flooding), and water pollution. Each of these are big problems themselves, so it's helpful to think of each element as part of the water crisis, but also as a problem in itself.

Water scarcity on a global scale is probably the most concerning. There is variation and fluctuation in the planetary hydrological cycle, and that means more floods. We've seen a lot of that in the news recently, not only in France but in the Mediterranean. Precipitation tends to be more concentrated, and it's harder for rivers not to flood under these hydrological conditions. This is certainly part of climate change, but in the long term these intense fluctuations lead to a baseline *decline* in water availability – especially freshwater availability.

We have higher temperatures on average, which means that in the places where snow accumulates, there is less and less of it because it falls as rain and no longer as snow. The other big subject is, of course, glaciers. [For example] in the Pyrenees, there are basically no longer glaciers. That means that there is less water available, and this has repercussions on all sorts of levels. It impacts the amount of water in mountain rivers, which has repercussions downstream and in aquifers. It's a wicked problem: on the one side, you have water scarcity, and then on the other hand you have massive episodes of flooding that can be so intense that our infrastructure is no longer capable of handling them.

And remember, there were three legs to this crisis. The third one is pollution. The pollution story is part of what makes water a problem for our society, because we need not just water, but clean water, and we are facing a very dire situation in terms of the amount and quality of pollutants present on land and thus in water. Some of these pollutants were not even on the radar twenty years ago, which makes things even more complicated. There was a huge amount of legislation in western countries in the 60s, 70s, and 80s, to reduce the amount of certain pollutants, yet all these legislations didn't include things like the so-called forever chemicals, or microplastics. And this stuff we don't even know how to eliminate from water.

They are called forever chemicals because they do not decompose. It seems that there might be some microorganisms capable of breaking them down but research is still ongoing. As far as we know, it's impossible to decompose them on a human time scale. They accumulate and they don't break down. There was a survey on the amount of PFAS [Per- and Polyfluoroalkyl] in drinking water supply in France, and it's crazy – alarmingly high, almost everywhere in the country, and it's likely the same across Europe.

If you think of the amount of money that needs to be spent to make sure that the drinking water supply is free from PFAS in French cities or European cities, it is just mind-blowing.

So, pollution is the third leg of the problem. Climate change, flooding, and water pollution overlap in many ways. When a river floods, it can move sediment that is deep in the riverbed and has accumulated pollution, sometimes from industrial activities that no longer exist. Some problems of river restoration, which often includes giving rivers room to expand (a solution for floods), face opposition from farmers as they do not want their fields to be contaminated with all the pollution that is present in sediment.

Maxim: Going back to the water crisis as a balance between water scarcity and surplus, to what extent can dams and hydropower be seen as a way to open more opportunities for water management in times of crisis?

Well, that's historically the solution that has been adopted in many rivers. I'll take an example very close to us: the Seine River Basin. The Seine River Basin is now almost entirely controlled by reservoirs. There are four big reservoirs built upstream in the tributaries which were conceived to do precisely that: store excess water to prevent flooding downstream and release water when there was not enough. The main purpose was to regulate the level of the river for navigation, because the Seine suffered historically from droughts.

Now, the problem with that is that the infrastructure – the size of the reservoirs, the operation of the system – was designed on a certain set of assumptions on how the river would work in the future. The assumptions are based on historical observation, typically recording water gauges, discharge, flow, precipitation, these kinds of things. Except that, if you talk to geologists, they'll tell you that, due to high CO2 emissions we might soon be entering a hydrological and climatic regime which is not analogous to the one of the Holocene, so all these assumptions no longer hold. [Geologists] say we should look at precedents or analogs in the Miocene, and a river of the Miocene is really a very different kind of beast. This means that we could face a situation in which the dams are completely overwhelmed.

Now, I'm not saying that we should remove dams and let the rivers flow freely, but even if we take the situation from a purely hydrological perspective – eliminating completely the ecological and environmental problems –, it's a very dangerous bet to make. It might not work in terms of defence from flooding, because it could be overwhelmed, and then water scarcity means that no matter how many dams you build, these dams will be empty. I think that's a serious constraint to hydro as a model for the energy transition.

Maxim: All hydro dams are inherently complex endeavours. What factors truly determine whether a hydro dam can be considered successful?

Laila: And what are the biggest drawbacks from having a dam?

Well, the two questions are entangled. I think it's very much context dependent, and there is not one answer. This context dependency has multiple facets. One is the social facet, which means the costs and the benefits of a specific project. Not in the absolute, not in the abstract, but what is that specific project going to cost in terms of life, livelihoods, and consequences on other water usage. Here I'm really remaining on the purely anthropocentric side of the problem. If you look at the history of hydro this kind of cost-benefit analysis was not always well thought through. We have examples of all sorts of projects that created a lot of damage for very little results, and we also have projects with little damage and higher benefits.

It's more of an empirical question which really depends on the cost benefit in terms of who loses (because there are always losers) and who gains. What's interesting is that in the history of hydro, especially in authoritarian regimes, dams have been constructed because high level decision makers decided that hydro had to happen. They wanted hydro and they wanted the dam – all the assessment of cost benefits was almost a *pro forma* and was not taken seriously.

In many cases they ended up with projects that failed spectacularly. That's the case of the first big dam on the Yellow River. They had to redesign it entirely because they completely disregarded the problem of sedimentation of the dam, and the dam filled with sediment in three years. Or, you have the cases of big dams in Brazil that put underwater large swathes of the Amazonian forest close to Manaus and didn't manage to supply more than a very tiny part of the energy growth that was necessary in that region.

"It's very important to understand that water does not exist in isolation. It's part of ecosystems, it's part of livelihood, and whenever you're talking about water, you're also talking about ecologies."

So that's the kind of problem when you start from the assumption that you need the hydro and you don't take the cost-benefit analysis seriously. I'm not saying that it has to be only a local inquiry and no one else has a say – you could also of course take into account those who benefit from the dam –, but sometimes the energy demand that justified the project was not there.

On the ecological side, you could have all sorts of negative feedback from dam construction. Many scholars are now focused on the Mekong River, which flows down the Himalayan plateau through Southeast Asia. The upper part of the Mekong is in China and there's a lot of hydro development there, and now also in the downstream countries. The problem is that these dams might be good in terms of energy production, but they are destroying Cambodia's largest inland fishery – the Tonlé Sap Lake – which depends on the flood of the Mekong. The dams are trapping sediment, and in consequence the river downstream digs the bed because it has a lot of energy that it no longer uses to push the sediment downstream. It erodes its bed, which becomes so low that it no longer floods the lake. This can lead to the complete disappearance of the ecology of the Tonlé Sap, which is also an economic and livelihood question. But trapping sediment might also lead to the complete submersion of the delta of the Mekong, which hosts Ho Chi Minh City, a metropolis of millions, because the sediment of the Mekong is what keeps the delta afloat. Deltas, basically, are created by the river. It is the sediment of the river that, year after year, deposits in the delta, and keeps the delta growing. If all the sediment is trapped behind the dam, there's no sediment to nourish the delta. Combined with sea level rise, this may mean the disappearance of the Mekong Delta, and that's a serious problem. It's very important to understand that water does not exist in isolation. It's part of ecosystems, it's part of livelihood, and whenever you're talking about water, you're also talking about ecologies. If you're talking about ecologies, you're also talking about the people's lives. Inhabitants of Ho Chi Minh City might not think that they are connected to the geomorphology of the Mekong River, but they are.

Laila: Have you encountered any historical examples which epitomize 'best practices' for energy planning with sustainable river or water stewardship?

That's a very good question, but it's also a very hard one. There are so many bad cases – maybe because the bad cases tend to get more attention. Scholars tend to focus on what didn't work because it creates more attention and historically it creates more archives, there might be a bias there.

Perhaps the question could be: is it possible to have something that works? In that sense it depends on what you consider as good or working. From my own understanding of water systems and rivers, they are ecological systems, but they are also systems that inherently create community. The history of river use is so layered, that when modern energy arrives there's so much already in rivers that it inherently creates losers. It's just impossible to intervene in a river where there are other forms of uses without infringing on at least some river uses.

Even in the Arctic there is a lot that happens around rivers. The Yukon River has been very important for indigenous livelihoods, through salmon runs. Building a dam there, in what looks like a very isolated and "undeveloped" river would still create losers. And there've been projects of dams on the Yukon River that have been stopped by thinking of the question of indigenous livelihood. You always have losers, and if you think of a good project or a good practice as something that does not create losers, I think that's just inherently impossible.

Then the matter would be – if I could reframe the question – what is an acceptable loss? What are we willing to sacrifice in terms of water use, in terms of ecologies, because any way you're sacrificing something. That is a political question – I don't think there is a technical question to that answer. It's as a society that we decide what we value. What are we willing to sacrifice?

Laila: Wouldn't inaction – i.e., maintaining the status quo – be implicitly sacrificing good quality water and water access?

Absolutely. This is why I don't think there is an easy answer. My answer is not to say we shouldn't do anything. There's always a sacrifice to be made on one side or the other. It's a political question and you're right in pointing that out.

But perhaps in terms of river use more generally it's even harder than just the energy calculation behind any given dam, because you have so many more parameters that you have to consider. Are fish important? If you build a dam, you can create staircases or fish passages, but we know after 150 years of having fish passages that there's certain species that can use it and others that just disappear. There was salmon in the Seine, until the beginning of the 20th century. There was sturgeon in the Po River, and there was salmon in the Rhine. Now, a lot of good things have come out of developing these rivers. It's hardly just a story of destruction and loss – it's also a story of gain. I think that's the tragedy of the modern period. We are in this situation, with species wiped out, ecosystems impoverished, and a climate crisis because of a lot of good things that have happened to us. Human life on this planet on average is much better than it used to be two hundred years ago.

Coming back to rivers, I don't want to give the impression that the problem is just fish, because the problem could also be irrigation or agriculture. A kind of trade-off you might have to consider is: do you keep water behind the dam to produce hydro, or do you release water to irrigate the fields? This is not theoretical. In the last 20 years, during droughts in places like the Po Valley, it's been a very specific question that people had to answer, because there was just not enough water for all. So, what do you do with that water? If you keep it in the dam so that you can ensure that there is enough energy to sustain air conditioning, for instance (because droughts typically tend to occur along with heat waves), you condemn agriculture to losing the harvest of the year. And vice versa.

> ***"A kind of trade-off you might have to consider is: do you keep water behind the dam to produce hydro, or do you release water to irrigate the fields? This is not theoretical."***

Of course, there are regulations which try to set up the good practices that you're asking about. For instance, if you're running a thermoelectric or nuclear power plant along the river in a country like France, you must make sure that the temperature of the water you release does not exceed a threshold –

and that threshold is the outcome of a negotiation. It's a very long answer to say that it's not an easy answer.

Maxim: What should policy makers consider when weighing or trying to quantify the ecosystem services provided by free-flowing rivers against the energy benefits of new hydropower plants?

I don't think it's really possible to quantify these kinds of services, although there are people who are trying. Stanford was running this natural capital project for several years, attempting to find metrics for ecosystem services that would allow us to do a kind of quantitative cost-benefit analysis. I think the problem is that we don't know enough about the chain of links that exist between beings to really be able to quantify the consequences.

The same might be said for biodiversity. When you build a dam, you reduce the amount of water that ends up in the river, and by doing so you're also shrinking the amount of wet area. This wet area provides functions that have economic benefits. It hosts what we call microbial communities, which process nitrogen and phosphorus that ends up in rivers due to fertilizers. From rivers, it then ends up along the coast and generates what are called dead zones, which can create major economic damages through dead fish. How do you price that? How do you price the disappearance of microbial communities from the flood plains?

Insurance companies are trying to price things like flood risk, and they're trying to come up with ways in which you could quantify ecosystem services on this side. But they might not take into account things like microbial communities. Then there's the problem of money of course, because it's super expensive to build infrastructure for adaptation, including ecosystem restoration. Public money is hard to find these days, after 40-50 years of cutting taxes and shrinking state budgets, so states are trying to come up with ways in which you could get investors to invest – but what is the return on this kind of investment?

All of this is to say that I think it's very hard, and even when it's done it's very limited. I don't know of anyone who has priced microbial communities. I know of insurance companies that tried to price the flood risk reduction function of flood plains, but not the nitrogen reduction function of flood plains.

And yet, you do have some very important economic benefits from microbial communities on flood plains because it's good not to have eutrophication. It's good for all sorts of industries. It's good for the fishing industry, it's good for the tourism industry – especially if you operate at a seaside destination affected by eutrophication phenomena.

My impression is also that the pricing of ecosystem services is a tool that diverts attention from what should be a political conversation on the costs and benefits, on what we are willing to sacrifice and to which ends. We should find ways, and maybe institutions, to reach agreements, rather than relying solely on market mechanisms.

What is the right geographical scale for having this kind of conversation? Perhaps there isn't just one single good scale, but the watershed, the river basin, is certainly a good scale. Not the best one necessarily, and not the only one for sure, but it's a good one because it allows you to take into account many variables. It even includes the soil that, in the end, affects the river. Think of the pollutants, for instance, that eventually end up in the river. It's often a soil use problem that ends up being a river problem.

We do have institutions for watershed-scale decision making, but these institutions haven't been designed democratically. They've been designed as technocratic institutions, where experts convene with stakeholders, and often only economic stakeholders. If you take a more expansive view of what a river is and how it functions, perhaps these institutions could be reformed as a forum for truly democratic debate.

There are tensions within watershed institutions about precisely these kinds of things. These institutions operate in increasingly complex situations due to things like droughts and floods, and there's a lot of tension around the fact that there's not enough water, and when there is water, it might be polluted. Whatever decisions you're making, there are a lot of trade-offs and increasing public attention around decisions that used to be taken on a purely technocratic base. It's possible that this is one of the directions in which things might evolve. It's certainly something that I think would be beneficial, probably more than a kind of market-price quantification of ecosystem services.

Maxim: Is the changing nature of river pollution (i.e. 'forever chemicals' and new pollutants) an area of focus for academics and experts?

Every ore has its own features, and they all tend to be very dirty. But in terms of the history of mining and rivers there are very bad consequences, and it goes back a long time. One example you may have heard is hydraulic mining.

There is a wonderful book, an old book from the 50s, called *Gold Versus Grain*, which looks at the Sacramento River. The gold is the gold mining in California, and the grain is the grain that was cultivated downstream in the valley. In the no-regulation, free-for-all approach to mining in the late 19th century, mining companies were just blasting the mountains and all this waste ended up in the river. So large was the amount of sediment ending in the river that the bed of the river raised to the point that the river could no longer stay within its bed and kept flooding and flooding. So all the farmers got angrier and angrier, and it eventually led to a major lawsuit against the gold industry, which ended up in a loss for the industry and the imposition of more regulation for hydraulic mining.

You then also have stories in which the problem is the toxicity. There's this classic story of the Ashio mines in Japan, which is a major pollution example from 19th century mining. They were mining copper, and it was very dirty and very toxic. The byproducts ended up in the river, and when the river flooded it spread all these toxic byproducts across the fields; with major ecological and health consequences. People were not happy about it, but the response was not to clean up the river, or to prevent the mind from dumping toxic byproducts into the river, but instead to prevent the river from flooding.

If you look at the more recent period, you have oil refineries along rivers and that's a 20th century story. You've probably heard of Cancer Alley in Louisiana along the Mississippi River. A similar very dirty story of chemicals, partly petrochemicals, is also the Rhône River here in France. There is a very long history of pollution of the river and the delta with the concentration of oil refineries in the Etang de Berre (west of Marseille). There too, there were fisheries and people living there who suffered greatly from pollution.

Yet as a society, we haven't agreed that this is a problem, at least not always. This goes back to the political questions that we were discussing before: what made all this pollution possible in most cases was the fact that, in the end, at least part of society thought that it was a price worth paying. This is what they were ready to sacrifice, and I think we should take that seriously. It's easy from our perspective to scold the people of the past for not seeing that they were sacrificing something that we value and consider so important. Yet we also need to recognize that they had very good reasons for doing so. The world that pollution was ushering in had so many benefits compared to what they were sacrificing that, for many of them, it was a no-brainer. What we gained was material wellbeing and better conditions of life – progress, and abundance. So it's really a matter of disagreement on what to value more and what could be sacrificed. The fact that there were consequences was clear to everybody from the start. If there is one lesson of environmental history, it is that we have always been aware of what we're doing to the environment. It's just that there were people who thought that it was a price worth paying, and there were people who didn't agree with that. In the end, modern societies have tended to privilege the sacrifice side of the disagreement.

Now, of course, you can tell the story in a much more nuanced way because it also depends on whether this choice was made by democratic societies, and who had a voice in making those choices. Was it really a matter of the majority being convinced, or was it a matter of specific interests being more powerful? That's another question.

Laila: Looking into the future. Will regions experiencing rapid electrification face challenges regarding water-energy trade-offs? If so, of what nature?

Difficult question to ask a historian! As historians we tend to be wary of making predictions. So here I guess I'll stop being a historian, and I'll be more of an informed citizen.

Well, it's hard to imagine a country where there will not be trade-offs. The fact that the hydrological cycle worldwide is changing so much, and from what we know of how the climate works, even if we stop CO_2

"Should they privilege the production of energy in the form of electricity or in the form of food? It would be surprising if this kind of trade-off would not emerge."

emissions today there's so much already in the atmosphere that a lot of changes are locked-in and not just the ones that we're experiencing today. The matter is not whether it changes, but how much it is going to change. The problem of water and rivers being a problem of multi-usages by nature, water-scarce regions will face decisions like the ones we've discussed. Should they privilege the production of energy in the form of electricity or in the form of food? It would be surprising if this kind of trade-off would not emerge.

What makes me hopeful is really the potential of renewables like solar and wind. There are some serious trade-offs to producing solar panels, but I think in a situation in which water is going to be scarce that's one of the things that makes me hopeful. Maybe we could find solutions by producing electricity with other means than hydropower dams, and we could use the rivers to feed cities and keep growing crops – perhaps even desalinate water from the ocean, which is very expensive right now in terms of costs but perhaps with very cheap solar energy it might become more feasible.

Maxim: I think that's a lovely optimistic point to end on! Thank you once again for having spoken to us, this has been an incredible conversation, and we've learnt a lot. ■

PART II

Case Studies

Brownfield Blues, Water Legacies and the Touro Mine: Local Frictions in Europe's Push for Energy Independence

Clotilde Cerdán

Clotilde Cerdán works as a strategy consultant focusing on environmental projects in the extractive industries. With experience advising both public and private sector clients, she designs actionable strategies at the intersection of energy transition and environmental policy. She holds a Master's degree in Environmental Science from the University of Sydney, where she completed her thesis on critical mineral mining policy, and a Bachelor's in Geography from McGill University.

The European Union's Critical Raw Materials Act (CRMA), developed as part of the EU Green Deal Industrial Plan, defines a set of policies aiming to strengthen the EU's supply chain resilience in key industries such as clean energy, tech and defense. These measures, which include targets such as extracting at least 10% of the EU's annual strategic raw material consumption domestically by 2030, are indicative of a broader global resurgence in industrial policy and mining activity. Copper is one of the minerals designated as a strategic raw material under the EU's CRMA in 2024.[3] Its electrical and electronic conductivity make it a foundational input in components essential to renewable energy systems, power grids, electric vehicles, electronic devices, aircrafts and defense technologies.

Within the context of increased geopolitical competition over energy security, this case study examines the Touro project, a copper mining development in Galicia, northwest Spain, to consider how energy-driven efforts to expand domestic extraction can generate water-related conflicts. It explores how the water-energy nexus manifests at local scales, focusing on the distinct dynamics of brownfield developments within this novel landscape, showing that even where extraction is pursued through "lower-impact" pathways, accelerated domestic mining does not automatically translate into public acceptance, particularly when communities anticipate persisting impacts on water resources.

Brownfields: low risk, high reward?

The Touro project is a brownfield development, meaning that it is being built on land that was previously exploited. Copper mining began at the site under Atlantic Copper's management during the 1970s and lasted until the late 1980s, when mining activities were stopped as a result of both low copper prices and declining ore quality.

Brownfield projects are often seen as a way to mitigate the negative impacts of mining, causing less additional disruption to the local environment. They also benefit from existing support infrastructure, such as access roads, reducing new development as well as capital costs. Consequently, brownfield developments are generally considered preferable, all things equal, to greenfield developments. Mining companies may infer that brownfield developments may ease the process of securing their Social License to Operate (SLO), a community's ongoing acceptance of operations, inherently tied to local context, sustainability, and the provision of benefits at the local level.[4,5] However, evidence from the Touro project challenges this view. Despite the theoretical potential for easier social acceptance, it has been met

[3] European Parliament and Council, *Regulation (EU) 2024/1252 of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020*, Official Journal of the European Union L, 2024/1252 (3 May 2024), http://data.europa.eu/eli/reg/2024/1252/oj.

[4] Jason Prno, "An Analysis of Factors Leading to the Establishment of a Social License to Operate in the Mining Industry," *Resources Policy* 38, no. 4 (2013): 577–590.

[5] Hugh Breakey, Graham Wood, and Charles Sampford, "Understanding and Defining the Social License to Operate: Social Acceptance, Local Values, Overall Moral Legitimacy, and 'Moral Authority,'" *Resources Policy* 102 (2025): 105488.

with strong local opposition, focused on its perceived failure to adequately address ongoing impacts on local water resources.

Water, mining legacies and social acceptance

The negative impacts of mining on local environments and communities, inherent to extractive processes, have long been documented. Not least among these is mining's impact on water resources. While mining currently accounts for less than 1% of total water abstraction in the EU,[6] the sector is highly water-intensive on a per-unit-of-output basis, requiring a continuous and substantial supply of water to process ore and manage tailings. Mining can affect water resources through direct water consumption, groundwater extraction, chemical contamination, acid mine drainage, tailings dam failures as well as sedimentation and thermal discharge. All of which negatively impact local ecosystems and populations.

Atalaya Mining, the current operator of the Touro project, which is looking to renew copper extraction, has inherited the site's past contamination. Since operations ceased in the 1980s, significant acid mine drainage from the open-pit mine has been documented, leading to the concentration of heavy metals in tributaries of the Ulla river. The company has sought to distance itself from this past, stating: "Atalaya is now operating a new water treatment plant at Touro, which is addressing the legacy issues associated with acid water runoff from the historical mine".[7] Cobre San Rafael S.L., the company formed through the association of the Galician firm Explotaciones Gallegas S.L. and Atalaya Mining to develop the project, asserts: "We are in a region with a long mining tradition and legacy. The historic Touro mine ceased operations in 1986, when environmental requirements like those in place today did not exist".[8] Furthermore, Atalaya Mining has developed a water-recirculation plan in alignment with the growing global trend in industrial water management aimed at reducing dependence on both water abstraction and discharge, opting instead for in-situ water treatment practices.

Despite these assurances, local communities and environmental groups argue that mitigation efforts have remained insufficient, citing repeated pollutant discharges, elevated levels of toxic metals in local streams and persistent impacts on aquatic ecosystems.[9] They maintain that the mine's legacy and proposed expansion continue to pose a risk to the Ulla basin and surrounding environment. Public opposition is exacerbated by the proposed nearby development of a large-scale cellulose plant. Organizations like the Platform in Defense of the Arousa Estuary argue that the impact of these two developments would jeopardize both the environment and the maritime economy.[10] The projects have become focal points for broad regional mobilizations, with thousands of protestors arguing they threaten water quality, the ecological integrity of rivers as well as local livelihoods in sectors including agriculture, fishing, and tourism.[11]

While brownfield sites may, in theory, facilitate SLO acquisition, this hinges on communities having perceived benefits from mining and/or having established a local mining identity. In cases like the Touro project, where negative impacts are pervasive,

[6] European Environment Agency, "Water Abstraction by Source and Economic Sector in Europe," November 28, 2025, https://www.eea.europa.eu/en/analysis/indicators/water-abstraction-by-source-and.

[7] Atalaya Mining Copper, "Proyecto Touro," *Atalaya Mining*, n.d., accessed January 16, 2026, https://atalayamining.com/operations/proyecto-touro/

[8] Cobre San Rafael, "Compromiso Sostenible," *Cobre San Rafael*, n.d., accessed January 15, 2026, https://cobresanrafael.gal/plan-de-recuperacion-integral-de-aguas/

[9] Iberian Mining Observatory, "Mina de Touro, A Coruña, Spain," last modified June 30, 2024, https://www.minob.org/english/mina-de-touro.html.

[10] Brión Insua, Rodrigo. "Buses desde cada rincón de Galicia acudirán a la manifestación del domingo contra Altri y la mina de Touro." *Galicia Press*, December 12, 2025. https://www.galiciapress.es/articulo/movimientos/2025-12-12/5701218-buses-desde-cada-riincon-galicia-acudir-manifestacion-domingo-contra-altri-mina-touro

[11] El Mundo, "Miles de personas protestan en la ría de Arousa contra la macrocelulosa de Altri y la reapertura de la mina de Touro," *El Mundo*, March 22, 2025, https://www.elmundo.es/espana/galicia/2025/03/22/67ded056fc6c8331788b4573.html.

these advantages fail to materialize. Such that, even while the project is backed by political support, public pressure poses a persistent barrier in the form of legal challenges, sustained mobilization and heightened scrutiny.[12]

Facing the tide: an evolving landscape constrains local resistance

Spain hosts 7 of the 47 Strategic Projects identified under the CRMA, granting them priority treatment and faster, more coordinated approvals.[13] This designation underscores broader policy efforts to streamline permitting processes,[14] reflecting the current sense of urgency surrounding critical mineral mining.[15] As a result of these accelerated procedures, public resistance may have less opportunity to adequately scrutinize projects or meaningfully reshape them through the permitting process. This wider policy direction is echoed in investor sentiment. The latest Fraser Institute's Annual Survey of Mining Companies, indicates that investors in Spain show decreasing concern for issues like protected areas (-29 points from 2023 levels) and disputed land claims (-19 points) while concern over the interpretation and enforcement of existing regulations has nominally grown (+13 points) (Figure 1).[16]

This streamlining agenda extends beyond individual project designations. The European Commission's proposal to review the Water Framework Directive, specifically aiming to simplify processes and reduce bottlenecks to promote critical raw material mining, epitomizes the broader push to lower regulatory friction as the EU re-shores its supply chains.[17]

The Touro project highlights this pattern: in 2024 it was designated a "strategic industrial project" by the Xunta de Galicia (the regional government authority), a decision subsequently challenged by environmental groups.[19] This status classifies Touro as a project of public interest, giving it legal priority

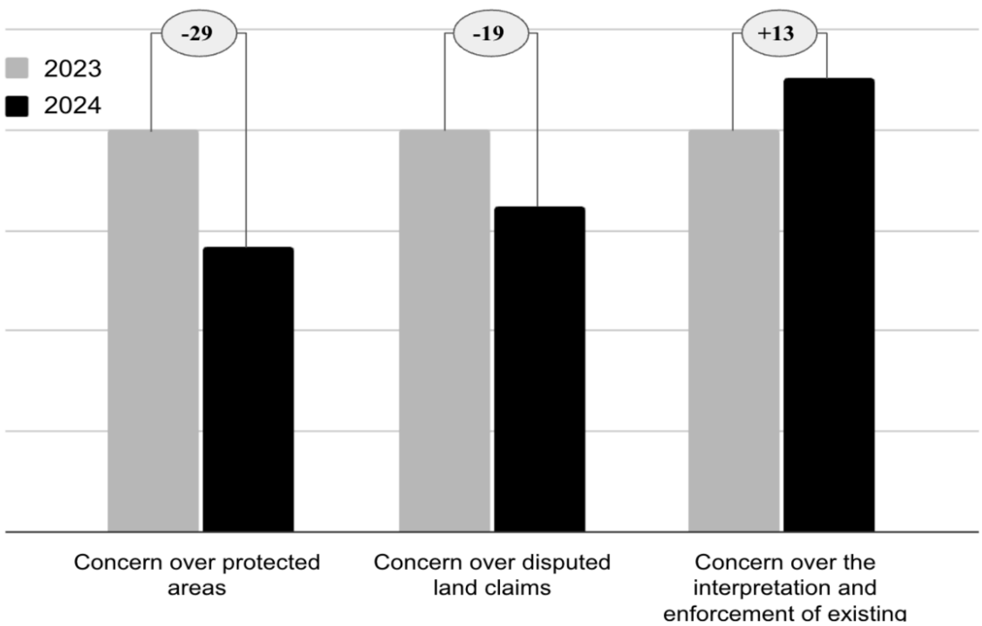


Figure 1: Change in investor concern in Spain (adapted from the Fraser Institute), indexed to 2023 = 100.

[12] Ecologistas en Acción, "Presentan un contencioso contra a Xunta de Galicia por declarar a reapertura da mina de Touro como Proxecto Industrial Estratéxico só para sortear o rexeitamento ambiental," *Ecologistas en Acción*, March 3, 2025, https://www.ecologistasenaccion.org/332316/el-informe-del-hidrologo-steven-emerman-senala-graves-deficiencias-de-seguridad-en-el-proyecto-de-reapertura-de-la-mina-de-touro

[13] European Commission, "Commission Selects 47 Strategic Projects to Secure and Diversify Access to Raw Materials in the EU," Press Release (IP 25 864), March 25, 2025, *European Commission*, https://ec.europa.eu/commission/presscorner/detail/en/ip_25_864

[14] John R. Owen, Deanna Kemp, Jill Harris, Alex M. Lechner, and Éléonore Lèbre, "Fast Track to Failure? Energy Transition Minerals and the Future of Consultation and Consent," *Energy Research & Social Science* 89 (2022): 102665.

[15] Amelia Hine, Chris Gibson, and Robyn Mayes, "Critical Minerals: Rethinking Extractivism?" *Australian Geographer* 54, no. 3 (2023): 233–250.

[16] Julio Mejía and Elmira Aliakbari, *Fraser Institute Annual Survey of Mining Companies, 2024* (Vancouver, BC: Fraser Institute, July 2025), https://www.fraserinstitute.org/sites/default/files/2025-07/annual-survey-of-mining-companies-2024_0.pdf

[17] European Commission, *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: RESourceEU Action Plan. Accelerating Our Critical Raw Materials Strategy to Adapt to a New Reality*, COM(2025) 945 final, Brussels, December 3, 2025, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52025DC0945

[18] *Ibid*

[19] Ecologistas en Acción, "Presentan un contencioso contra a Xunta de Galicia."

over other land uses alongside streamlined administrative procedures and shorter permitting timelines.

The Touro case illustrates a profound challenge at the heart of the water-energy nexus within Europe's pursuit of energy independence. While the CRMA aims to secure vital resources for the energy transition, the case demonstrates that brownfield re-development offers no automatic guarantee of social license, particularly when communities perceive unmitigated impacts on water resources. This underscores a critical need for policies that not only foster strategic resilience but also reconcile the demands of the energy transition with the protection of indispensable water resources and the concerns of local populations. ■

A Shared Path to Green Hydrogen? Water, Infrastructure, and Policy Lessons from France and Namibia

Julia Brahy

Julia Brahy is a French-American dual citizen and a recent graduate of the University of Toronto Munk School of Global Affairs & Public Policy, where she completed a Master of Global Affairs. She specialised in Environmental Studies at the University of Toronto School of the Environment, with a focus on international climate policy and sustainable development. Her work explores the intersection of energy transitions, climate adaptation, and international development. Julia was the inaugural University of Toronto Climate Adaptation, Resilience, and Empowerment (CARE) Sciences Po Scholar and has professional experience at the World Bank. She is driven by a commitment to advancing innovative, inclusive climate policy solutions in global governance spaces.

Introduction

Green hydrogen is increasingly presented as essential for decarbonising heavy industry, fertiliser production, and long-distance transport. Yet despite strong political backing, very few large-scale projects have reached construction. High costs, infrastructure gaps, water constraints, and investor uncertainty continue to slow deployment. France and Namibia illustrate two very different responses to these barriers. France is expanding its domestic hydrogen market within an established industrial economy, using public subsidies and regulation to reduce investor risk. Namibia is pursuing an export-led strategy centred on a single large-scale project designed to supply green ammonia to Europe and Asia. Both approaches are ambitious. Both face structural constraints. Comparing them may clarify the practical policy trade-offs governments confront when turning hydrogen strategies into real projects.

Water: A Political Input

Electrolysis requires water, but the policy challenge depends less on absolute volumes than on local scarcity and public perception. In Namibia, water is a central political issue. The Hyphen Hydrogen Energy project – the flagship of the national strategy – is located in a highly arid region. To avoid drawing on groundwater, the project includes a dedicated desalination plant intended to supply both hydrogen production and potable water to the nearby town of Lüderitz.[20] This design reduces direct competition with local water users. However, desalination introduces new risks.[21,22] It is energy-intensive, affects marine ecosystems, and requires long-term cost recovery. While presented as a technical solution, it has not eliminated debate about environmental impacts and local governance capacity. In Namibia, water is not just a production input – it is integral to the project's social legitimacy.[23]

In contrast, France benefits from established governance and relatively abundant freshwater, ensuring that water availability is not a binding physical constraint. Instead, the primary challenge lies in regulatory compliance. Since the 2025 amendments to the EU Taxonomy, French hydrogen developers must navigate the "Do No Significant Harm" (DNSH) principle, which requires systematic assessments of impacts on water bodies and

[20] Hyphen Africa, *The Hyphen Project*, accessed January 19, 2026, https://hyphenafrica.com/the-hyphen-project/.

[21] Government of Namibia, *Green Hydrogen and Derivatives Strategy*, Ministry of Mines and Energy, 2022, 9–46, https://www.ensafrica.com/uploads/newsarticles/0_namibia-gh2-strategy-rev2.pdf.

[22] International Energy Agency (IEA), *Global Hydrogen Review 2023*, Paris: IEA, 2023, 11–163, https://iea.blob.core.windows.net/assets/ecdfc3bb-d212-4a4c-9ff7-6ce5b1e19cef/GlobalHydrogenReview2023.pdf.

[23] Namibia Water Corporation Ltd, *Integrated Annual Report 2021/22: Resilience in the Time of the Covid-19 Pandemic*, Windhoek: NamWater, 2023, 6–101, https://www.namwater.com.na/images/docs/NAMWATER_2021_IAR_Web_Final.pdf.

ecosystems.[24] In practice, these strict permitting rules have steered project siting toward resource optimisation, such as co-locating electrolysers with existing industrial wastewater systems or established supply networks. The lesson is straightforward: water planning must be integrated early. In water-scarce contexts, governments must anticipate public scrutiny and environmental concerns.[25] In water-abundant contexts, regulatory clarity can prevent future delays. In both cases, ignoring water governance can risk slowing projects in the future.

Energy Infrastructure and Market Orientation

A notable difference between France and Namibia lies in how hydrogen is positioned within the national economy. France's 2025 National Hydrogen Strategy treats hydrogen primarily as a domestic decarbonisation tool. It targets 8 GW of capacity by 2035, powered by renewables and nuclear energy.[26] Deployment is decentralised through regional hubs in industrial areas such as Fos-sur-Mer, Dunkirk, and Normandy.[27] By linking electrolysers directly to steel, chemicals, refining, and heavy transport demand, France avoids building large transport networks before consumption is secured. This reduces early systemic risk – but progress has been slow. Despite subsidies and contracts-for-difference, installed capacity remains limited, and plans for an integrated hydrogen pipeline network have yet to advance. France's model prioritises integration and demand-certainty over speed.[28] In sum, France's cautious approach might help integrate demand but might not encourage rapid scale-up.

Namibia's strategy centres on a single export-oriented mega-project: the Hyphen initiative. This approach integrates large-scale wind and solar generation with 1.5 GW of electrolysis in its first phase, alongside purpose-built desalination, storage, and ammonia export infrastructure.[29] By creating this integrated ecosystem, Namibia aims to supply European and Asian markets where domestic renewable capacity is constrained.[30] While this model promises significant scale and export revenue, it concentrates risk. Unlike more diversified strategies, Namibia's national hydrogen vision depends heavily on this single concession, and final investment decisions are still pending. Consequently, any delays in permitting, financing, or securing long-term offtake agreements could have disproportionate consequences for the country's broader energy ambitions. The contrast reveals a clear trade-off: decentralised, demand-led deployment lowers risk but slows scale. Centralised, export-led deployment accelerates ambition but magnifies exposure.

Financing and Risk Allocation

Hydrogen remains capital-intensive and commercially uncertain. Both countries rely on strong state involvement, but their financing structures differ significantly. France embeds hydrogen support within a mature industrial policy framework. Under France 2030, nearly €9 billion has been allocated to hydrogen-related investments.[31] Support mechanisms include competitive tenders, investment subsidies, and contracts-for-difference that guarantee price stability.[32] This model has produced tangible progress. Several projects have secured funding, and domestic electrolyser

[24] European Commission, *EU Taxonomy: Technical Guidance on the "Do No Significant Harm" Principle*, Brussels, 2021, 1–16, https://commission.europa.eu/document/download/993e026c-4118-46ed-b7ff-5224c19aa254_en?filename=2021_02_18_epc_do_not_significant_harm_-technical_guidance_by_the_commission.pdf.

[25] Clean Hydrogen Partnership, *Study on Hydrogen in Ports and Industrial Coastal Areas*, accessed January 19, 2026, Brussels: Clean Hydrogen Joint Undertaking, https://www.clean-hydrogen.europa.eu/media/news/press-release-study-hydrogen-ports-and-industrial-coastal-areas-2023-03-30_en.

[26] European Hydrogen Observatory, *National Hydrogen Strategy: France*, accessed January 19, 2026, https://observatory.clean-hydrogen.europa.eu/hydrogen-landscape/policies-and-standards/national-strategies/france.

[27] Ministère de la Transition Écologique et Solidaire, *National Low Carbon Strategy Project: The Ecological and Inclusive Transition Towards Carbon Neutrality*, 2018, 5–99, https://www.ecologie.gouv.fr/sites/default/files/documents/Projet%20SNBC%20EN.pdf.

[28] European Hydrogen Backbone, *Implementation Roadmap: Cross Border Projects and Costs Update*, 2023, 7–28, https://ehb.eu/files/downloads/EHB-2023-20-Nov-FINAL-design.pdf.

[29] Ibid.

[30] Ibid.

[31] Green Hydrogen Organisation, *France*, GH2 Country Portal, accessed 19 January 2026, https://gh2.org/countries/france.

[32] Ibid.

manufacturing is expanding. However, it is fiscally demanding: long-term sustainability depends on falling technology costs and stable public budgets. Moreover, heavy reliance on subsidies may slow the transition to market-based competitiveness.[33]

Namibia's financing model is concentrated and externally oriented, positioning the state as a strategic facilitator using blended finance to 'crowd in' private capital. Key to this is the SDG Namibia One Fund and catalytic support from multilateral institutions – such as the African Development Bank's US$10 million loan – which provide the de-risking and credibility essential for the Hyphen project.[34,35] However, with large-scale construction yet to commence, the strategy remains tethered to pending final investment decisions (FIDs) and the security of long-term export contracts. By anchoring national ambition to a limited number of 'mega-projects', Namibia faces high execution risk; cost escalations, logistical delays, or weakening global demand could cause the national strategy to stall. The policy implication is not that one model is superior. Rather, financing structures must align with institutional capacity and risk tolerance. Mature economies may absorb high subsidy costs. Smaller economies may attract private capital through scale, but must manage concentrated exposure.

Environmental & Socio-Economic Impacts

Beyond technical viability, green hydrogen requires a 'social licence to operate', particularly where industrial expansion intersects with sensitive ecosystems. In France, hydrogen projects operate within dense national and European regulatory systems. Permitting processes are lengthy and detailed. Although this ensures high levels of scrutiny, the resulting 'regulatory density' often hampers the pace of deployment, reflecting the broader tension between environmental ambition and industrial acceleration within the European Union.[36] This slows deployment but provides predictability, as environmental compliance is embedded in existing institutions.

In Namibia, the governance challenge is more visible. The Hyphen project borders the ecologically sensitive Tsau //Khaeb National Park. Its scale has sparked debate about biodiversity impacts and the compatibility of industrial development with conservation. The government has mandated Environmental and Social Impact Assessments, with both enforcement capacity and transparency remaining critical to long-term legitimacy.[37] Socio-economic expectations may also differ. France frames hydrogen as a tool for industrial renewal and job creation within established value chains, while Namibia presents hydrogen as a transformative development opportunity, projecting thousands of jobs and new export revenues.[38] Whether this translates into broad-based local benefits depends on skills training, local procurement, and avoiding enclave-style development. In both contexts, social licence cannot be assumed. To maintain long-term project durability, governments must transcend procedural compliance and headline employment figures, addressing deeper concerns regarding community participation and equitable risk distribution.

Trade-offs in Early-Stage Hydrogen Strategy

The comparison highlights four recurring trade-offs for governments entering the hydrogen sector:

1. Project Scale vs. Risk Distribution
France spreads deployment across multiple industrial hubs, limiting exposure to single-project failure. Namibia concentrates ambition in one flagship development, increasing both potential returns and vulnerability.

[33] *Ibid*.
[34] *Ibid*.
[35] African Development Bank, "*African Development Bank Approves $10 Million to Catalyse Namibia's Large Green Hydrogen Project*" news release, 2025, https://www.afdb.org/en/news-and-events/press-releases/african-development-bank-approves-10-million-catalyse-namibias-large-green-hydrogen-project-89480.
[36] Green Hydrogen Organisation, *France*, GH2 Country Portal, accessed 19 January 2026, https://gh2.org/countries/france.
[37] Reuters, *RWE Withdraws from $10 Billion Namibia Green Hydrogen Project*, 2025, https://www.reuters.com/sustainability/climate-energy/rwe-withdraws-10-billion-namibia-green-hydrogen-project-2025-09-29/.
[38] Green Hydrogen Organisation, *France*, GH2 Country Portal, accessed 19 January 2026, https://gh2.org/countries/france.

2. Fiscal Support vs. Fiscal Exposure
France's subsidy-driven model has produced measurable progress but requires sustained public spending. Namibia relies on blended finance to mobilise private capital, yet remains dependent on foreign demand and investor confidence.

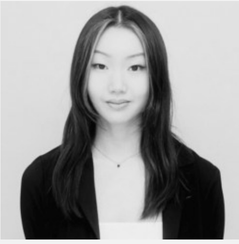
3. Water Solutions vs. Environmental Scrutiny
Desalination in Namibia avoids groundwater competition but raises new ecological concerns. France's reuse-oriented approach reduces controversy but depends on regulatory coordination. In both cases, water planning is central to legitimacy.

4. Regulatory Density vs. Speed
France's dense permitting framework slows deployment but reduces political risk. Namibia's faster, concession-based approach accelerates planning but has generated stronger public debate.

These cases suggest that hydrogen strategy is less about adopting a universal model and more about managing trade-offs. Governments must align ambition with institutional capacity, environmental constraints, and fiscal resilience. Without that alignment, political and execution risks can outweigh technological potential. ■

Managing Trade-offs in the Water-Intensive Semiconductor Industry

Evelyn Mang



Evelyn Mang is a second-year student in the Sciences Po Master's in Environmental Policy program. Alongside her studies, Evelyn is a Project Officer for Nature-Based Solutions at GCE Europe and a Water Researcher for a program run by CARE and the World Sufficiency Lab. She has internship experience at FEDARENE, the European network for energy agencies and regions, and has also worked at the Canadian federal department for Women and Gender Equality.

Introduction

Through the EU Chips Act, a legislative package adopted in 2023, the EU has set an agenda to bolster its technological leadership, specifically in semiconductor manufacturing. Semiconductor power systems are critical for important technologies ranging from AI processors and computation to electric vehicle batteries and photovoltaic energy systems. As such, boosting semiconductor manufacturing is emerging as a key strategic pillar for industrial development.

The EU Chips Act, therefore, is the EU's bid to join the race for semiconductor dominance by presenting a strategy to invest in the development of EU semiconductor production, strengthen the sector's supply chain resilience, research and development, and more.[39] However, as this case study illustrates, the water intensity of semiconductor production poses a key risk to this strategy and needs to be mitigated to enable a European semiconductor industry.

The Water-Intensive Process of Manufacturing Semiconductors

A key reason why semiconductor production is so water-intensive is its need for ultrapure water (UPW), a type of highly purified water that requires 1.5 litres of fresh water for every litre of UPW produced.[40] UPW is needed to rinse semiconductor wafers approximately 100 times to ensure that no pollutants or impurities damage their circuits.[41] This process results in wastewater containing heavy metals and chemical residues that is then treated to be disposed of or recycled.[42]

From the fabricators' perspective, disruptions in this process risk corroding or contaminating equipment, reducing output, and ultimately leading to supply chain delays.[43] This threat is particularly pronounced in areas experiencing water scarcity. Semiconductor fabricators, therefore, have an interest in advancing their water recycling capabilities to minimize negative ecological impacts and mitigate risks to economic outputs and supply chain flows.

The STMicroElectronics Facility in Crolles, France

One of the most prominent EU semiconductor manufacturers, STMicroelectronics, operates a semiconductor manufacturing facility in Crolles, France, a small town north of Grenoble with a population of around 8,500 people.[44] This facility relies on local fresh water for its activities, using the equivalent volume that a city of 100,000 would

---

[39] "European Chips Act | Shaping Europe's Digital Future." European Commisson. Accessed January 15, 2026. https://digital-strategy.ec.europa.eu/en/policies/european-chips-act.

[40] Water Europe. *Socio-Economic Study on the Value of the EU Investing in Water*. Brussels, Belgium, 2024. https://watereurope.eu/wp-content/uploads/2024/10/Water-Europe_Final-Report_15102024-1.pdf, appendix 1 – page 10.

[41] Water Europe, *Socio-Economic Study on the Value of the EU Investing in Water*.

[42] Examples of common pollutants include contaminants like nickel, copper, cobalt, and industrial chemicals such as hydrofluoric acid, ammonium hydroxide, and phosphoric acid. See Water Europe, *Socio-Economic Study on the Value of the EU Investing in Water*, appendix 1 – page 11.

[43] Water Europe, *Socio-Economic Study on the Value of the EU Investing in Water*.

[44] Institut national de la statistique et des études économiques (INSEE). "Comparateur de Territoires – Commune de Crolles." 2022. https://www.insee.fr/fr/statistiques/1405599?geo=COM-38140.

consume[45] and around 15% of Grenoble's water supply.[46] At this facility, the largest share of water consumption is attributable to UPW,[47] but cooling, ventilation, heating, and providing drinking water are also contributing factors.[48] In 2023, an average of 41% of water used by the Crolles plant was recycled, with new initiatives aiming to boost this number.[49] However, as the water purity level needed for UPW is so high, it is difficult to recycle discharge water for this purpose. Recycled water is therefore more often funnelled towards other purposes like cooling.[50]

In 2024, the STMicroelectronics facility in Crolles began a pilot project to increase the recycling rate of its wastewater, aiming to reuse this water for the plant's manufacturing of softened water or ultrapure water, ultimately reducing the volume of water the plant retrieves from public sources.[51] STMicroelectronics has outlined expectations that the project will result in the plant recycling up to 40 m^3 of water per hour, an improvement from the previous rate of 15m^3 of water per hour.[52]

However, a new set of trade-offs also emerges with improved water recycling capabilities. STMicroelectronics has warned that increasing water recycling would also increase the concentration of polluting materials in the water it releases back to the local water supply and has sought approval to increase the concentration rate of pollutants in the water it releases.[53]

One of the projects the EU is supporting in line with the EU Chips Act is the construction and operation of a new semiconductor manufacturing facility by STMicroelectronics and GlobalFoundries, which will be adjacent to STMicroelectronics' existing Crolles facility.[54] The total private and public investment in this expansion project adds up to €7.4 billion,[55] with the French government supporting the project with €2.9 billion in funding,[56] underscoring the project's strategic importance to the EU and France.

In 2023, the announcement of plans for this new facility, combined with the firm's already heavy use of the same water that residents rely on, sparked protests in the Isère department. Protesters expressed anger about the potential increase in pollution and threat to the local water supply that this expansion posed.[57] Between 1968 and 2020, the annual water balance in Isère decreased by 186mm, with the Auvergne-Rhône-Alpes region projecting future trends of further water scarcity in the face of climate change,[58] adding further emphasis to the local backlash to the plans.[59]

---

[45] Ridha Loukil. "Comment STMicroelectronics tente de limiter la consommation d'eau de son plus grand
site en France." L'Usine Nouvelle, March 10, 2023.
https://www.usinenouvelle.com//article/comment
stmicroelectronics-tente-de-réduire-la-consommation-d'eau-de-son-plus-grand-site-en-france.N2109196.

[46] Fanny Breuneval. "STMicroelectronics accusé d'accaparer l'eau à Grenoble." *Novethic*, April 6, 2024.
https://www.novethic.fr/environnement/biodiversite/st-microelectronics-grenoble-crolles-extension-manifestation-accaparement-eau.

[47] Exact figures from STMicroelectronics are not available. See STMicroelectronics "2024 Sustainability Report | 2023 Performance: Water." STMicroelectronics, 2024.
https://sustainabilityreports.st.com/sr24/environment/water.html.

[48] Exact figures from STMicroelectronics are not available. See STMicroelectronics "2024 Sustainability Report | 2023 Performance: Water." STMicroelectronics, 2024.
https://sustainabilityreports.st.com/sr24/environment/water.html.

[49] STMicroelectronics. *Déclaration Environnementale 2023 Site de Crolles*. 2023.
https://www.st.com/content/dam/aboutus/sustainability/reports/pdf/st-crolles-emas-declaration-2023-fr.pdf, 19.

[50] "STMicroelectronics "2024 Sustainability Report | 2023 Performance: Water." STMicroelectronics, 2024.
https://sustainabilityreports.st.com/sr24/environment/water.html.

[51] STMicroelectronics. "STMicroelectronics in Crolles, France."
https://www.st.com/content/st_com/en/about/manufacturing-at-st/our-facilities/crolles-st-site.html.

[52] STMicroelectronics, *Déclaration Environnementale*.

[53] Breuneval, "STMicroelectronics accusé".

[54] GlobalFoundries. "STMicroelectronics and GlobalFoundries to Advance FD-SOI Ecosystem with New 300mm Manufacturing Facility in France." GlobalFoundries, July 11, 2022. https://gf.com/gf-press-release/stmicroelectronics-and-globalfoundries-to-advance-fd-soi-ecosystem-with-new-300mm-manufacturing-facility-in-france/.

[55] European Commission. "State Aid: Commission Approves French Measure to Support STMicroelectronics and GlobalFoundries to Set up New Microchips Plant." April 28, 2023.
https://ec.europa.eu/commission/presscorner/detail/en/https:\/\/ec.europa.eu\/commission\/presscorner\/detail\/en\/ip_23_2447.

[56] STMicroelectronics. *Projet d'extension Du Site de Crolles*. 2024.
https://www.isere.gouv.fr/contenu/telechargement/76396/597164/file/2_Rapport_pages_313_%C3%A0_362.pdf.

[57] Breuneval, "STMicroelectronics accusé".

[58] L'observatoire Régional Climat-Air-Énergie (ORCAE). "Impacts Du Changement Climatique." January 15, 2026. https://www.orcae-auvergne-rhone-alpes.fr/analyses-thematiques/climat/impacts-du-changement-climatique.

[59] Le Monde, and AFP. *Contre l'accaparement de l'eau, des centaines de personnes ont manifesté devant l'entreprise STMicroelectronics en Isère*. April 1, 2023.

Navigating the Future of Water Stress Linked to the Semiconductor Industry

As the semiconductor industry develops in complexity and scale, the sectors' water use will need to be managed to ensure water security for the regions it draws water from, heightening conflicts between the needs of residents and the demands of the semiconductor industry. More complex semiconductor nodes also require purer water and higher volumes of water consumption, adding to the potential for higher water demands from semiconductor manufacturers in the future.[60]

The threat of water scarcity is a critical consideration for the EU as it embarks on a mission to boost its technological sectors and prove itself as a global leader in strategic outputs like semiconductors. But risks also extend beyond the EU - as climate change intensifies global water scarcity, key strategic sectors like semiconductor manufacturing will suffer from water scarcity while also contributing to these shortages, posing risks to the availability of fresh water supplies and future technological developments. ■

https://www.lemonde.fr/planete/article/2023/04/01/contre-l-accaparement-de-l-eau-des-centaines-de-personnes-ont-manifeste-devant-l-entreprise-stmicroelectronics-en-isere_6167885_3244.html.

[60] Socio-Economic Study on the Value of the EU Investing in Water. Water Europe, Appendix 1 - Page 10

Case Studies

Decarbonising Desalination: A Comparative Case Study of Fossil and Renewable-Powered Plants

Clara Klint

Clara is a master's student in International Energy Transitions at Sciences Po. She holds a BSc in Political Science from the London School of Economics. She is passionate about industrial policy and energy economics. She has experience working on energy technology supply chains at the International Energy Agency and previous experience in foreign direct investment consultancy and energy market research.

For economic growth and resilience of its digital economy, Europe will need more data centres. Seen from a European perspective, placing large data centres in the Nordic might be considered resource efficient. Firstly, cheap land and abundant renewable energy make Sweden, Finland and Norway attractive locations for electricity-intensive data centres – as highly decarbonised electricity grids allow data centre operators to claim their electricity and business model is clean. Secondly, while water scarcity intensifies in Europe, the Nordics have a stable, cool climate that reduces water intensity of data centres. Thirdly, the Nordics have well-developed district-heating networks. Channelling data centre waste heat into the district heating systems could increase resource efficiency. In this case study, I take a closer look at the case for heat reuse and barriers preventing its large-scale implementation, discussing policy development across the Nordics.

Why now?

Currently, the need for AI computing is making data centres hotter.[61] Because of this, the industry is yet again moving towards liquid-cooling, which is more efficient than air cooling at transporting heat away. While requiring more water, the waste heat from liquid cooling systems can also hold higher temperatures of around 50-60 °C, which allows more efficient reuse compared to air-cooled systems, whose waste heat is usually only 25-35 °C.[62] Paired with industrial heat pumps, temperatures can be raised to efficiently service district heating systems.

Real Life Examples

Heat reuse might help increase local acceptance of data centres. Data centres put large demands on energy and capacity connections while creating relatively few permanent jobs for local communities.[63] Data centre heat reuse could benefit local communities while also promoting resource efficiency. In the Finnish town of Mantsala, a local data centre has been delivering waste heat for a decade. As the city previously relied heavily on natural gas for heating, the data centre has lowered the heating costs for its residents, creating direct benefits for the local community.[64,65] Some larger projects are also underway. Energy company Fortum and Microsoft plan to utilise 75% of waste heat from a new data centre to heat the urban area of Espoo. Microsoft's data centre will be able to meet 40% of the city's heating needs – and allow the city to meet its climate targets by eliminating the need for fossil fuels in heating. While this project has attracted a lot

[61] Genkina, Dina. "Next-Gen AI Needs Liquid Cooling." IEEE Spectrum, October 13, 2025. https://spectrum.ieee.org/data-center-liquid-cooling.
[62] Mikko Wahlroos et al., "Future Views on Waste Heat Utilization – Case of Data Centers in Northern Europe," *Renewable and Sustainable Energy Reviews* 82, no. Part 2 (November 13, 2017): 1749-64, https://doi.org/10.1016/j.rser.2017.10.058.
[63] Juho Kostiainen, "Finland: Data Centers – Midas Touch or Achilles' Heel," Nordea Corporate, November 20, 2025, https://corporate.nordea.com/article/101924/finland-data-centers-midas-touch-or-achilles-heel.
[64] Lars Paulsson, Kai Lundgren, and Kati Pohjanpalo, "Power-Hungry Data Centers Are Warming Homes in the Nordics," *Bloomberg*, May 14, 2025, https://www.bloomberg.com/news/features/2025-05-14/finland-s-data-centers-are-heating-cities-too.
[65] "District Heating From Data Centre Waste Heat, Mäntsälä - Sitra," Sitra, November 18, 2019, https://arkisto.sitra.fi/en/cases/district-heating-from-data-centre-waste-heat-mantsala/.

of attention,[66] a key question is whether this type of strategy can be implemented at greater scale or whether such projects are merely PR boons for tech companies.

Policy Landscape

The commitment to incentivise district heating reuse varies among the Nordic governments. Despite 240 out of its 290 municipalities using district heating, Sweden long offered generous electricity tax reductions and subsidies *without* any requirements for grid effects or heating reuse. No nationwide reuse or data centre strategy has been formulated. As part of its new data centre strategy, Norway has opted for a 'soft' approach, recently adopting a law which mandates data centre developers to investigate the potential of heat recovery of new establishments.[67] However, upon completing the assessment, there is no obligation to realise the plans. In this way, the Norwegian government wants to nudge data centres to identify worthwhile local offtake opportunities like local industry in need of heat. Whilst this might encourage low-hanging fruit partnerships to materialise, the policy will likely fail to bring about more complex projects with higher infrastructure and investment requirements - as with district heating integrations. The Finnish government appears most assertive - capping, electricity tax from heat-recovering data centres to incentivise heat reuse.[68] However, a recent study suggests that the Finnish electricity tax reduction might still not be enough to make reuse worthwhile.[69]

Barriers to Successful Heat Reuse

Successful policy must address the differing incentive structures between data centre operators and district heating operators, which include:

Location: In general, the placement of data centres is primarily determined by electricity prices and ease of grid connection. This tends to be further from cities, making it harder to utilise heat for district heating as substantial infrastructure investments must be made.

Timeline: Smaller data centres often host other companies' data operations with contracts typically running only a few years. But for district heating operators, becoming ready for heat reuse usually requires large investments into industrial heat pumps and pipes. These investments require long-term certainty to be worthwhile. This creates incentives mismatch which could deter investment in waste heat reuse projects.[70]

Business case: For large players, like the American tech giants - who own their own server halls and might have longer time horizons - selling waste heat will have a small impact on the bottom line. As such, utilising waste heat might be seen more as a sustainability boon than a core business consideration. Therefore, we cannot simply assume that the data centres will act as sellers and district heating companies as buyers. Additionally, during times of high electricity prices, the use of heat pumps might render the reuse of heat unaffordable.[71]

Planning: Ideal waste heat temperature differs for district heat companies and data centres. For data centres, ending up with lower temperature waste heat is usually cheapest. But higher temperatures are needed for district heating. Otherwise, expensive heat pump solutions are needed to raise the temperature of the water, which risks making the whole endeavour energy inefficient anyway. Therefore, energy companies need to be involved

[66] Fortum. "Waste Heat From Data Centres." Accessed February 15, 2026. https://www.fortum.com/services/heating-cooling/data-centres-helsinki-region.

[67] Ministry of Digitalisation and Public Governance, "The data centre industry - a sustainable industry of the future for the digital Norway," *Regjeringen*, October 7, 2025, accessed February 15, 2026, https://www.regjeringen.no/en/documents/the-data-centre-industry-a-sustainable-industry-of-the-future-for-the-digital-norway/id3112356/.

[68] Seela Tervo, Pauli Hiltunen, and Sanna Syri, "Data Center Waste Heat Utilization in District Heating in a Volatile Low-carbon Electricity Market," *Cleaner Environmental Systems* 19 (November 25, 2025): 100373, https://doi.org/10.1016/j.cesys.2025.100373.

[69] *Ibid 8.*

[70] Arianna Tofani, "A case study on the integration of excess heat from Data Centres in the Stockholm district heating system" (KTH, 2022), https://kth.diva-portal.org/smash/get/diva2:1723944/FULLTEXT01.pdf.

[71] *Ibid 8.*

with data centres in early stages of planning to coordinate temperatures.

Conclusion

Letting data centres establish themselves without first having a plan for heat reuse is unlikely to produce desirable reuse integrations. To achieve successful large-scale utilisation of waste heat, energy companies and data centres must cooperate already in the planning stage. Designing supportive policy and incentive structures matter, too. Promising examples include Helsinki's conditional energy tax reduction which incentives companies to find the most efficient heat reuse cases. The message is clear: reusing heat from data centres will not come automatically but must be encouraged through supportive planning and policy mechanisms. ■

Decarbonising Desalination: A Comparative Case Study of Fossil and Renewable-Powered Plants

Sofía García-Escribano

Coming from Spain, Sofía García-Escribano Camino is currently pursuing a degree in Industrial Engineering in Madrid, complemented by a semester of academic exchange at Sorbonne Paris. Alongside her engineering training, she is developing a parallel academic foundation in Humanities.

Introduction

Well over half the world's population already experiences some for m of water scarcity each year.[72] As climate change accelerates and population grows, desalination has emerged as a critical tool, now supplying freshwater around the world to over 300 million people.[73] Currently, 22,000 desalination plants are estimated to be in action, the majority of which are concentrated in the MENA region.

However, this solution to water scarcity presents an energy-water paradox, as desalination is a massive energy consumer. The current global production of about 99 million m³/day[74] of desalinated water involves an electrical energy consumption which accounts for approximately 0.8% of global electricity consumption. Because 90% of these plants are still powered by fossil fuels, they emit between 494 to 856 million tons of CO_2 annually, depending on feedwater salinity.[75] These emissions further reinforce the causes of climate change and thus water scarcity.

The challenge is no longer whether water can be produced, but if that can be done without contributing to further environmental degradation. The aim of this study is to investigate whether renewable-powered desalination can match the operational performance and economic feasibility of traditional fossil fuel-based plants.

To showcase the spectrum of desalination evolution, three representative case studies have been selected:

- Ras Al-Khair (Saudi Arabia): A massive-scale plant representing the traditional fossil fuel model.
- Al Khafji (Saudi Arabia): A pioneer in large-scale solar-powered reverse osmosis, demonstrating the shift toward renewables in the MENA region.
- Sydney (Australia): An example of the renewable energy certificate model, where a large-scale plant is powered by offsets from dedicated wind farms.

Ultimately, this analysis argues that the transition towards a sustainable desalination model is both technically and economically feasible. However, success depends less on the desalination technology itself and more on the integration of renewable energy storage and supportive policy frameworks. In this study, the analysis of Ras Al-khair plant is established as the baseline and is then compared against emerging renewable models. Finally, the study concludes by identifying technical and policy frameworks that could enable the transition towards zero-carbon water.

The metrics used to describe each plant are *specific energy consumption* (SEC), *carbon intensity* (CI) and *levelized cost of water* (LCOW) and described in Table 1. The corresponding figures for each of the plants are detailed in Table 2.

[72] World Bank Group, "The Role of Desalination in an Increasingly Water-Scarce World" (March 2016)

[73] Madhuri et al., "Solar energy-driven desalination: A renewable solution for climate change
mitigation and advancing sustainable development goals" (January 2025): https://doi.org/10.1016/j.desal.2025.118575

[74] European Commission, "Desalination," Blue Economy Observatory, accessed on 12 January 2026, https://blue-economy-observatory.ec.europa.eu/eu-blue-economy-sectors/desalination_en.

[75] Lorenzo Rosa, "Global energy, costs, and emissions from reverse osmosis desalination under future water scarcity" (January 2026), https://doi.org/10.1016/j.watres.2025.124825.

Box 1. Understanding Desalination

By Sofía García-Escribano

Desalination is the process of removing salt and impurities from saline water to produce suitable for human consumption, irrigation or industry.

Feedwater sources

- Seawater (60.8%): the primary source, with most plants installed along the coastline.
- Brackish water (20.6%): water whose salinity is between that of fresh and marine water.[76]

The outputs

- Freshwater: often requires post treatment to adjust pH levels or mineral content.
- Brine: a high salinity product that must be carefully managed to avoid environmental damage.

Main Desalination Technologies

	Thermal desalination	Membrane (Reverse Osmosis)
Mechanism	Heats water to evaporation, leaving behind the salts and impurities, then condenses vapor to liquid.	Forcing saline water through a semi-permeable membrane that retains dissolved impurities such as salts. The most widespread membrane-based technology is reverse osmosis (RO).
Energy use	High: 15-25.5 kWh/m^3 [77]	Low: 3-6 kWh/m^3 [78]
Strengths	Handles very high-salinity water and produces extreme purity.	Dominant global technology due to its lower energy footprint.[79]
Challenges	Energy intensive due to the heat required for the two phase changes of water.	High-energy pumps are required to pressure water across the membrane.
Global scope	27% of all installed systems.[80]	69-73% of all installed systems.[81]

[76] RES4Africa Foundation, Powering Desalination with Renewable Energies in Morocco, (Rome: RES4Africa Foundation, 2023), https://res4africa.org/wp-content/uploads/2023/06/desalination_morocco_FINAL_DIGITAL.pdf.
[77] Fadoua, Abdelhadi, "Comparative Analysis of Desalination Technologies: Energy Performance and Renewable Energy Integration with Focus on Reverse Osmosis Systems" (December 2025): https://doi.org/10.1051/e3sconf/202568000031.
[78] *Ibid.*
[79] U.S. Department of Energy, "Desalination Basics," Office of Energy Efficiency and Renewable Energy, accessed on 10 January 2026, https://www.energy.gov/eere/ito/desalination-basics.
[80] Jochen Bundschuh, "State-of-the-art of renewable energy sources used in water desalination: Present and future prospects", https://doi.org/10.1016/j.desal.2021.115035.
[81] *Ibid.*

Fossil fuel plants: Ras Al-Khair

The Ras Al-Khair Desalination Plant is located on the eastern coast of Saudi Arabia and serves approximately 3.5 million people.[82] The plant uses a hybrid desalination system where thermal multi-stage flash (MSF) units lower salinity before water enters the reverse osmosis (RO) stage. While reliable, the use of MSF requires nearly triple the energy of the RO units.The plant's annual carbon emissions are estimated at 1.3 million tons of CO_2, being primarily increased by the thermal desalination process. The substantial initial capital and operational expenditures (labor, maintenance, consumables), paired with an annual production of 325 million m^3 of water annually, determines the LCOW.

Renewable options: Al Khafji Plant & Sydney

Al-Khafji Desalination Plant (Solar)

The Al Khafji is a solar desalination plant located in the North-Eastern coast of Saudi Arabia. This plant was launched in 2018, becoming the world's first large-scale desalination plant powered by solar and supplies water to 150,000 people. By utilizing RO exclusively, the plant has low energy requirements (low SEC). Solar energy supplies roughly 60% of the plant's annual energy demand. During daylight hours, the power produced by PV panels is fed to the desalination plant, with the excess power being fed to the grid. During nighttime hours or low irradiance periods[83], the plant remains grid dependent.The initial investment of this plant may appear very small compared to that of Ras Al-Khair, but it is important to notice the difference in production capacity. The largest proportion of OPEX is represented by the cost of the energy required to run the plant, so a technology like RO that results in low SEC will therefore ensure a low LCOW.

Sydney Desalination Plant

The Sydney Desalination Plant, located in southern Sydney, can supply up to 15% of the city's water demand. The plant employs RO and depends on the

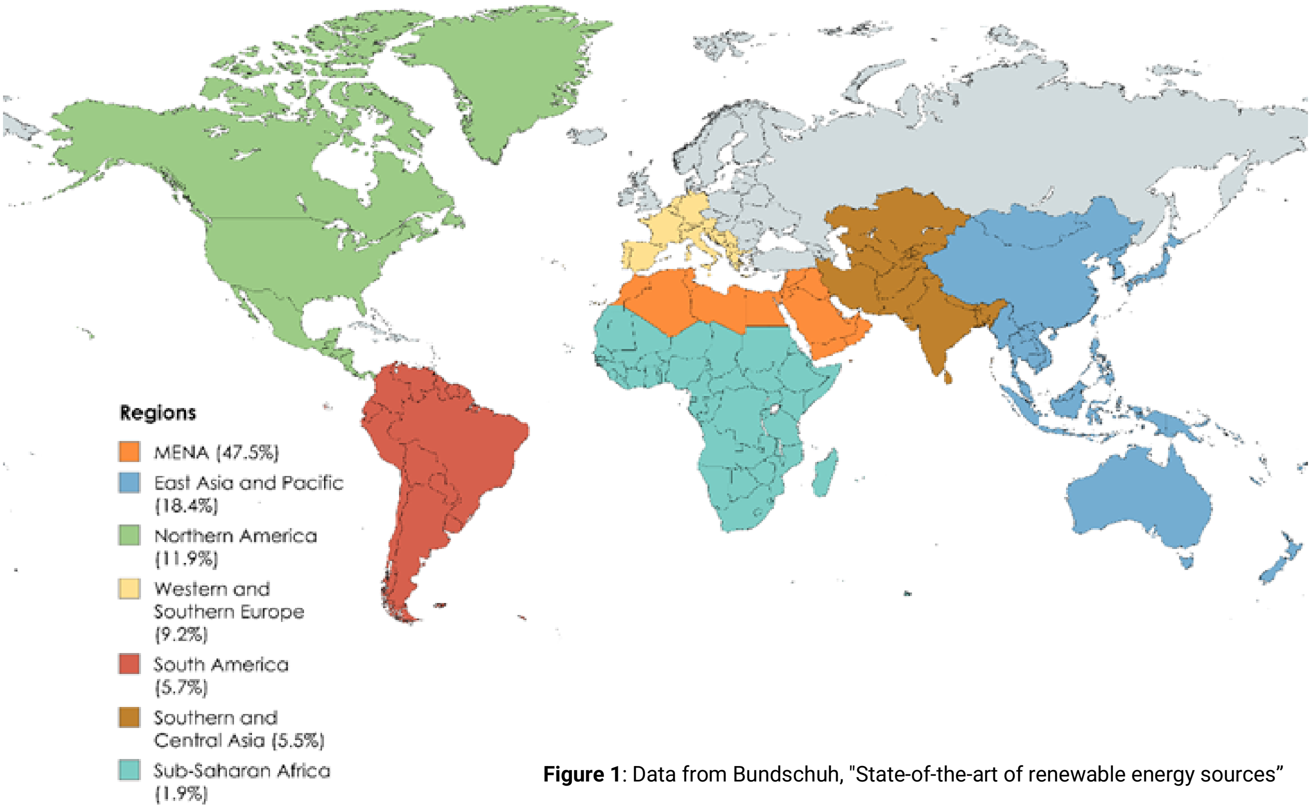


Figure 1: Data from Bundschuh, "State-of-the-art of renewable energy sources"

[82] Archirodon, "Ras Al-Khair Desalination Plant, Jubail," accessed on 12 January 2026, https://www.archirodon.net/ras-al-khair-desalination-plant-jubail/.

[83] The Saudi International Water Technology Conference 2011, "Al-Khafji Solar Water Desalination" (2011) https://kh.aquaenergyexpo.com/wp-content/uploads/2022/11/solar-water-desalination.pdf

Table 2: Figures for each plant

Capital Wind Farm located 270 km apart, which produces 140.7 MW[84], enough to cover the 38 MW required by the desalination plant. The plant achieves net-zero carbon emissions through renewable energy certificates. For every megawatt the plant consumes from the standard electricity grid, the wind farm pushes a megawatt of clean energy into the grid elsewhere. This offsets the carbon intensity to effectively zero. By using this system rather than building a power line to connect both facilities, CAPEX lowers. While renewable certificate costs introduce a premium, the strategy delivers price stability amid volatile coal and gas markets, insulating LCOW.

Critical analysis

The increasing global demand for freshwater, combined with growing concern over environmental impacts, highlights the urgent need for desalination systems that are both reliable and environmentally sustainable. However, the transition from fossil fuel powered plants such as Ras Al-Khair to renewable models such as Al Khafji and Sydney entails a complex interplay between technical constraints and economic incentives. The technology necessary for the renewable powered alternatives is already mature. However, the key technical constraint for renewables remains the temporal mismatch between energy production and water demand, which limits the plant's ability to operate continuously. Al Khafji illustrates this challenge: solar only covers 60% of annual energy needs without storage.

A critical insight is the potential economic advantage of water storage compared to electrical energy storage.[85] In many contexts, storing freshwater in tanks can be more cost effective than storing surplus electricity in battery arrays. Batteries remain expensive, degrade over relatively short lifetimes (8-15 years) and introduce additional environmental burdens. In contrast, freshwater storage tanks offer much higher lifetimes (40-50 years), with lower initial and maintenance costs. Future reductions in battery cost may significantly influence the relative attractiveness of each method. Therefore, water storage deserves careful consideration as an efficient and more durable alternative, particularly in contexts where water demand is relatively stable and storage space is available.[86]

Sydney presents a different approach by relying on the grid through renewable energy certificates. This

Table 1: Key Metrics Description

Metric	Relevance to the study	Calculation method
Specific energy consumption (SEC)	Energy efficiency of production	$SEC = \frac{Total\ energy\ consumed (kWh)}{Total\ volume\ of\ water\ produced\ (m^3)}$
Carbon intensity (CI)	Environmental impact	$CI = \frac{Total\ CO_2\ emissions\ (kg)}{Total\ volume\ of\ water\ produced\ (m^3)}$
Levelized cost of water (LCOW)	Long term financial feasibility of the plant, considering construction and running costs.	$LCOW = \frac{Sum\ of\ costs\ over\ lifetime\ (USD)}{Sum\ of\ water\ produced\ over\ lifetime (m^3)}$

[84] Iberdrola Australia, "Capital Wind Farm," Operating Renewable Energy Assets, accessed February 10, 2026, https://www.iberdrola.com.au/our-assets/asset-map/operating-renewable-energy-assets/capital-wind-farm.

[85] Ajiwiguna, T. A., G.-R. Lee, B.-J. Lim, S.-H. Cho, and C.-D. Park. "Optimization of Battery-Less PV-RO System with Seasonal Water Storage Tank." (2021) https://doi.org/10.1016/j.desal.2021.114934

[86] M. J. Al-Mubarak and A. J. Conejo, "Storing Freshwater Versus Storing Electricity in Power Systems with High Freshwater Electric Demand" (2024), https://doi.org/10.35833/MPCE.2023.000306

Decarbonising Desalination: A Comparative Case Study of Fossil and Renewable-Powered Plants

Table 2: Figures for each plant

Metric	Ras Al-Khair *Fossil-Hybrid*	Al Khafji *Solar RO*	Sydney *Wind Offset*
Daily Production Capacity	1,036,000 m^3/day[87]	60,000 m^3/day [88]	250,000 m^3/day [89]
Primary Technology	Hybrid (MSF + RO)	Seawater RO	Seawater RO
Energy Source	Natural Gas / Grid	100% Solar PV + Grid	Grid+Wind Certificates
Total CAPEX	\$7.2 – \$7.6 billion[90]	\$130 million	\$1.803 Billion
OPEX (\$ / m^3)	\$0.65 [91]	\$0.30 – \$0.45	\$0.55 – \$0.70
SEC (Energy use)	13–15 MSF & 3–5 RO kWh/m^3	3-5 kWh/m^3	3.6 – 4.2 kWh/m^3
Carbon Intensity	7.08 kg CO_2/m^3 for thermal units and 2.02 CO_2/m^3 for RO units[92]	0.8 kg CO_2/m^3 [93]	Net-Zero

ensures that net-zero emissions can be attained independently from renewable energy generation at the moment. In contrast, the hybrid membrane and thermal model of Ras Al-Khair forces the plant into high energy consumption and high carbon impact, as the sources are fossil fuels.

These diverging technical configurations translate directly into different economic profiles. Traditional facilities, like Ras Al-Khair, often involve lower CAPEX, but are subjected to the volatility of gas prices and the possible financial burden of carbon taxes. In contrast, the renewable plants like Al Khafji or Sydney require higher upfront investment due to the cost of wind turbines, solar panels, or long term power purchase agreements. However, once constructed, they have near zero marginal energy costs: since the energy source is free, the OPEX is primarily limited to maintenance. This insulates water prices from fluctuations in fossil fuel markets.

The transition to these renewable-driven models cannot be achieved by market forces alone, it requires robust policy frameworks. In the case of Sydney, the renewable energy certificates provide a model for cities that lack the space for on site solar or wind farms. Conversely, regions with solar potential could implement policies that encourage capacity oversizing and water storage, rather than continuous operation. Additionally, carbon pricing mechanisms could play an important role by aligning economic incentives with environmental goals.

Conclusion

The technology necessary to enable a transition of desalination from carbon-intensive to renewable alternatives is already present and can be economically successful, as demonstrated by Al Khafji and Sydney desalination plants. The primary challenge lies no longer in the engineering design, but on the infrastructure and policy. The reliability of fossil fuel powered plants like Al-Khair can be matched by renewable alternatives by implementing models such as water storage or renewable energy certificates. When evaluating the levelized cost of water, the advantages of wind and solar outperform the volatility of natural gas and carbon pricing. ■

[87] B.Suliman et al., "Desalination and Its Impact on the Mediterranean Ecosystem" (2024)
[88] Enas Taha Sayed, "Recent progress in renewable energy based-desalination in the Middle East and North Africa MENA region" (2023) https://doi.org/10.1016/j.jare.2022.08.016.
[89] Sydney Desalination Plant, "Securing Sydney's Water for the Future", accessed on 17 January 2026, https://sydneydesal.com.au/.
[90] International Journal of Applied Science and Research. "Synergizing Cost Optimization and Environmental Engineering in Water Desalination: Best Practices for Sustainable Project Management." (January 2025): https://doi.org/10.54536/ajec.v4i3.5414
[91] *Ibid*.
[92] Amer A. AL-Ghamdi,"Optimal emission plan for independent power producers using generation mix to meet Saudi Arabia environmental goals" (May 2024).
[93] Environmental Balance Company, "Greenhouse Gas Emission Estimation and Carbon Footprint Assessment Report" (June 2025)

Marine Carbon Dioxide Removal: A Blind Spot for Science and a Moral Hazard for Policy?

Lavanya Kapoor

Lavanya Kapoor is a first-year student at Sciences Po pursuing a Master in Public Policy. Having previous experience in applied policy research, field work, and data synthesis, she has a particular interest in education policy, environment policy, and the intersection of gender and policy in practice.

In the IPCC's sixth assessment report, carbon dioxide removal (CDR) strategies are framed as crucial to most mitigation pathways. These strategies rely on carbon capture and storage (CCS), creating 'negative emissions technologies' crucial "for decarbonising hard-to-abate industrial emissions" from steel, cement, aviation, and other such industries.[94] Yet within the expanding CDR landscape, a notable shift is underway. Direct ocean capture (DOC) and other marine CDR (or mCDR) technologies, such as those being developed by Captura, Equatic, and SeaO2, are increasingly positioned as the future of efficient, purportedly scalable, and viable climate change mitigation.[95] In this context, examining mCDR as a case-study serves as a lens to explore the water-energy nexus in light of several tradeoffs: between carbon removal and energy consumption, between mCDR and the impact on marine ecosystems, between technological optimism and scientific uncertainty, and finally, between immediate-term emissions reductions and long-term policy reliance on future CDR. This case-study argues that despite mCDR being increasingly framed as a viable climate solution, there remains profound uncertainty regarding its environmental impacts and feasibility. Overreliance on CDR tomorrow risks giving ourselves a carte-blanche to emit today, raising concerns long associated with moral hazard in climate policy.

DOC is a CDR technology that removes carbon from seawater through electrochemical processes.[96] The ocean is already a massive carbon sink, absorbing around 20-40% of anthropogenic CO2.[97] Hence, the attractiveness of mCDR lies in harnessing the ocean's natural absorption of CO2, by either acidifying seawater to extract and store CO2, or basifying seawater to extract solid calcium carbonate.[98] After drawing out CO2 from seawater, the treated water is released back into the ocean, allowing it to continue serving as a carbon sink for additional CO2 uptake.[99]

There are many reasons DOC is attractive to policymakers. Notably, numerous companies are piloting mCDR technologies, demonstrating its potential for scalability, such as Captura and Equinor's collaborative facility in Hawaii.[100] [101] While the IPCC has maintained focus on CCS, it has moved away from bioenergy-CCS due to concerns over land-use competitiveness.[102] DOC plants,

[94] Kara Hunt, "What Does the Latest IPCC Report Say About Carbon Capture?," Clean Air Task Force, April 20, 2022, https://www.catf.us/2022/04/what-does-latest-ipcc-report-say-about-carbon-capture/.
[95] Emma Parry et al., "Ocean carbon dioxide removal: What's on the horizon?," McKinsey Sustainability, September 22, 2025, https://www.mckinsey.com/capabilities/sustainability/our-insights/ocean-carbon-dioxide-removal-whats-on-the-horizon.
[96] Jiawen Yu, "Direct Ocean Capture Vs. Ocean Alkalinity Enhancement for Scalable Ocean Carbon Dioxide Removal," International Journal of Energy 8, no. 1 (November 18, 2025): 53–60, https://doi.org/10.54097/5zh22n06.
[97] *Ibid.*
[98] Antaeres Antoniuk-Pablant, "Marine Carbon Dioxide Removal: What It Is and How It Works," Carbon Direct, March 31, 2025, accessed January 20, 2026, https://www.carbon-direct.com/insights/marine-carbon-dioxide-removal-what-it-is-and-how-it-works.
[99] Ove Hoegh-Guldberg et al., "The Ocean as a Solution to Climate Change: Updated Opportunities for Action," Ocean Panel, September 21, 2024, https://doi.org/10.69902/98e3de92.
[100] Andrea Willige, "These 4 Companies Are Removing Carbon Dioxide From the Ocean. Here's How," World Economic Forum, October 25, 2024, accessed January 20, 2026, https://www.weforum.org/stories/2024/10/direct-ocean-capture-carbon-removal-technology/.
[101] Tara Bojdak, "Equinor and Captura Validate Direct Ocean Capture for Commercial Deployment," Captura, November 12, 2025, https://capturacorp.com/equinor-and-captura-validate-doc/.
[102] Samira García-Freites, Clair Gough, and Mirjam Röder, "The Greenhouse Gas Removal Potential of Bioenergy With Carbon Capture

meanwhile, can be deployed offshore and are hence unaffected by land costs. Direct air capture (DAC) is similar to DOC in that it draws CO2 from the atmosphere, but has been deemed inefficient due to the low concentration of CO2 in the air.[103] Conversely, the ocean holds around 150 times more CO2 than the atmosphere, making it the more cost-efficient and attractive option for policymakers.[104] However, despite these advantages, DOC raises three key challenges: the unexplored impact of DOC on marine ecosystems, the carbon-tradeoff that makes mCDR a costly technology, and finally, the issue of policy fragmentation along two axes: spatial and temporal.

First, the environmental impacts of mCDR on marine ecosystems are not only underresearched, but likely to be adverse. Since DOC often relies on electrochemical processes, releasing this chemically modified seawater into the ocean could risk marine ecosystems.[105] On the other hand, proponents contest that ocean acidification already impacts marine life and coastal communities, hence the changing chemistry of the ocean is a cost in both DOC and do-nothing scenarios.[106] However, this framing diminishes the role of cumulative and spatially concentrated effects, especially considering the lack of monitoring and evaluation mechanisms. The Ocean Panel, in its Blue Paper on responsible evidence-based decision making on mCDR for Paris targets, acknowledged that significant knowledge gaps persist and that strong public oversight would be required to ensure these projects remain environmentally sound.[107]

Second, while DOC indeed benefits from higher carbon concentration in oceans relative to air, water is significantly more dense than air and "moving and processing seawater" thus requires more energy.[108] Compared to DAC, DOC is hence undoubtedly energy-hungry, although energy consumption and costs may be reduced by relying on existing infrastructure such as desalination plants in close vicinity. However, this simultaneously limits their capture potential, revealing a tradeoff between scalability and efficiency.[109] Notably, DOC is not the only proposed mCDR technology, yet others in its category (such as mineralisation and ocean-alkalinity-enhancement) are worse still in terms of energy efficiency and environmental feasibility.[110]

The third and last pillar is policy fragmentation, which spatially and temporally complicates governance and risks long-term mitigation failure. Spatially, mCDR technologies often fall across ambiguous jurisdictional frameworks. While the UN Convention on the Law of the Sea does not explicitly mention mCDR, it enables coastal states to withhold consent for certain scientific projects if they harm the marine environment.[111] Given the poorly understood marine impacts of mCDR, governance of DOC, if it becomes scalable and viable, is likely to be fragmented and inconsistent, with possible disparities in domestic and international regulations. This may cause uneven environmental safeguards across jurisdictions, possibly complicating the already unequal climate justice landscape by exposing vulnerable communities to increased risks. The London Convention and the London Protocol, the international agreements most relevant to

---

and Storage (BECCS) to Support the UK's Net-zero Emission Target," *Biomass and Bioenergy* 151 (June 21, 2021): 469-86, https://doi.org/10.1016/j.biombioe.2021.106164.

[103] Andrea Willige, "These 4 Companies Are Removing Carbon Dioxide From the Ocean. Here's How," World Economic Forum, October 25, 2024, accessed January 20, 2026, https://www.weforum.org/stories/2024/10/direct-ocean-capture-carbon-removal-technology/.

[104] *Ibid*.

[105] Antaeres Antoniuk-Pablant, "Marine Carbon Dioxide Removal: What It Is and How It Works," Carbon Direct, March 31, 2025, accessed January 20, 2026, https://www.carbon-direct.com/insights/marine-carbon-dioxide-removal-what-it-is-and-how-it-works.

[106] Committee on A Research Strategy for Ocean-based Carbon Dioxide Removal and Sequestration, Ocean Studies Board, Division on Earth and Life Studies, and National Academies of Sciences, Engineering, and Medicine, *A Research Strategy for Ocean-based Carbon Dioxide Removal and Sequestration, National Academies Press eBooks*, 2021, https://doi.org/10.17226/26278.

[107] Ocean Panel, "Marine CDR Governance Principles" December 8, 2025, https://oceanpanel.org/publication/marine-carbon-dioxide-removal/.

[108] Freya Chay et al., "Mapping the Efficiency of Direct Ocean Removal," CarbonPlan, June 4, 2025, https://carbonplan.org/research/dor-efficiency-explainer.

[109] Matthew D. Eisaman, "Negative Emissions Technologies: The Tradeoffs of Air-Capture Economics," *Joule* 4, no. 3 (March 1, 2020): 516–20, https://doi.org/10.1016/j.joule.2020.02.007.

[110] Chameera Jayarathna et al., "Review on Direct Ocean Capture (DOC) Technologies," *SSRN Electronic Journal*, January 1, 2022, https://doi.org/10.2139/ssrn.4282969.

[111] Ocean Panel, "Marine CDR Governance Principles" December 8, 2025, https://oceanpanel.org/publication/marine-carbon-dioxide-removal/.

mCDR, do not yet have wide membership, and lack a robust governance framework for DOC deployment.[112] While the London Protocol has been amended to allow sub-seabed carbon sequestration, provisions for risk assessments, and room for policy adaptation, its evolution suggests an acceptance of new mitigation methods before their long-term risks are fully understood.[113] Moreover, by embedding negative-emissions technologies into net-zero pathways, policymakers have deferred immediate emissions reductions – undeniably the most reliable method for Paris targets – in favour of future carbon removal prospects. The allure of CCS technologies lies in their licensing of present emissions rates, while appearing on track to fulfilling Paris commitments.[114] This reliance on speculative technologies is dangerous: the cost is inaction, where short-term politico-economic conveniences outweigh the urgent need to decarbonise.[115] In other words, relying on DOC as a future solution may undermine the very climate management it is intended to support.

This case-study of DOC and mCDR has illustrated its increasingly prominent yet precarious position in contemporary climate policy. While it is appealing due to the ocean's natural potential as a carbon sink and promises scalability and efficiency, we grapple with DOC's three fundamental challenges presented in this article. While DOC is underresearched, its potentially adverse impacts on marine ecosystems and coastal communities warrant better scientific understanding and transparency. It is framed as a cost-effective pathway, yet, DOC's carbon intensity and tradeoff between efficiency and scalability provide insight into the long-run challenges. Most important for policymakers, perhaps, is considering the spatial and temporal fragmentations of the regulatory landscape. Together, these gaps highlight the need for rigorous science and governance, and we must rethink the embeddedness of mCDR in net-zero pathways. Today, amid scientific uncertainty and political convenience, mCDR (and other CCS technology) has become a policy crutch for a future we may not have the time to wait for. ■

[112] *Ibid*.
[113] Korey Silverman-Roati and Romany Webb, "Climate Governance Under the London Convention and Protocol: Lessons From Sub-Seabed Carbon Sequestration," Climate Law Blog, October 10, 2025, https://blogs.law.columbia.edu/climatechange/2025/10/10/climate-governance-under-the-london-convention-and-protocol-lessons-from-sub-seabed-carbon-sequestration/.
[114] Jason Hickel and Giorgos Kallis, "Is Green Growth Possible?," *New Political Economy* 25, no. 4 (April 17, 2019): 469–86, https://doi.org/10.1080/13563467.2019.1598964.
[115] *Ibid*.

Water and Energy as Weapons: The Insights from the Russia-Ukraine War

Oleksandra Pakshina

Oleksandra is a Master's student in International Security at Sciences Po Paris, specializing in Global Risks and European Studies. She was previously the leader of the Ukraine Working Group 2025, based in Washington, DC, that brought together young people to develop Ukraine's post-war reconstruction policy recommendations, for which they later advocated on Capitol Hill. Many of their policies focused on fostering economic stability and development. Oleksandra also hosted the Ukraine Security Conference at the Elliott School of International Affairs, where experts discussed the future of the transatlantic partnership in response to the war in Ukraine.

Water might not be the first association that comes to our minds when we hear the word "energy." Nevertheless, in the Russian illegal war in Ukraine, their connection is clear – both are part of the critical energy infrastructure. Water is needed for most of the types of energy production and cooling-down processes in electricity generation, while energy supply is crucial for the functioning of other types of critical infrastructure – such as hospitals and communications centers – as well as water supply through pumping in urban systems, wastewater treatment, and central heating.[116] The Water Conflict Chronology has reported over 80 water-related conflicts in Ukraine since the start of the Russian full-scale invasion in 2022.[117] The database makes the distinction in the type of attacks between: 1) water is a "trigger," 2) water is a "weapon," and 3) water is a "casualty."[118] Russia uses all three of them, either combined or separately. In this case study, I look at the example and the impact of Russian attacks on Ukraine's energy and water infrastructure, and the interconnectedness of these systems.

In its illegal war on Ukraine, Russia uses the tactics of "exhaustion," also known as "attrition."[119]

This tactic consists of targeting civilian and energy infrastructure and, in so doing, "exhausting" civilian society, so that the country would be forced to surrender. This winter, millions of Ukrainians have been left without electricity, heating, and often water supply, with blackouts lasting more than 16 hours, while record-breaking temperatures outside reach -26 Celsius.[120] Before the start of the full-scale invasion in 2022, more than half of Ukraine's electricity generation came from the nuclear power plants, while hydropower accounted for an estimated 10%.[121] Ukraine's production capacities have significantly dropped since then, but these sectors remained dominant in 2025 with the addition of thermal electricity.[122] For both types of energy generation, water remains an essential component. Hydroelectric power can be produced thanks to the moving water.[123] Nuclear reactors can generate electricity through boiling or pressurized water

[116] Sophie Lambroschini, "Water in the War in Ukraine: between Mobilization and Collapse," Books & Ideas, effective February 11, 2025, https://laviedesidees.fr/Water-in-the-War-in-Ukraine-between-mobilization-and-collapse.

[117] "Water Conflict Chronology," Pacific Institute, accessed February 22, 2026, https://www.worldwater.org/conflict/list/.

[118] Oleksandra Shumilova, Klement Tockner, Alexander Sukhodolov, et al., "Impact of the Russia–Ukraine armed conflict on water resources and water infrastructure," *Nature Sustainability* 6, no. 5 (2023): 578, https://doi.org/10.1038/s41893-023-01068-x.

[119] Aurelian Raţiu, Silviu Nate and Ilie-Andrei Broscăreanu, "The Russian-Ukrainian Conflict - The Irregular Approach as a War of Attrition," *International conference Knowledge-based organization (KBO)*, Nicolae Balcescu Land Forces Academy, 31, no. 1 (2025): 177-183, https://doi.org/10.2478/kbo-2025-0022.

[120] "Freezing on the front line: The Ukrainians struggling to survive in -26C cold with scarce food and no power," Independent, effective February 11, 2026, https://www.independent.co.uk/news/world/europe/russia-ukraine-invasion-peace-talks-power-outage-food-b2917971.html.

[121] Maciej Zaniewicz and Danylo Moiseienko, "Ukraine's Energy Sector is a Key Battleground in the War with Russia," Brookings, effective October 7, 2025, https://www.brookings.edu/articles/ukraines-energy-sector-is-a-key-battleground-in-the-war-with-russia/.

[122] Zaniewicz and Moiseienko, "Ukraine's Energy Sector."

[123] "Hydropower Explained," U.S. Energy Information Administration, last modified April 20, 2023, https://www.eia.gov/energyexplained/hydropower/.

reactors, where, in both types, boiled water is used to make steam, which has to be cooled afterward.[124]

As mentioned earlier, water is crucial for the operation of any nuclear power plant. On June 6, 2023, Russia breached the Kakhovka Dam in Eastern Ukraine, which was also used for the water provision to the Zaporizhzhia nuclear power plant in the Eastern part of Ukraine.[125] The water released from the Kakhovka Dam accounted for 73% of its original volume of 18.3 km^3.[126] It resulted in extensive downstream flooding with freshwater and pollutant releases, killing many riverine, estuarine, and marine populations in the Black Sea.[127] The drainage of the Khakovka Reservoir had an immediate ecological impact, with the loss of 11,400 tons of fish and abnormal quantities of various bacteria, both in the area of the dam and the Black Sea through the interconnectedness of the water inflows.[128] The attack resulted in dozens of deaths and large damage, submerging 620 km^2 of four Ukrainian regions.[129] It had a direct impact on the electricity, with an immediate loss of 350 MW of hydro generation capacity in the region.[130] The disaster had direct implications for the agricultural sector, as hectares of land, as much as 580,000, used for irrigation were lost.[131] This, in return, resulted in significant Ukrainian export shortages, while being one of the world's top exporters of stable with 46% of global exports in sunflower oil before the war in 2020.[132] We can see a direct impact of the Russian attack on the dam in the environmental, energy, and agricultural sectors, but there remains a threat of a potential secondary radioactive pollution through the uncontrolled release of radioactive material accumulated in the sediments along the Dnipro River after the Chornobyl disaster in 1986.[133]

The environmental consequences are huge not only for Ukraine but also for Europe through the connection to the European hydrological system. The Kakhovka Reservoir supports one of the largest irrigation canals in Europe, measuring more than 1,600 kilometers in length.[134] Moreover, Ukraine is also connected to European water flows through two major ways: the Danube River Basin and the Black Sea, which is continuously under the Russian attacks and which flows into the Mediterranean Sea through the Bosphorus. Two percent of the Ukrainian rivers also flow into the Baltic Sea.[135]

Another important point of the discussion is nuclear energy, and the potential risks due to the war, as well as the impact of the Kakhovka disaster discussed earlier. The cooling systems of the Zaporizhzhia nuclear power plant, the largest in Europe and the ninth in the world, rely heavily on water from Kakhovka.[136] While currently under the Russian occupation, it is hard to know the real state of the reactors, whether they are cooled enough, and if all

[124] "How it Works: Water for Nuclear," Explainer, Union of Concerned Scientists, last modified July 15, 2013, https://www.ucs.org/resources/water-nuclear.
[125] Lei Nguyen, "The Environmental Impact of the Kakhovka Dam Explosion in Ukraine," Earth.Org, effective June 28, 2023, https://earth.org/the-environmental-impact-of-the-kakhovka-dam-explosion-in-ukraine/.
[126] Yuriy Kvach, Carol A Stepien, Galyna G Minicheva, et al, "Biodiversity effects of the Russia–Ukraine War and the Kakhovka Dam destruction: ecological consequences and predictions for marine, estuarine, and freshwater communities in the northern Black Sea," *Ecological processes* 14, no. 1 (2025), https://doi.org/10.1186/s13717-025-00577-1.
[127] Yuriy Kvach et al., "Biodiversity effects of the Russia–Ukraine War and the Kakhovka Dam destruction," 22.
[128] Yuriy Kvach et al., "Biodiversity effects of the Russia–Ukraine War and the Kakhovka Dam destruction," 15-21.
[129] "Two Years Since the Kakhovka Dam Destruction: EU and IOM Launch EUR 30 Million Project for Kryvyi Rih's Water System Recovery," United Nations Ukraine, effective June 6, 2025, https://ukraine.un.org/en/295827-two-years-kakhovka-dam-destruction-eu-and-iom-launch-eur-30-million-project-kryvyi-rih's#:~:text=The%20Kakhovka%20Dam%2C%20captured%20by,Mykolaiv%2C%20Dnipropetrovsk%2C%20and%20Zaporizhzhia.
[130] "Expert reaction to reported attack on Ukraine's Kakhovka dam," Science Media Centre, effective June 6, 2023, https://www.sciencemediacentre.org/expert-reaction-to-reported-attack-on-ukraines-kakhovka-dam/.
[131] Peter Gleick, Viktor Vyshnevskyi, et Serhii Shevchuk, "Rivers and Water Systems as Weapons and Casualties of the Russia-Ukraine War," *Earth's future* 11, no.10 (2023): 8, https://doi.org/10.1029/2023ef003910.
[132] "Ukraine's food exports by the numbers," Food, Water, and Clean Air, World Economic Forum, last modified June 3, 2025, https://www.weforum.org/stories/2022/07/ukraine-s-food-exports-by-the-numbers/.
[133] Shumilova et al., "Impact of the Russia–Ukraine armed conflict on water resources and water infrastructure," 580.
[134] Nadja Neumann, "War in Ukraine threatens freshwater resources and water infrastructure," IGB, effective March 2, 2023, https://www.igb-berlin.de/en/news/war-ukraine-threatens-freshwater-resources-and-water-infrastructure.
[135] Neumann, "War in Ukraine."
[136] Calla Wahlquist and Donna Lu, "Zaporizhzhia nuclear power plant: everything you need to know," The Guardian, effective March 4, 2022, https://www.theguardian.com/world/2022/mar/04/zaporizhzhia-nuclear-power-plant-everything-you-need-to-know.

the safety measures are followed. Russia has previously denied access for the International Atomic Energy Agency's experts, under the international agreements, such as the IAEA Safeguards Agreements and Additional Protocols, to the inspection of the occupied nuclear facilities.[137] The experience of the Chornobyl disaster increases concerns. Following the explosion in 1986, a large amount of radiation spread throughout Ukraine and the rest of Europe, both through the wind and water flows. In the context of the current war, Russians continuously target the Chornobyl power plant, increasing the possibility of a nuclear threat.[138] While attacks on the nuclear power plants are prohibited under the 1977 First Additional Protocol (AP I), and the 1977 Second Additional Protocol (AP II) to the Geneva Conventions of 1949 – the main legal document in case of an armed conflict – Russia has repeatedly violated international agreements.[139]

With this case study, I argue that the Russian breach of the Kakhovka Dam in Ukraine can be considered the crime of ecocide.[140] While it has been two and a half years since the attack, we can still observe its impact, primarily through water access, environmental indicators, and agricultural and irrigational processes. Russia has not stopped its attacks on the energy and water infrastructure in Ukraine, which are extremely vulnerable in the winter. These attacks result in serious disruptions, which in turn lead to continuous blackouts and water supply shortage which have become a reality for many Ukrainians. Russian tactics of "exhaustion" through attacks on the civilian and critical infrastructure have shown that electricity and water are often used as a sabotage technique and are a part of both hybrid and regular warfare. While Ukraine is a primary target, Russian hybrid warfare has gone beyond the territory of Ukraine, with numerous cases of hybrid attacks on the European energy and other critical infrastructure, including cyberattacks, and is likely to increase.[141]

The topic of the use of energy and water infrastructure as a weapon in an armed conflict cannot be fully covered in a single case study, where further implications have to be studied. This article aimed to provide an overview of examples where water and energy can be used as "weapons" in an armed conflict and their potential risks. The Russian illegal war in Ukraine has shown that while we often take energy and water for granted, they can be used as a weapon against the civilian population. ■

---

[137] Diana Khalilova, "IAEA experts can't access 3 reactor halls at Russian-occupied Zaporizhzhia nuclear plant," *The Kyiv Independent*, January 4, 2024, https://kyivindependent.com/iaea-experts-cant-access-3-reactor-halls-at-russian-occupied-zaporizhzhia-nuclear-plant/.

[138] "Ukraine: Chernobyl nuclear power plant hit by Russian drone strike," *Le Monde*, effective February 15, 2025, https://www.lemonde.fr/en/international/article/2025/02/15/ukraine-chernobyl-nuclear-power-plant-hit-by-russian-drone-strike_6738194_4.html.

[139] Abby Zeith and Eirini Giorgou, "Dangerous forces: the protection of nuclear power plants in armed conflict," *ICRC*, October 18, 2022. https://blogs.icrc.org/law-and-policy/2022/10/18/protection-nuclear-power-plants-armed-conflict/.

[140] Armenak Ohanesian, "Holding Russia Accountable for the Crime of Ecocide in Ukraine," *Kennan Institute*, April 11, 2023, https://www.wilsoncenter.org/blog-post/holding-russia-accountable-crime-ecocide-ukraine.

[141] Charlie Edwards, "Russia's hybrid war in Europe enters a dangerous new phase," The International Institute for Strategic Studies, November 26, 2024, https://www.iiss.org/online-analysis/online-analysis/2024/11/russias-hybrid-war-in-europe-enters-a-dangerous-new-phase/.

Case Studies

The Unequal Burdens of the Green Energy Transition: Water Extractivism in Salar de Atacama, Chile

Sophie Schut

Sophie is a graduate student in Environmental Policy at Sciences Po. She graduated from University College Utrecht with a major in political science and human geography. She is currently writing her master's thesis on inland fisheries in Indonesian peatlands through the lens of political ecology. Simultaneously, she is working in the water team of the Sciences Po Sufficiency Lab. She has previously had research internships at environmental NGOs, such as Tropenbos Indonesia and Indigenous Livelihood Enhancement Partners.

In the context of the green energy transition, lithium demand is increasing to support electrification.[142] To this end, mining has intensified in the Lithium triangle, a region of salt flats with large lithium-bearing brine reserves in the Andes between Chile, Argentina, and Bolivia.[143] Exploring lithium mining in Salar de Atacama (SdA), a 3,000 square-kilometre salt flat in northern Chile, this case study shows how lithium mining companies have overexploited water sources in SdA, with severe impacts for ecosystems and local livelihoods. In doing so, the case highlights how "green" narratives have been mobilised to legitimise lithium mining projects, creating unequal burdens in the face of the green energy transition.[144]

Hydrological and Ecological Burdens

With current available technologies, lithium extraction from brine is one of the most profitable techniques.[145] Lithium bearing brine is pumped up from aquifers into large evaporation ponds, where the exposure to the sun and low humidity create a fast rate of evaporation. Hence, mining companies in SdA have branded lithium mining as a sustainable process, where natural conditions are simply enhanced, allowing it to be cost effective and energy efficient.[146]

Within the SdA, there are two mining companies. SQM Salar, a subsidiary of the Chilean mining company SQM, which is authorised to extract around 1,600 litres of brine per second alongside 240 litres of freshwater. Albemarle Corporation, a US-based mining company, is authorised to extract approximately 442 litres of brine and 23.5 of freshwater per second.[147] Within this context, brine is framed both within law and by companies as a mineral, thereby not recognising that brine extraction is also a form of water extraction.[148]

The sustainability of lithium mining has been disputed by ecologists and hydrologists. An increasingly large body of scientific evidence is showing that the Lithium industry has significantly impacted the groundwater levels.[149] This has a significant impact on surrounding lagoons and wetlands such as the Soncor and Quelana, that are

[142] Ingrid Garcés and Gabriel Alvarez, "Water Mining and Extractivism of the Salar de Atacam, Chile," July 29, 2020, 189–99, https://doi.org/10.2495/EID200181.
[143] Daniela Soto Hernandez and Peter Newell, "Oro Blanco: Assembling Extractivism in the Lithium Triangle," The Journal of Peasant Studies 49, no. 5 (2022): 945–68, https://doi.org/10.1080/03066150.2022.2080061.
[144] Hernandez and Newell, "Oro Blanco."
[145] Bárbara Jerez, Ingrid Garcés, and Robinson Torres, "Lithium extractivism and water injustices in the Salar de Atacama, Chile: The colonial shadow of green electromobility," Political Geography 87 (2021): 102382, https://doi.org/10.1016/j.polgeo.2021.102382
[146] Hernandez and Newell, "Oro Blanco."
[147] Cristián Flores Fernández and Rossella Alba, "Water or Mineral Resource? Legal Interpretations and Hydrosocial Configurations of Lithium Mining in Chile," Frontiers in Water 5 (2023): 1075139, https://doi.org/10.3389/frwa.2023.1075139.
[148] Jerez, Garcés, and Torres, "Lithium extractivism and water injustices," 102382.
[149] Wenjuan Liu et al., "Spatiotemporal Patterns of Lithium Mining and Environmental Degradation in the Atacama Salt Flat, Chile," International Journal of Applied Earth Observation and Geoinformation 80 (2019): 145–56; Beatriz Bustos-Gallardo et al., "Harvesting Lithium: Water, Brine and the Industrial Dynamics of Production in the Salar de Atacama," Geoforum 119 (2021): 177–89.

fed by the groundwater.[150] Lowering water tables have also been related to drying streams in dry season. Furthermore, because brine and freshwater are layered within the aquifer, the extraction of brine can cause freshwater to be drawn downward.[151] This has resulted in changing salinity levels of surface water, affecting both ecosystems and irrigation systems.[152]

Engagement under Green Imperative

Within Chile's National Lithium Strategy (2023) lithium is framed as a way to contribute to the global green economy and as a sustainable development opportunity, helping to develop infrastructure, provide jobs, and benefit sharing mechanisms with remote communities.[153] It particularly highlights the importance of consulting Indigenous communities and their Free Prior and Informed Consent (FPIC), in line with the International Labour Organisation (ILO) convention 169. Despite these supposed benefits and increased emphasis of sustainability, engagement between communities in the SdA and lithium mining corporations have been contested.[154]

Even though there are official procedures in place to ensure community consultations, these processes have not meaningfully involved the Atacameño people.[155] The Consejo de Pueblos Atacameños (CPA), a council representing 18 Indigenous communities, have filed multiple lawsuits against SQM and Chile's development agency for insufficient FPIC. Despite this, cancelling long-term concessions to SQM and Albemarle are not discussed by the government. Instead consultations are limited to discussions of benefit-sharing and compensation schemes.[156] In 2018, such consultations even led to a contested agreement that allowed SQM to expand its extraction rights. Thus, FPIC has primarily been used as a tool to legitimise the lithium agenda.

Some Atacameño have expressed that they believe that the state and corporations will not halt the lithium extraction despite lack of indigenous community support.[157] They have therefore shifted their strategy to lobby for enhanced regulation and strategically engage with lithium corporations to extract maximum benefits from the corporations, so that "when the company dries up the salt flat, they won't be here anymore, so hopefully they leave behind good schools for the coming generations".[158] For example, in 2018, the CPA entered into an agreement with Albemarle, to share 3.5% of sales to be used for public services such as infrastructure or education.[159] Yet, such agreements have also been disputed within the CPA, as some argue that entering into such agreements is a form of condoning lithium mining, and by extension the destruction of wetlands.[160]

---

150 Andreas Link et al., "Toward a Localized Water Footprint of Lithium Brine Extraction: A Case Study from the Salar de Atacama," Water 17, no. 22 (2025): 3311.

151 MA Marazuela et al., "Hydrodynamics of Salt Flat Basins: The Salar de Atacama Example," Science of the Total Environment 651 (2019): 668–83.Marazuela et al., "Hydrodynamics of Salt Flat Basins: The Salar de Atacama Example"; Garcés and Alvarez, "Water Mining and Extractivism of the Salar de Atacam, Chile."

152 MA Marazuela et al., "Hydrodynamics of Salt Flat Basins: The Salar de Atacama Example," Science of the Total Environment 651 (2019): 668–83.Marazuela et al., "Hydrodynamics of Salt Flat Basins: The Salar de Atacama Example"; Garcés and Alvarez, "Water Mining and Extractivism of the Salar de Atacam, Chile."

153 Isabella R. Whelan, "Complexities of Community Consultation in Chile's Lithium Industry" (honors thesis, Colby College, 2023), https://digitalcommons.colby.edu/honorstheses/1426/

154 Mauricio Lorca et al., "Mining Indigenous Territories: Consensus, Tensions and Ambivalences in the Salar de Atacama," The Extractive Industries and Society 9 (March 2022): 101047, https://doi.org/10.1016/j.exis.2022.101047.

155 Ramón Balcázar M. and Melisa Argento, "From Socio-Environmental Conflict to Responsible Lithium Mining: Understanding the Governance of Dispossession from the Salt Flats of Chile and Argentina," The Extractive Industries and Society 25 (March 2026): 101724, https://doi.org/10.1016/j.exis.2025.101724.

156 Cristián Flores Fernández, "Beyond Extractivist Logic? Contested Dynamics of Lithium Frontier Expansion in Chile," Energy Research & Social Science 122 (April 2025): 104029, https://doi.org/10.1016/j.erss.2025.104029.

157 D. Soto-Hernández, Lithium Extraction in Chile: Ontological, Ecological and Economic Dimensions (London: Taylor & Francis, 2025).

158 Ciaran O'Faircheallaigh and Sally Babidge, "Negotiated Agreements, Indigenous Peoples and Extractive Industry in the Salar de Atacama, Chile: When Is an Agreement More than a Contract?," Development and Change 54, no. 3 (2023): 641–670; D. Soto-Hernández, Lithium Extraction in Chile: Ontological, Ecological and Economic Dimensions (London: Taylor & Francis, 2025).

159 D. Soto-Hernández, Lithium Extraction in Chile: Ontological, Ecological and Economic Dimensions (London: Taylor & Francis, 2025).

160 D. P. Soto, The Energy Transition and Lithium Extraction in Chile: Decolonising Resource-Making in the Salar de Atacama Basin (PhD diss., University of Sussex, 2023), University of Sussex research repositoryhttps://sussex.figshare.com/articles/thesis/The_energy_transition_and_lithium_extraction_in_Chile_decolonising_resource-making_in_the_Salar_de_Atacama_basin/24259660.

Implications of the SdA

In the SdA, Lithium companies have intensified their extraction, without substantial FPIC from communities. New procedures for community involvement and benefit sharing have simply served to legitimize the status quo. Simultaneously, this case study shows how uncertainty in ecological and hydrological knowledge can be mobilised to legitimise extraction. Corporations continue to claim that they are extracting brine, which they argue has no other uses and minimally impacts the ecosystem. In the face of controversy, it is important to take precautions against the potential harm done and take seriously the observations of the CPA. ■

PART III

Critical Essays

Behind the Cloud: Water, Power, and Digital Extraction

Marie-Alix Depuydt

Marie-Alix is a Young Associate at the OECD in the Environment Directorate, where she works on AI policy and the quantitative measurement of environmental services and impacts. Her work focuses on how digital infrastructure, data, and emerging technologies intersect with climate governance, sustainability metrics, and public policy design. She holds a joint honours degree in Political Science and International Development with a minor in Economics, and my academic research has explored energy transitions, climate finance, and the political economy of sustainability. Alongside professional work she has led international student initiatives including TEDx and Model United Nations conferences. She is particularly interested in applied policy solutions that bridge technological innovation, environmental integrity, and economic governance.

Disclaimer: *The views expressed in this essay are solely those of the author and do not necessarily reflect the views or positions of any affiliated institutions.*

Today's economy runs on systems largely immaterial and invisible to users.[161] Cloud computing, artificial intelligence (AI), 5G networks and the Internet of Things (IoT) now form the backbone of modern life.[162] At the center of this system are data centers. Data centers are composed of servers, memory drives, high-bandwidth networks, cooling systems and backup power systems.[163] Far from operating invisibly, data centers rely on vast and continuous inputs of electricity and water to maintain hardware reliability and operational efficiency.[164] Their location is a key decision as meteorological factors and proximity to key data consumers, most notably the US, must be considered.[165] This is particularly evident in the United States, which remains the industry's gravity well; it not only hosts nearly half of all global facilities but is also the headquarters for the 'Big Three' providers who control 59% of world hyperscale capacity. Consequently, siting decisions are often tethered to U.S. infrastructure and regulatory norms, even as the environmental risks are distributed globally.

Since Chat-GPT was released to the public in 2022, daily individual use has skyrocketed, exacerbating the intensifying pressure on the already limited resources: water and energy. Compared to a single google search, which requires half a milliliter of water, ChatGPT-4 and similar generative AI platforms consume 519 millimeters of water for each 100-word email generated, according to The Washington Post (although this figure largely depends on the data center's location).[166] To counter the fact that they add pressure on two already constrained resources, big tech companies have positioned their digital architectures as necessary tools for economic, social and political progress, especially for governments of developing countries.

[161] De Freitas, Marcus Vinícius. "AI Data Centers and Energy Demands." Policy Center for the New South, October 2025. https://www.policycenter.ma/sites/default/files/2025-10/PP_38-25%20%28Marcus%20Vini%CC%81cius%20De%20Freitas%29.pdf.

[162] Al Kez, D., A. M. Foley, F. W. Hasan Wong, A. Dolfi, and G. Srinivasan. "AI-Driven Cooling Technologies for High-Performance Data Centres: State-of-the-Art Review and Future Directions." *Sustainable Energy Technologies and Assessments* 82 (2025): 104511.

[163] International Energy Agency. "Energy and AI." Accessed January 20, 2026. https://iea.blob.core.windows.net/assets/601eaec9-ba91-4623-819b-4ded331ec9e8/EnergyandAI.pdf.

[164] Al Kez, D., A. M. Foley, F. W. Hasan Wong, A. Dolfi, and G. Srinivasan. "AI-Driven Cooling Technologies for High-Performance Data Centres: State-of-the-Art Review and Future Directions." Sustainable Energy Technologies and Assessments 82 (2025): 104511.

[165] McGovern, Gerry, and Sue Branford. "AI Data Center Revolution Sucks Up World's Energy, Water, Materials." Mongabay, November 14, 2025. https://news.mongabay.com/2025/11/ai-data-center-revolution-sucks-up-worlds-energy-water-materials/.

[166] Ovide, Shira. "Energy AI Use Electricity Water Data Centers." *The Washington Post*, September 18, 2024. https://www.washingtonpost.com/technology/2024/09/18/energy-ai-use-electricity-water-data-centers/.

Behind the Cloud: Water, Power, and Digital Extraction

These dynamics increasingly resemble older forms of extractive processes, historically associated with colonial plantation systems, such as tobacco, cotton, coffee and sugar production, which supplied Global North consumption while concentrating environmental degradation and resource depletion in producing regions. In today's digital world, the framing used by tech corporations has rewarded them with preferential tax treatment, expedited permitting and regulatory exemptions, particularly in countries like Mexico.[167] The resulting localisation inherently externalises energy and water costs to local communities that host the infrastructure, while the economic and informational value generated accrues elsewhere.[168] In this sense, the expansion of data centers and related infrastructure can be seen as the reproduction of extractive logics, in which environmental burdens are geographically displaced to sustain consumption and innovation in the Global North.[169]

Although data centres are promoted as catalysts of digital progress, their siting and cooling system choices effectively outsource water and energy risks to already stressed communities, reproducing extractive logics under the banner of 'critical infrastructure'. For example, in Chile, Google's attempt to use potable groundwater for cooling all whilst a decade-long drought sparked fierce legal battles, illustrating how digital progress can effectively outsource environmental risk to the local communities least equipped to handle it.[170] This essay thus explores how data centre expansion in water-stressed regions, notably Mexico, restructures local water and energy governance, and to what extent this can be read as a new form of data colonialism.

2. The Materiality of the Cloud: Cooling, Energy, and Water Dependence

The large amount of infrastructure allowing data centers to function creates fixed environmental demands that bind data centres to local water and energy systems, transforming abstract digital services into geographically locked resource users. Cooling systems are central to data center operations, ensuring that servers remain within optimal temperature ranges allowing backup power systems to function reliably.[171]

Water usage can be divided into three groups: on-site water for data center cooling, off-site water for electricity generation and supply chain water for server manufacturing.[172] On-site water used for cooling, which consumes approximately 40% of total energy consumption,[173] is particularly difficult to recycle due to contamination from minerals and chemical additives, rendering it non-potable.[174] Accounting for all three scopes, the IEA estimates that an average 100 MW data center consumes 2 million liters of water a day, equivalent to 6,500 households.[175]

Cooling is typically achieved either through evaporative air cooling, which is water-intensive, or through more expensive liquid cooling systems. Both increase water demand, which increases risks, threatening global and national water security, especially in areas of existing water stress. Currently, 68% of data centers globally are located near

[167] Diaz-Cortes, Anayansi. "Data Centres Lured to Mexico Can Avoid Environmental Reporting." *Context*. Accessed January 20, 2026. https://www.context.news/ai/data-centres-lured-to-mexico-can-avoid-environmental-reporting.
[168] Li, Sen, and Chunyu Guo. "Local Externalities of Generative AI Infrastructure." SSRN. Accessed January 20, 2026. https://ssrn.com/abstract=5520874.
[169] McGovern, Gerry, and Sue Branford. "AI Data Center Revolution Sucks Up World's Energy, Water, Materials." *Mongabay*, November 14, 2025. https://news.mongabay.com/2025/11/ai-data-center-revolution-sucks-up-worlds-energy-water-materials/.
[170] News, PBS. 2024. "Google to Pause Plans for Big Data Center in Chile over Water Worries." PBS News. September 17, 2024. https://www.pbs.org/newshour/world/google-to-pause-plans-for-big-data-center-in-chile-over-water-worries.
[171] Ren, Shaolei, and Fangxin Wang. "The Water Footprint of Data Centers." *arXiv*, April 7, 2023. https://arxiv.org/pdf/2304.03271.
[172] *Ibid.*
[173] Al Kez, D., A. M. Foley, F. W. Hasan Wong, A. Dolfi, and G. Srinivasan. "AI-Driven Cooling Technologies for High-Performance Data Centres: State-of-the-Art Review and Future Directions." *Sustainable Energy Technologies and Assessments* 82 (2025): 104511.
[174] Sustainable ICT Blog (UK Government). "AI's Thirst for Water." September 17, 2025. https://sustainableict.blog.gov.uk/2025/09/17/ais-thirst-for-water/.
[175] International Energy Agency. "Energy and AI." Accessed January 20, 2026. https://iea.blob.core.windows.net/assets/601eaec9-ba91-4623-819b-4ded331ec9e8/EnergyandAI.pdf.

protected areas or Key Biodiversity Areas, which depend on clean water supplies for the survival of ecosystems and communities living there.[176] This paper conceptualises this as *water leakage,* a take on carbon leakage: the geographic displacement of water-intensive digital production from consumption centres to water-stressed regions, without corresponding accountability or compensation. By the end of the decade, it is projected that demand for water will exceed supply by 40% globally, driven by increased data center infrastructure.[177] In the face of backlash, and also in order to achieve net-zero targets, alternatives, including closed-loop, free, or immersion cooling, all of which reduce water dependence, have become increasingly feasible.[178] These will become important especially in the face of extreme heat, as higher ambient temperatures create higher cooling demands, leaving data centres located in hot and water-stressed regions facing disproportionately higher water and electricity burdens than equivalent facilities in temperate climates. This renders location an inherently political rather than purely technical choice.

3. Asymmetric Incentives in the Global South

The digital revolution Latin America is experiencing, also referred to as the 'gold rush of the 21st century' by the World Economic Forum, offers a vast array of tangible economic benefits.[179] Hosting a regional or hyperscale data center can help a local economy attract foreign direct investment in other adjacent industries, including cloud services, fintech, e-commerce and AI; boosting overall competitiveness across the sector.[180] It can also generate local strategic capacities, create well-paid and highly skilled jobs and enhance national security resilience.[181]

To accommodate the increased demand levels globally, large technology companies like Google, predominantly from the United States (US), are increasingly targeting less exploited regions, notably Latin America, drawn by vast natural resources, cheaper energy and governments willing to provide industrial policy incentives such as tax exemptions in hopes of securing future growth.[182] Yet, these regions remain among the least prepared for AI use, according to an Oxford Insights assessment.[183] Generally, countries across the Global South risk being exploited for their source of cheap labour and essential raw material to support the wealthier technological powers.[184]

Tech companies have mobilised what scholars have coined "weaponised temporality", constructing narratives of inevitability and obscuring the extractive realities behind AI infrastructure.[185] As a result, local communities increasingly bear the cost of the actions of private industry actors while foreign firms gain control over critical domestic infrastructure. This, in the long term, may raise concerns over both sovereignty and inequality, as governments may be left with little recourse if a foreign power decides to cut access or seize information.[186]

---

[176] Sustainable ICT Blog (UK Government). "AI's Thirst for Water." September 17, 2025. https://sustainableict.blog.gov.uk/2025/09/17/ais-thirst-for-water/.

[177] Harvey, Fiona. "Global Water Crisis Food Production at Risk." *The Guardian*, October 16, 2024. https://www.theguardian.com/environment/2024/oct/16/global-water-crisis-food-production-at-risk.

[178] Digital Realty. "Future of Data Center Cooling." Accessed January 20, 2026. https://www.digitalrealty.com/resources/articles/future-of-data-center-cooling.

[179]Alameer. "Data Centre Gold Rush AI." 22 April 2025. https://www.weforum.org/stories/2025/04/data-centre-gold-rush-ai/.

[180] *Ibid.*

[181] Erickson, Amanda. "Latin America's Data Center Gold Rush Comes with Some Big Risks." *Bloomberg Opinion*, June 18, 2025. https://www.bloomberg.com/opinion/articles/2025-06-18/latin-america-s-data-center-gold-rush-comes-with-some-big-risks.

[182] Millington, Isabella. "Many Latin Americans Living Near Data Centers Do Not Feel Welcome in the Future." *Tech Policy Press*. Accessed January 20, 2026. https://www.techpolicy.press/many-latin-americans-living-near-data-centers-do-not-feel-welcome-in-the-future/.

[183] Yu et al. "AI Divide Global North Global South." 16 January 2023. https://www.weforum.org/stories/2023/01/davos23-ai-divide-global-north-global-south/.

[184] Radwan, Ahmad. "Digital Colonialism: The Global South Facing Closed Screens." Al Jazeera Journalism Review, December 31, 2024. https://institute.aljazeera.net/en/ajr/article/2962.

[185] "Critical Minerals Workshop Summary Report." Institute for Advanced Study. Accessed January 20, 2026. https://ias.edu/sites/default/files/Critical-Minerals-Workshop_Summary-Report.pdf.

[186] M. Shahzaib Hassan, "Digital Colonialism: How Data Empires Are Rewriting Global Sovereignty," Modern Diplomacy, June 6, 2025, https://moderndiplomacy.eu/2025/06/06/digital-colonialism-how-data-empires-are-rewriting-global-sovereignty/.

Regulatory divergence amplifies these patterns. In the US, regulatory pressures are rising around stormwater runoff, contaminants and aging infrastructure is projected to cost $744 billion over the next two decades in repairs, making relocation of water-intensive activities increasingly attractive. Thus, it could be assumed that the recent developments in neighboring Latin American countries are not accidental.[187] Furthermore, countries including both Brazil and Mexico, for instance, do not have the same reporting requirements for emissions and electricity consumption as the EU, the UK or parts of North America, lowering compliance costs and lobbying pressures and hence further incentivising tech companies from settling in weaker governance environments.[188]

However, in the long term, it is expected that water and energy challenges will overpower the overall benefits brought by the sector. Investment could be slowed by bureaucratic licensing and permitting delays, and challenges in water stressed and energy-constrained regions will only intensify. Although firms increasingly acknowledge these risks, with Microsoft reporting in 2023 that 42% of its water came from water stressed regions and Google that 15% of its water consumption occurred in areas with "high water scarcity", it has not prevented them from continued expansion.[189] Instead, profit-maximising firms remain primarily accountable to shareholders, while governments bear responsibility for the long-term welfare of their citizens, creating misalignment between short-term incentives and long-term social costs.[190]

4. Case Study: Querétaro and the Externalization of Scarcity

As the US's neighbor, Mexico's business-friendly environment and entrepreneurial culture has made the country prime for foreign direct investment, especially with the recent fixation on near- or friend-shoring. Specifically, Mexico's central state of Querétaro in the Bajío region has been approached by various US tech firms in the hopes of establishing data centers. Possessing both oil and gas fields, wind and solar resources and critical minerals[191], low natural disaster risk and cheap land costs, it serves as the optimal region for American companies to operate. However, two-thirds of the country is arid or semi-arid, with water only available in limited quantities depending on the season and regional factors.[192]

Against this backdrop, major tech firms are expanding their footprints; notably, CloudHQ recently unveiled plans for a record-breaking 900 MW hyperscale campus designed for both cloud and AI workloads.[193] Microsoft, which already operates in the datacenter region, along with AWS and Google, solely cool its systems with direct outdoor air 95% of the year, theoretically requiring zero water, the remainder of the year, evaporative cooling is used - consuming 40 million liters of water.[194] All of this digital infrastructure grants Mexico the position as the second largest data center market in Latin America. However, as discussed earlier, the repurposing of water is a more energy-intensive process, raising energy demands regionally.[195] In addition, upcoming projects are expected to amount to 600 MW of installed capacity, compared to 160

[187] Brookings Institution. "AI Data Centers and Water." Accessed January 20, 2026. https://www.brookings.edu/articles/ai-data-centers-and-water/.
[188] International Energy Agency. "Energy and AI." Accessed January 20, 2026. https://iea.blob.core.windows.net/assets/601eaec9-ba91-4623-819b-4ded331ec9e8/EnergyandAI.pdf.
[189] Niranjan, Ajit. "Big Tech Datacentres Water." The Guardian, April 9, 2025. https://www.theguardian.com/environment/2025/apr/09/big-tech-datacentres-water.
[190] "Big Tech's Invisible Hand." Agência Pública. Accessed January 20, 2026. https://apublica.org/especial/big-techs-invisible-hand/.
[191] Wood. "Addressing Northern Mexico's Water-Energy Nexus." 8 July 2025. https://www.weforum.org/stories/2025/07/addressing-northern-mexicos-water-energy-nexus/.
[192] Javier Meza Ávila et al., "An Overview of Modeling Efforts of Water Resources in Mexico: Challenges and Opportunities," *Environmental Science & Policy* 137 (2022): 180–91, https://doi.org/10.1016/j.envsci.2022.07.005.
[193] "CloudHQ to Invest $4.8 Billion to Build Mexico Data Centers." Reuters, September 25, 2025. https://www.reuters.com/world/americas/cloudhq-invest-48-billion-build-mexico-data-centers-2025-09-25/.
[194] BBC News. "Data Centres Expand Their Lead over Households in Race for Water." Accessed January 20, 2026. https://www.bbc.com/news/articles/cx2ngz7ep1eo.
[195] Weston, Phoebe, and Nina Lakhani. "Mexico Datacentre: Amazon, Google, Querétaro Water." The Guardian, September 25, 2024.https://www.theguardian.com/global-

MW of existing capacity, although the latter is a very conservative projection.[196]

To power this infrastructure, the water extracted comes from the San Juan del Río Valley aquifer, a water source that is overexploited and already has a deficit of 56.9 million liters.[197] The government granted Microsoft a permit allocating 25 million liters annually and access to extract water from the aquifer for at least the next 13 years for its data center activities. This extra water consumption creates a water rationing system, or *el tandeo*, which has now become routine, leaving many households going days without running clean water.[198] This problem is exacerbated by the role played by the government, who has allowed big tech companies to bypass environmental reporting requirements and taxes.[199] Data centers are not classified as an industry but rather as service providers, granting them exemption from providing environmental impact reports as their activities are not considered fixed sources of emissions.[200] On top of this, tech companies are also exempt from certain greenhouse gas emission taxes, including direct and indirect sources of CO2, methane and other gases, as they are not considered fixed sources of direct emissions.[201] Even if the state questions water consumption, companies including Microsoft argue that they are solving the water crisis by creating a 'closed loop system'.[202] Yet, a recent study found that Microsoft and UN-Habitat framed data centers as solutions to water scarcity in Querétaro, despite reports identifying drought as a core challenge, while recommending only general infrastructure investments. In practice, Microsoft built data centers but made no investments in drought mitigation or local water resilience.[203] The opacity, protected by the state, leaves citizens unaware of the industry's impacts, putting local communities at a disadvantage. To further this problem, Mexico's Federal Electricity Commission (CFE) planned to expand the electrical grid capacity by 50%, primarily driven by the regional data center expansion.[204] This includes a new power station, El Sauz II, which will be powered by gas.

5. Water Leakage and Digital Colonialism

In Querétaro, the extractive dynamics of data colonialism materialise not through the physical export of commodities, but through the appropriation of local water and energy systems to sustain remote data consumption. While computational value generated by these facilities primarily serves users and firms in the United States, the environmental costs—aquifer depletion, electricity grid expansion, and increased fossil fuel dependence—remain territorially fixed within Mexico.

By hiding behind the facade of ideas like 'progress', 'productivity' and 'profit', the idea of resource capture is not dominant in discussions. Consuming scarce water that societies desperately need for drinking and agriculture has not been internalised as a cost to the tech companies. Water-scarce countries—and regions—outsource water-intensive production via trade, shifting pressure to vulnerable basins, as Lenzen et al. document in scarcity-weighted virtual water flows.[205] Data centers extend this to digital services: existing trade routes, now including AI infrastructure, convey pressure from consumption centers (US/EU queries) to regions of water scarcity (Latin American droughts). Unlike carbon's global mixing, water stays local—Querétaro's depletion funds Northern compute, with

development/2024/sep/25/mexico-datacentre-amazon-google-queretaro-water-electricity.

[196] *Ibid*.

[197] Arandia et al. "Backyard of AI: A Map of the 21st-Century Gold Rush." *Pulitzer Center*. 8 August 2025.

[198] Ayuso, Silvia, and Rodrigo Orihuela. "AI's Backyard: A Map of the 21st-Century Gold Rush." *El País*. Accessed January 20, 2026.

[199] Diaz-Cortes, Anayansi. "Data Centres Lured to Mexico Can Avoid Environmental Reporting." *Context*. Accessed January 20, 2026. https://www.context.news/ai/data-centres-lured-to-mexico-can-avoid-environmental-reporting.

[200] *Ibid*.

[201] *Ibid*.

[202] Millington, Isabella. "Many Latin Americans Living Near Data Centers Do Not Feel Welcome in the Future." *Tech Policy Press*. Accessed January 20, 2026. https://www.techpolicy.press/many-latin-americans-living-near-data-centers-do-not-feel-welcome-in-the-future/.

[203] *Ibid*.

[204] *Ibid*.

[205] Lenzen, Manfred & Bhaduri, Anik & Moran, Daniel & Kanemoto, Keiichiro & Bekchanov, Maksud & Geschke, Arne & Foran, Barney. (2012). The Role of Scarcity in Global Virtual Water Flows.

no atmospheric offset.[206]

Sociologist Michael Kwet posits that the Global South has become the 'digital veins' crossing the oceans, wiring up a tech ecosystem owned and controlled by a handful of mostly US-based corporations.[207] Although nowadays, colonisers do not invade subject states with soldiers, missionaries or trade monopolies, they instead are coming with cloud services, proprietary software and algorithmic governance, serving the role of deepening Global South countries dependence on Western technological infrastructure.[208] Water leakage operationalizes this colonialism: Querétaro starves its aquifer—all while computed value flows transatlantic, echoing tobacco, cotton, coffee and sugar plantations feeding Western tastes. Now, big tech seems to be exporting environmental harm by convincing countries that data centers are critical infrastructure that demands tax incentives and fast-tracking that bypasses climate and other environmental regulation.[209]

6. Conclusion

The expansion of data centers into Mexico and the wider Global South is not a technical necessity of the AI "gold rush" but a restructuring of territorial sovereignty. Where a single data center in a water-stressed valley uses as much water as 6,500 households, the "cloud" is no longer an abstract metaphor but a physical competitor for survival.

In order to counteract these extractive logics, a shift in governance is sorely needed. First, disclosure requirements should be standardized; tech giants cannot be protected from disclosing trade secrets all whilst depleting public aquifers. Second, water-energy impact assessments must be independent and mandatory, removing the service-provider classification that allows these facilities to bypass higher economic costs and broader scrutiny. Most importantly, we must reconsider the critical infrastructure status bestowed upon these sites. If infrastructure is truly critical, it must serve the public good of the host community-not just the low-latency requirements of a user in the Global North. Without these safeguards, the digital future will continue to rest on the same logic as the colonial past: the extraction of the South to power the innovation of the North. ■

[206] *Ibid*.
[207] Kwet, Michael. "Digital Colonialism: The Evolution of US Empire." *Longreads*, Transnational Institute. Accessed January 20, 2026. https://longreads.tni.org/digital-colonialism-the-evolution-of-us-empire.
[208] CCCB LAB. "Countering Digital Colonialism." Accessed January 20, 2026. https://lab.cccb.org/en/countering-digital-colonialism/.
[209] McGovern, Gerry, and Sue Branford. "AI Data Center Revolution Sucks Up World's Energy, Water, Materials." *Mongabay*, November 14, 2025. https://news.mongabay.com/2025/11/ai-data-center-revolution-sucks-up-worlds-energy-water-materials/.

Desalination in Kazakhstan's Industrial Mangystau and Atyrau Regions: Lifeline or Liability?

Nargiz Shantayeva

Nargiz Shantayeva is a Master's student in International Energy Transitions at Sciences Po PSIA, and an intern at the OECD Environment Directorate. Her interests and experience include decarbonization research, sustainability, and the energy transition, especially in the Central Asian region.

Zhansulu Sagynysh

Zhansulu Sagynysh is a student in Energy and Environment program at Rhein - Waal university, her professional interests are statics, analytical research and engineering.

"Desalination has tremendous allure. The thought is that if we can just get the salt out of the water, everything can be fixed. But it's a kind of siren song that will turn bad."

-R. Glennon, Professor Emeritus of Law and Water Policy Scholar, USA[210]

Introduction

Desalination, the process of removing salts and impurities from saline water to produce freshwater, is currently in active development in water-scarce Kazakhstan. In particular, the country's western regions coastal to the Caspian sea - Atyrau and Mangystau - are at the forefront of this technological rollout.[211] In Mangystau alone, six new desalination plants are under construction as of April 2025.[212] However, such rapid expansion of a technology often contested and even described as a "siren song", calls for a thorough analysis. How effective is desalination as a solution for western Kazakhstan given worsening climate change impacts, and what can be done to increase its feasibility? This article posits that although the expansion of desalination capacity in western Kazakhstan is contextualised by significant social and political needs, it also poses risks, including long-term environmental damage and escalating costs. Hence, it is red to integrate RES into co-generation or complete electricity generation within desalination, as well as explore integrating water re-use, as per a nexus-based approach to water-energy management.

Context

The Republic of Kazakhstan is the world's largest landlocked country. Its total renewable freshwater resources are estimated at 524 km^3, which is comparatively low given its vast territory.[213] These resources are also distributed unevenly, increasing structural vulnerability to water stress, particularly in such arid and industrialized regions as Mangystau

[210] Newburger, Emma. "Why Desalination Won't Save States Dependent on Colorado River Water.", CNBC, January 27, 2023. https://www.cnbc.com/2023/01/27/why-desalination-wont-save-states-dependent-on-colorado-river-water.html.

[211] EU Blue Economy Observatory. "Desalination," n.d. https://blue-economy-observatory.ec.europa.eu/eu-blue-economy-sectors/desalination_en.

[212] Qazinform.com. "President Urges Concrete Action to Address Water Scarcity in Mangistau," April 18, 2025. https://qazinform.com/news/president-urges-concrete-action-to-address-water-scarcity-in-mangistau-fb216f.

[213] Shibutov, Marat. "WATER MANAGEMENT IN KAZAKHSTAN." Industry Report. Switzerland Global Enterprise, April 2017. https://www.s-ge.com/sites/default/files/article/downloads/industry_report_kazakhstan_water_management_2017.pdf.

and Atyrau.[214] Indeed, these two regions occupy an essential position within Kazakhstan's water-energy nexus. They are simultaneously the country's oil & gas extraction hubs, and are located far from Kazakhstan's southern river runoff, depending heavily on external sources.[215] To illustrate, Atyrau and Mangystau together account for only about 13.4% of Kazakhstan's total water resources due to their geographical location.[216] This combination of external dependence and growing local demand results in serious structural drinking water deficits. Climate change further exacerbates these challenges by increasing evaporation rates, reducing river runoff, and disrupting natural freshwater renewal cycles.[217]

Against this background, the government has pursued a strategy of expansion of desalination capacity, beginning with the construction of the Caspian Desalination plant in Aktau in 2004.[218] In 2023, this was further supported with the adoption of a program to build nine new desalination plants, with a total investment of approximately 247 billion tenge (approximately €415.7 million as of January 17, 2026).[219] Today, the existing desalination plants have capacities between 5 000 and 50 000 m³/day.[220] The strategy entered its active operational phase in 2025 and aims to reduce the region's reliance on the deteriorating Astrakhan-Mangyshlak main water pipeline.[221] Kazakhstan also adopted a new water code in 2025 that, for the first time, explicitly emphasizes water security, responsible resource management, and climate change adaptation.[222] The updated legal framework is expected to strengthen national climate change adaptation efforts and improve water resource management efficiency.

Literature review

Existing literature on desalination varies significantly by the type of technology considered. For the purposes of this article, the focus will remain on membrane processes, or reverse osmosis (RO), due to its predominance in Kazakhstan, including Atyrau and Mangystau.

At the moment, RO is carried out using fossil fuel-sourced electricity, with brine disposal as an additional ecological concern. The combination of RO with renewable energy sources and alternative water governance pathways are being explored alongside innovations in membrane efficiency. Shokri and Fard (2023) quantified the potential of integrated RES-assisted water desalination systems in the water-energy nexus.[223] Madhuri et al. (2025) furthered the analysis of solar-powered desalination for sustainable freshwater solutions.[224] Particularly in Kazakhstan, Syrlybekkyzy et al. (2024) investigated the theoretical performance of desalination by solar distillation, while Ramazan et al. (2025) went further to explore site selection of wind-powered RO desalination systems in western Kazakhstan.[225,226]

---

[214] *Ibid.*
[215] Marat Karatayev et al., "The water-energy-food nexus in Kazakhstan: challenges and opportunities," *Energy Procedia*125 (September 2017): 63–70, https://doi.org/10.1016/j.egypro.2017.08.064.
[216] *Ibid.*
[217] UNDP, "The climate change impact on water resources in Kazakhstan," UNDP Kazakhstan, October 26, 2021, https://www.undp.org/kazakhstan/stories/climate-change-impact-water-resources-kazakhstan.
[218] "Программа Управления Отходами: ТОО 'Опреснительный Завод "Каспий."" Kokshetau, 2022.
[219] Azernews. "Kazakhstan Sets to Build Numerous Seawater Desalination Plants," April 29, 2023. https://www.azernews.az/region/209251.html.
[220] Azernewz, 2023; JSC NC KazMunayGas, 2025.
[221] JSC NC KazMunayGas, "Опреснительный Завод Морской Воды Кендерли Вышел На Производственную Мощность," JSC NC KazMunayGas, November 14, 2025, https://www.kmg.kz/ru/press-center/press-releases/kenderli-vyhod-na-moshchnost/.
[222] Аграрный Сектор. "10 июня в Казахстане вступил в силу новый Водный кодекс", June 10, 2025. https://agrosektor.kz/agriculture-news/10-iyunya-v-kazahstane-vstupil-v-silu-novyj-vodnyj-kodeks.html
[223] Shokri, Aref, and Mahdi Sanavi Fard. "Water-energy Nexus: Cutting Edge Water Desalination Technologies and Hybridized Renewable-assisted Systems; Challenges and Future Roadmaps." *Sustainable Energy Technologies and Assessments* 57 (April 3, 2023): 103173. https://doi.org/10.1016/j.seta.2023.103173.
[224] Madhuri, R.V.S., Zafar Said, I. Ihsanullah, and Ravishankar Sathyamurthy. "Solar Energy-driven Desalination: A Renewable Solution for Climate Change Mitigation and Advancing Sustainable Development Goals." *Desalination* 602 (January 15, 2025): 118575. https://doi.org/10.1016/j.desal.2025.118575.
[225] Syrlybekkyzy, Samal, Akmaral Serikbayeva, Botakoz Suleimenova, Lyailim Taizhanova, Baimbetov Dinmukhambet, Kamshat Jumasheva, and Farida Nurbayeva. "Study of the relation between the capacity of a heliostationary installation and climatic conditions in the Mangystau region." *Acta Innovations*. Vol. 54:01-11, 2024. https://kpi.yu.edu.kz/uploads/user_record/2025/05/27/Acta_Innovations_Q2_52_7_JDwOB7Y.pdf.
[226] Ramazan, Akhmet, Nurmaganbet Yermek, Lyailim Taizhanova, Samal Syrlybekkyzy, Nguyen Van Vu, and Mohammad Alhuyi Nazari. "Multiattribute Decision-making for Site Selection of Wind-powered Reverse Osmosis Desalination Systems in Western Kazakhstan."

This indicates that reverse osmosis has a recognised potential for sustainability improvements in Kazakhstan and in the world, including among other things through the integration of renewable energy sources into the production. This essay therefore evaluates the status quo-desalination practices in western Kazakhstan, along with a timeframe of impacts and recommendations for policymakers.

Critical discussion

Kazakhstan's decision to pursue an expansion of desalination capacities in Atyrau and Mangystau regions is justified by several sound sociopolitical rationales. The primary one is the rapid demographic expansion in Aktau, Atyrau, and rural areas of the Mangystau region. Due to a combination of economic and cultural particularities of the west, population growth in western Kazakhstan is higher-than-average, which places serious strain on existing water infrastructure.[227] For instance, Aktau's population increased from 200 000 in 2021 to approximately 270 000 in 2022, all while traditional water sources, such as groundwater and river flows, are reaching their capacity limits.[228] This inevitably translates into higher water demand, including household consumption. An additional complicating factor is the high rate of deterioration within water supply networks, reaching 71.5% in urban Mangystau alone.[229] Given the west's extensive political role as an oil & gas centre of Kazakhstan, such local resource insufficiency becomes an issue of national significance. In this context, commissioning new desalination facilities, such as the Kenderli plant, establishes new critical water reserves, mitigating the risk of shortages and supporting social stability.

Another no less important rationale is enhancing Kazakhstan's overall hydropolitical independence in the context of decreasing flows and climate change. For decades, west Kazakhstan has depended on the Astrakhan-Mangyshlak pipeline, which transports water from a tributary of the Volga River in Russia. This water source had become increasingly constrained as the pipeline deteriorated, only undergoing modernisation in December 2023.[230] Volga River Basin's precipitation levels are further reduced due to climate change, contributing to decreasing water supplies in Atyrau and Mangystau.[231] Thus, continued extensive reliance on this single transit channel under these circumstances is perceived by the government as a systemic risk to the region's development. At the same time, climate change predictions complicate Kazakhstan's water security beyond the Volga River too, as increased evaporation rates and rising temperatures are affecting water resource availability originating from upstream Central Asian states as well. For instance, on January 12, 2026 reservoirs in southern Kazakhstan reported 1.9 billion m^3 (bcm) less water than the previous year, demonstrating decreased water supply from the Syr Darya and Amu Darya river basins.[232] Therefore, given the fact that as much as 44% of the country's water resources originate from abroad, the decision to expand desalination capacity in Kazakhstan can be considered a policy aimed to strengthen hydropolitical independence from neighbouring states.[233] In this sense, desalination is not simply a solution for surging water demand, but a safeguard against diminishing supply levels and dependence on neighbours, ensuring the political and social stability of western Kazakhstan.

International Journal of Low-Carbon Technologies 20 (January 1, 2025): 1789–98. https://doi.org/10.1093/ijlct/ctaf102.

[227] Razzokov, Nodirbek. "Population growth slowed down in Kazakhstan in 2025." *OneUZ*, September 7, 2025. https://one.uz/en/news/world/20960-population-growth-slowed-down-in-kazakhstan-in-2025.html#google_vignette.

[228] Tanirbergen, Saulet. "Vanishing Sea: How Caspian Sea is Disappearing Right Before Our Eyes." *The Astana Times*, June 18, 2025. https://astanatimes.com/2025/06/vanishing-sea-how-caspian-sea-is-disappearing-right-before-our-eyes/.

[229] TengriNews. "Как в Мангистау решают проблему дефицита питьевой воды", May 28, 2025. https://tengrinews.kz/kazakhstan_news/kak-v-mangistau-reshayut-problemu-defitsita-pitevoy-vodyi-571281/

[230] Times of Central Asia. "Kazakhstan Launches Modernized Water Pipeline in Atyrau and Mangystau Regions - the Times of Central Asia." *The Times Of Central Asia* (blog), June 27, 2024. https://timesca.com/modernized-water-pipeline-launched-in-atyrau-and-mangystau-regions/.

[231] Ricci, Riccardo. "The Caspian Sea is drying up, and Kazakhstan asks Russia to collaborate in managing the Volga River." Renewable Matter, June 4, 2025. https://www.renewablematter.eu/en/caspian-sea-drying-up-kazakhstan-russia-volga-river.

[232] Pannier, Bruce. "Kazakhstan Warns of Severe Water Shortages as Syr Darya Levels Drop". The Times of Central Asia, January 14, 2026. https://timesca.com/kazakhstan-warns-of-severe-water-shortages-as-syr-darya-levels-drop/

[233] UNDP, 2021.

Desalination in Kazakhstan's Industrial Mangystau and Atyrau Regions: Lifeline or Liability?

Nevertheless, the current trajectory of desalination capacity growth in Kazakhstan is a source of serious environmental and economic concerns. The environmental risk is related to brine production and the carbon footprint of present desalination plants. Brine, as a byproduct of desalination, is characterised by high salinity and temperature, and often contains chemicals such as $AlCl_3$, NaOCl, $FeCl_3$, and H_2SO_3.[234] According to UNEP (2021), for each liter of drinking water, desalination plants produce approximately 1.5 liters of brine. According to the Ministry of Water Resources of Kazakhstan (2025), the total peak drinking water deficit in Atyrau and Mangystau can reach 53 000 m^3/day, or 53 ML/day (megalitres).[235] Rounding up the total deficit for July and August and assuming that it is covered entirely by new desalination capacity, total produced brine volume can in theory reach 5 GL (gigalitres) in only 2 months.[236,237] In addition to such chemical pollution of the Caspian Sea, desalination also presents a threat to maritime ecosystems, since increased salinity and temperature from brine can deplete dissolved oxygen and create dead zones.[238] Given the already compromised ecological state of the Caspian, this is a crucial shortcoming. Another environmental hazard of modern desalination is its carbon footprint, stemming from the reliance of current technology on hydrocarbons for electricity generation. Climate change activists argue that in an attempt to solve a consequence of climate change, desalination may increase fossil fuel consumption and GHG emissions, slowing down nationwide mitigation efforts.[239,240] According to ClimateADAPT (2023), "large-scale RO systems require 0.5-2.6 kWh/m^3 for brackish water", which would result in an energy demand of 26.5-137.8 GWh/day to cover the deficit in Atyrau and Mangystau regions.[241,242] Considering Kazakhstan's 2023 emission factor for electricity & heat generation and the prevalence of coal-based generation in the Kazakh grid, this electricity consumption by desalination plants may theoretically emit approximately 13.25-68.9 ktCO_2/day during peak deficit period.[243] These factors, under a continued expansion of desalination in Kazakhstan, will increasingly worsen pressures on the environment both around the Caspian Sea and beyond.

The economic risks associated with desalination are also tied to the technology's reliance on fossil fuels for electricity generation. In constructing new desalination plants with fossil fuel-based electricity generation, Kazakhstan would effectively tighten its dependence on hydrocarbon markets, on top of their existing chokehold on the local economy. Herndon (2013) explains that "while the projects may ease water strains for area utilities, they'll increase the suppliers' exposure to variable energy prices".[244] This represents a potential economic and political risk for western Kazakhstan, due to the region's existing dependence on energy prices and Kazakhstan being an energy exporter. Despite the prevalence of regulated grid electricity tariffs, true fuel cost pass-through will inevitably be internalised

[234] Madhuri et al., 2025; UNEP. "Пять вещей, которые нужно знать об опреснении." UN Environment Programme, January 11, 2021, https://www.unep.org/ru/novosti-i-istorii/istoriya/pyat-veschey-kotorye-nuzhno-znat-ob-opresnenii.
[235] Amirkhanov, Zhomart. "Дефицит Питьевой Воды Летом На Западе Казахстана Составляет 53 Тысячи Кубометров В Сутки," August 6, 2025, Ak Zhaiyk, https://azh.kz/ru/news/view/118207.
[236] These are the 2 hottest months for western Kazakhstan according to https://en.climate-data.org/asia/kazakhstan/west-kazakhstan-2127/r/august-8/
[237] Author's own calculations, counting for full months of July and August, converting cubic meters into liters.
[238] UNEP, 2021; Shokri & Fard, 2023; Madhuri et al., 2025.
[239] I.e. worsening water scarcity.
[240] ClimateADAPT. "Desalinisation", 2023, https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/desalinisation; World Economic Forum. "The desalination process gives us freshwater - at a huge environmental cost, December 16, 2022. https://www.weforum.org/stories/2022/12/desalination-process-freshwater-negative-environmental-cost/; Sustainability Directory, "Desalination Social Equity", September 8, 2025. https://prism.sustainability-directory.com/term/desalination-social-equity/ .
[241] ClimateADAPT, 2023. Brackish water values were chosen because the Caspian Sea is less saline than most seas and this value is closer to its salinity levels according to preliminary research.
[242] Author's own calculations - multiply drinking water deficit volume by electricity requirements per cubic metre of water.
[243] Author's own calculations using the 2023 CO2 emission factor for elec. & heat generation. Multiply emission factor by estimated daily energy consumption from footnote 14. Emission factor data from https://www.irena.org/-/media/Files/IRENA/Agency/Statistics/Statistical_Profiles/Asia/Kazakhstan_Asia_RE_SP.pdf.
[244] Herndon, Andrew. "Energy Makes Up Half of Desalination Plant Costs: Study", May 1, 2013. https://www.bloomberg.com/news/articles/2013-05-01/energy-makes-up-half-of-desalination-plant-costs-study?leadSource=uverify%20wall&embedded-checkout=true

by one actor or another. The resulting price translation dynamic, should a spike in energy prices occur, will thus endanger the profitability of the plants, and negatively impact either the end consumer or the government budget. This cascade effect is hence a significant economic drawback of expanding desalination capacities in western Kazakhstan using fossil fuel-based technologies. In sum, desalination capacity additions in western Kazakhstan are occurring within a context of both significant socio-political demand and no less significant concerns over environmental and economic implications.

This diverse combination of factors induces active debates over the feasibility of desalination for Kazakhstan. To evaluate the tradeoff, it is necessary to weigh the relevant temporal impacts. In the *short term* (1-5 years), expanding desalination will likely produce a net-positive result, owing to high socioeconomic and political returns, and comparatively limited environmental impacts. This is characterised by instant improvements to the drinking water supply, and subsequent increase in political legitimacy. Public acceptance in western Kazakhstan (Zhanaozen, Aktau, Atyrau) is especially important for the Kazakh government, given these cities' protest history from 2011 and 2022.[245]

In the *medium-term* (5-15 years), the impact of additional desalination fleet may approach neutrality, mainly due to surfacing brine pollution and worsening climate change consequences. Under scenarios where brine management remains unmitigated, as brine accumulates in the Caspian shores, the harm to local marine ecosystems may become more pronounced, and such climate change impacts as increased droughts, floods, and extreme temperatures will pressure water access even more. It is important to note that climate change impact may not necessarily be caused by desalination plants, but will definitely affect their production profile and access to resources. Additional economic losses related to a potential increase in the country's carbon tax may further frustrations and endanger political stability.

Finally, in the *long-term* (15+ years), a predominance of fossil fuel-based desalination plants may reveal a net-negative impact on the environmental, economic, and therefore political well-being of Atyrau and Mangystau regions. If fossil fuel dependence persists beyond 2040, with a locked-in dependence on energy prices and availability, desalination plants' project economics may face stranded-asset risks, while environmental damage reaches its full scale[246]. In combination with more extreme climate events and ecosystem degradation, this may result in further economic losses and a fall in political legitimacy, creating a negative feedback loop across different factors.

Conclusion and recommendations

In sum, although the expansion of desalination capacity in western Kazakhstan is contextualised by significant social and political needs, it also poses risks, including long-term environmental damage and escalating costs. Several measures have already been taken in Atyrau and Mangystau. More than 8500 km of existing water supply networks have been reconstructed, and a large-scale infrastructure renewal is planned by 2029 to reduce network deterioration rates.[247] On the demand side, residents of Mangystau were asked to reduce their drinking water consumption and to use water sparingly.[248] However, ways to address the environmental impact of desalination plants and the macro-level efficiency

245 Rymbetov, Serik. "Social Unrest in Kazakhstan Turns Violent, Ends Nazarbayev Era", January 20, 2022. https://jamestown.org/social-unrest-in-kazakhstan-turns-violent-ends-nazarbayev-era/

246 Seto, Karen C., Steven J. Davis, Ronald B. Mitchell, Eleanor C. Stokes, Gregory Unruh, and Diana Urge-Vorsatz, "Carbon Lock-In: Types, Causes, and Policy Implications", September 2, 2016, *The Annual Review of Environment and Resources*, DOI: 10.1146/annurev-environ-110615-085934.

247 Official Information Source of the Prime minister of the Republic of Kazakhstan. "Presidential Directives Implemented: Ten Regions of Kazakhstan Achieve 100% Water Supply Coverage", July 1, 2025. https://primeminister.kz/en/news/presidential-directives-implemented-ten-regions-of-kazakhstan-achieve-100-water-supply-coverage-30221

248 Government of Kazakhstan, "В Мангистау реализуется 9 крупных проектов для снижения дефицита воды", June 9, 2022, Akimat of Mangystau region, https://www.gov.kz/memleket/entities/mangystau/press/news/details/385991?lang=ru

of water resources utilisation in Kazakhstan are yet to be developed.

Following international examples, Kazakhstan would benefit greatly from integrating renewable energy sources (RES) into desalination plants either in co-generation or full production capacity. For example, in Shandong, China, researchers were able to power a small desalination plant entirely by seawater and low-grade waste heat from nearby steel and petrochemical plants.[249] This allowed them to leverage industrial waste heat, effectively decreasing air emissions. Kazakhstan could also leverage waste heat from its industrial areas in the west, as well as integrate RES in co-generation, managing desalination in a way that balances RES intermittency with reliable traditional generation methods.[250] Potential benefits include a 30-fold decrease in CO_2 emissions if switching to solar PV from coal, and an opportunity profit from avoiding further reliance on coal.[251]

In addition, western Kazakhstan should approach desalination in an integrated, nexus-based manner, co-planning water management with other sectors and taking into account climate change predictions. One of such measures could be integrating water re-use for irrigation or other non-ingesting purposes with the desalination process. Currently, Kazakhstan's water consumption per $ of GDP is 109 m^3, twice as large as in the US or Russia.[252] Thus, taking into account predicted decreases in water availability due to climate change, desalination plants should be coupled with water reuse.[253] This strategy could potentially increase water resources utilisation and contribute towards climate change adaptation.[254] Overall, such an approach's effectiveness in Central Asia has been explored by the OECD through the "Water-Energy-Land-use Linkages" project, or "Nexus."[255] By adopting nexus approaches in desalination, the government could greatly increase efficiency in addressing socioeconomic and environmental challenges. Nexus-based cross-sectoral planning, such as integrating water re-use, may increasingly prove helpful in securing climate, energy, water, and food security in Kazakhstan in the coming years.

Hence, it is recommended to integrate RES into co-generation or complete electricity generation within desalination, as well as explore integrating water re-use, as per a nexus-based approach to water-energy management. Such measures can allow decision-makers to balance both present and future considerations regarding drinking water access and beyond. ■

[249] Chik, Holly. "Chinese Desalination Plant Makes Fresh Water Cheaper Than Tap Water – Plus Green Hydrogen." *South China Morning Post*, December 7, 2025. https://www.scmp.com/news/china/science/article/3335518/chinese-desalination-plant-makes-fresh-water-cheaper-tap-water-plus-green-hydrogen.
[250] Shokri & Fard, 2023; Madhuri et al, 2025.
[251] *Ibid*
[252] The Astana Times. "Kazakhstan's Water Usage: Challenges, Path to Reform.", January 31, 2025. https://astanatimes.com/2025/01/kazakhstans-water-usage-challenges-path-to-reform/. ; Shibutov, 2017.
[253] Pistocchi, Alberto, Tobias Bleninger, Christian Bryer, Upeksha Caldera, Chiara Dorati, Daniele Ganora, Millán Muñoz, et al. "Can seawater desalination be a win-win fix to our water cycle?" *Water Research* 182 (September 1, 2020). https://doi.org/10.1016/j.watres.2020.115906.
[254] ClimateADAPT, 2023.
[255] OECD. "Water-Energy-Land Use Linkages", n.d., OECD, https://www.oecd.org/en/about/programmes/water-energy-land-use-linkages.html

Green Hydrogen Won't Flow Without Water: Rethinking EU Energy Security for Resilient Trade with Water Scarce Partners

Manon Pituello

Manon Pituello is a graduate of the Master in European Affairs at Sciences Po Paris, where she specialised in the EU's foreign policy through the lens of energy geopolitics, climate governance and economic security. Holding a bachelor's degree in European Studies with a minor in European and International Law from Maastricht University, her academic work has focused on EU energy security, decarbonisation strategies, and the EU's neighbourhood and (energy) trade relations, including a bachelor's thesis on EU–Russia energy relations centred on the Nord Stream 2 case. Alongside her studies, she has conducted applied policy research and contributed to analytical and advisory work relating to EU neighbourhood, industrial, energy and climate policy through roles at the OECD Eurasia Division and the European Affairs Departments of TotalEnergies and the French Ministry of Economy.

Introduction

The European Union's energy transition is increasingly embedded in both economic and geopolitical considerations. In 2019, the European Green Deal was introduced as a new growth strategy to decouple economic growth from resource use by turning to green markets.[256] In 2025 the EU was engaged in a "race [to] be the first to achieve climate neutrality [and] shape the global economy" in which it cannot "leave any strategic vulnerabilities exposed".[257] Mirroring traditional fossil energies, renewables have become strategic assets in a global competition for power.

In this context, energy security, defined as the uninterrupted "stable and abundant supply of energy" through "reliable, affordable access to all fuels and energy sources", remains a core objective of EU external engagement.[258] These five pillars – continuity, stability, abundance, reliability, affordability – presuppose more than technological capacity or market access: they rely on political stability in supplier countries and a sufficient degree of mutual economic interests. Nonetheless, this approach failed to prevent Russia's weaponisation of natural gas to destabilise the EU economy in the last decades, revealing the limits of mutual economic benefits and interdependence as a security guarantee.[259]

Against this backdrop, the REPowerEU Plan aims to phase out Russian fossil fuels and diversify its energy suppliers and mix, by scaling up renewables and enhancing energy efficiency. It notably raised the 2030 renewable energy target to 45% and introduced the aim of importing 10Mt of green hydrogen by 2030, adding to the 10Mt to be produced within the EU.[260] More generally, the EU

---

[256] European Commission, 'Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic And Social Committee and the Committee of the Regions – The European Green Deal', COM(2019)640 final, December 11, 2019, 2, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52019DC0640 ; Maria Sandberg, Kristian Klockars and Kristoffer Wilen, 'Green growth or degrowth? Assessing the normative justifications for environmental sustainability and economic growth through critical social theory,' *Journal of Cleaner Production* 206 (2019): 138, https://doi.org/10.1016/j.jclepro.2018.09.175.

[257] Ursula Von der Leyen, 'Europe's Choice – Political Guidelines for the Next European Commission 2024-2029' July 18, 2024, 6. https://commission.europa.eu/document/download/e6cd4328-673c-4e7a-8683-f63ffb2cf648_en?filename=Political%20Guidelines%202024-2029_EN.pdf.

[258] Martin Russell (European Parliamentary Research Service), 'Energy Security in the EU's External Policy' *European Union* (2020), https://www.europarl.europa.eu/cmsdata/210517/EPRS_IDA(2020)649334_EN.pdf.

[259] Fabienne Bossuyt and Peter van Elsuwege, *Principled pragmatism in practice : the EU's policy towards Russia after Crimea*, (Brill | Nijhoff, 2021), 370-382.

[260] European Commission, 'Communication on the REPowerEU Plan,' COM(2022)230 final, May 18, 2022, 7, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483, the REPowerEU Plan refers to 'renewable hydrogen' which is defined in recitals 2 and 4 of the Delegated Act on Renewable Liquid and Gaseous Transport Fuels of Non-Biological Origin as hydrogen produced via electrolysis and supplied with renewable electricity. As the EU legal definition of renewable hydrogen corresponds to that of green hydrogen, and for the purpose of clarity and consistency, the term

expects green hydrogen to cover around 10% of its energy demand by 2050.[261] The EU hydrogen strategy's inherent external aspect thus requires it to continue investment and trade activities while mitigating the related risks and reducing its energy dependencies – the 'derisking' principle.

Green hydrogen is an energy carrier produced from electrolysis, which splits freshwater using renewable electricity. Its production is highly freshwater-dependent (9-30L/kg of hydrogen);[262] hence, the EU's ability to meet its hydrogen target is contingent upon freshwater availability in partner regions. This situation could generate new dependencies as only 3% of Earth's water is freshwater and most of it is inaccessible or used for agriculture.[263] Moreover, a recent UN report emphasised that the world moved from a global water crisis to a 'global water bankruptcy', meaning a chronic shortage that prevents water systems from realistically reverting to their historical baselines.[264] Meanwhile, the energy-security-water nexus remains overlooked in EU policies, leaving a key resource constraint unaddressed and the EU's own energy security exposed. Thus, how can the EU's hydrogen strategy mitigate the geopolitical threats to its energy security if it generates or worsens water insecurity in partner regions?

This essay aims to show how the EU's current extraction-focused trade approach to its diversification strategy threatens its long-term energy security. Focusing on emerging green hydrogen markets, it applies Paul A. David's theory of the first step to assess the EU's risks and opportunities of (not) being the first to trade this molecule at scale. First, this essay investigates the factors that could enable the EU to capitalise on green hydrogen development by leveraging the renewable potential of Southern Mediterranean countries. Second, it examines the EU's failure to account for water scarcity and related socio-political risks in partner countries, thereby undermining key pillars of its energy security strategy. Last, the analysis suggests a way forward for the EU's hydrogen strategy based on a necessary win-win dynamic: it argues that the EU must pursue an actionable agenda for local value creation that accounts for water considerations in its hydrogen and green partnerships.

1) An ideal situation – The EU is set to benefit from a green hydrogen market

Compared to primary renewable energy sources and other energy carriers, green hydrogen has not yet developed into a globally traded commodity. This entails low price transparency and competition as well as higher costs, including for transportation.[265] In a global context of financial constraints and intensified economic competition, actors seeking to play a role in the development of a green hydrogen market will therefore prioritise speed and cost-efficiency.

Hydrogen can be liquified for maritime transport or transported via pipelines in a gaseous state. However, scholars and economists agree that pipelines are generally the most economically viable, technologically mature and simplest transportation option for hydrogen imports.[266] Furthermore, green hydrogen trade is promising: in terms of infrastructure capacity, green hydrogen pipelines

'green hydrogen' is used interchangeably with the EU term 'renewable hydrogen' throughout this paper.

[261] Directorate-General of Energy (European Commission), 'Hydrogen,' *European Commission website*, n.d., accessed Jan 14, 2026, https://energy.ec.europa.eu/topics/eus-energy-system/hydrogen_en.

[262] Kaitlyn Ramirez, Tessa Weiss, Thomas Kirk and Chathurika Gamage, 'Hydrogen Reality Check: Distilling Green Hydrogen's Water Consumption," *RMI website*, August 2, 2023, accessed Feb 9, 2026, https://rmi.org/hydrogen-reality-check-distilling-green-hydrogens-water-consumption/; OECD, *Towards a Renewable Hydrogen Strategy for Mongolia* (OECD Publishing, 2025), 101. https://doi.org/10.1787/15122489-en.

[263] Lizica Spiru Paraschiv, Simona Paraschiv and Alexandru Serban, 'An overview of energy intensity of drinking water production and wastewater treatment,' *Energy Reports* 9, no. 11 (2023): 118, https://doi.org/10.1016/j.egyr.2023.08.074.

[264] Kaveh Madani, *UNU-INWEH Report – Global Water Bankruptcy: Living Beyond Our Hydrological Means in the Post-Crisis Era* (United Nations University Institute for Water, Environment and Health, 2026), DOI: 10.53328/INR26KAM001.

[265] International Renewable Energy Agency, 'Hydrogen,' *IRENA website*, n.d. https://www.irena.org/Energy-Transition/Technology/Hydrogen.

[266] Ghassan Wakim, Alex Carr and Hagan Han, *Techno-economic Realities of Long- Distance Hydrogen Transport - A Cost Analysis of Importing Low-Carbon Hydrogen to Europe* (Clean Air Task Force, 2023), https://www.catf.us/resource/techno-economic-realities- long-distance-hydrogen-transport/.

can transport larger energy volumes than high-voltage direct current lines (<13.5GW vs. 3-5 GW).[267] However, transporting large quantities of hydrogen over long distances is both inefficient and expensive regardless of the channel.[268] Consequently, two additional constraints will shape green hydrogen market development: (1) politics, as building new cross-border pipeline infrastructure is politically difficult, and (2) distance, as pipelines require proximity for true cost-efficiency. Therefore, green hydrogen trade requires both strategic and geographic closeness.

Infrastructure repurposing could answer both considerations. Existing pipelines have established political legitimacy and their retrofitting costs are inferior to the financial needs for developing new pipelines. As per the EU Hydrogen Strategy and the REPowerEU Plan, green hydrogen has become an EU strategic priority to replace natural gas imports and use in industrial processes and transport. The extensive pipeline infrastructure allowing to supply the EU with natural gas could then be repurposed to that effect, thereby preventing over 200,000 km of transmission gas pipelines from becoming stranded assets.[269] The EU and several leading industry voices like Siemens indeed emphasise that minor modifications would be required, with only a slightly smaller energy transportation capacity for green hydrogen compared to natural gas (volumes remain high).[270] The EU is thus well-equipped to benefit from the development of a green hydrogen market.

As such, the EU will turn to its neighbours for hydrogen supplies. In fact, then Commissioner Frans Timmermans admitted that the EU will never be able to produce its own hydrogen in sufficient quantities.[271] Thus, seeking the most cost-effective import routes, the EU will naturally rely on its existing gas infrastructure connecting it to its neighbours, particularly Southern neighbours which supply around one-fifth of its gas and benefit from untapped renewable (solar and wind) capacity potential exceeding 3 TW.[272] Consequently, the EU's green hydrogen trade opportunities are likely to deepen regional energy integration in a way that regionalises green growth, as its Mediterranean partners' abundant untapped renewable capacities create significant scope for hydrogen production linked to EU demand.[273]

2) A reality check – New markets, same old paradigm in EU energy trade

The EU is ideally located to create a green hydrogen market with neighbouring countries. As per Paul A. David's theory of the first step (developed using the example of the QWERTY keyboard), small, early events can lock in a particular standard if it is the first to gain widespread adoption despite better

[267] Aliaksei Patonia and Rahmatallah Poudineh, 'Hydrogen pipelines vs. HVDC lines: Should we transfer green molecules or electrons?,' *Oxford Institute for Energy Studies* (2023): 1-5, https://www.oxfordenergy.org/wpcms/wp-content/uploads/2023/11/ET27-Hydrogen-pipelines-vs.-HVDC-lines.pdf, hydrogen and electricity lines should not be seen as competing but as integral parts of a larger interconnected system in which they can together best speed up the decarbonisation.
[268] Wakim, Carr, and Han, *Techno-economic Realities of Long-Distance Hydrogen Transport*.
[269] Luc Van Nuffel et al., *Final Report on the impact of the use of the biomethane and hydrogen potential on trans-European infrastructure* (Publications Office of the European Union, 2019), 51, https://www.europeangashub.com/wp-content/uploads/2019/11/Trinomics-biomethane-and-hydrogen-study.pdf.
[270] Christopher Findlay, 'Can gas lines and other existing infrastructure handle hydrogen?,' *Siemens Energy website*, September 11, 2020, accessed Jan 14, 2026, https://www.siemens-energy.com/global/en/home/stories/repurposing-natural-gas-infrastructure-for-hydrogen.html.
[271] Frans Timmermans, quoted by Leigh Collins, 'Europe is never going to be capable of producing its own hydrogen in sufficient quantities: EU climate chief,' *Recharge News website*, May 4, 2022, accessed Jan 14, 2026, https://www.rechargenews.com/energy-transition/europe-is-never-going-to-be-capable-of-producing-its-own-hydrogen-in-sufficient-quantities-eu-climate-chief/2-1-1212963.
[272] European Council, 'Where does the EU's gas come from?' *Council website*, November 13, 2025, accessed Feb 5, 2026. https://www.consilium.europa.eu/en/infographics/where-does-the-eu-s-gas-come-from/; Karim Elgendy, *Great sea connections: Financing the Eastern Mediterranean's energy transition* (The Atlantic Council of the United States, 2025), 4, https://www.atlanticcouncil.org/in-depth-research-reports/report/great-sea-connections-financing-the-eastern-mediterraneans-energy-transition/; Gabrielle Cassetti and Filomena Annuziata, 'Setting the scene for an interconnected, renewable Mediterranean energy system,' *ECCO Climate* (2024), https://eccoclimate.org/wp-content/uploads/2024/10/The-basis-for-an-interconnected-mediterranean-energy-system_Research-paper_ECCO.pdf, based on data from the Global Solar and Wind Atlas, the Southern shore of the Mediterranean could host 2.5 TW of solar capacity and 1 TW of wind capacity.
[273] AstrodyneTDI, "Understanding Power Requirements for Hydrogen Generation," AstrodyneTDI website, n.d, accessed Feb 5, 2026. https://www.astrodynetdi.com/blog/understanding-power-requirements-for-hydrogen-generation

alternatives emerging later on, hence giving the standard-setter a first-mover advantage.[274] For instance, the EU's gas imports are historically structured around pipeline infrastructure, long-term contracts with Russian suppliers and the belief that mutual commercial dependence ensures security (technological, contractual and normative lock-ins).[275] Similarly, Chinese manufacturers were able to dominate global solar PV production due to early cheap production costs, policy support and large scaling capacity, which in turn supported the EU's rapid and most cost-efficient solar rollout (supply-chain lock-in).[276] As production standards and economies of scale consolidate around Chinese supply chains (normative and market lock-ins), switching toward alternative industrial models becomes increasingly costly (technological-industrial lock-in).

Following David's theory, changing business-as-usual in existing renewable markets entails high switching costs and is therefore difficult to achieve; establishing a new norm must be sought in markets that are yet to emerge. The EU is thus best able to shape green hydrogen trade, as green hydrogen is not yet a traded commodity – i.e. to itself define the standards that will enhance its long-term energy security when it comes to hydrogen, which shall rely on "new long-term, mutually beneficial partnerships".[277] Having laid the groundwork for such a market by setting production and import targets, the EU now aims to place the derisking principle at the core of its green hydrogen partnerships and broader diversification strategy: eliminating economic (market barriers and trade distortion, currency), political (instability) and energy supply risks (weaponisation).[278]

The EU's conception of 'supply risks' or 'natural resources availability' is restricted to energy and raw materials, falling short of water considerations on which the very existence of green hydrogen rests. Indeed, the EU Hydrogen Strategy identifies Southern Neighbourhood countries as priority partners "taking into account natural resources [available], physical interconnections and technological development".[279] Water constraints are not once mentioned; yet, the Middle East and North Africa are the most water-stressed regions, with 83% of the population being exposed to extremely high water stress, projected at 100% by 2050.[280]

The EU's first Green Partnership on energy, climate and the environment was signed in 2022 with Morocco, which aims to become a major green hydrogen exporter by 2050. However, Morocco is severely affected by water scarcity and drought: it has lost three-quarters of its average available water in 50 years, from 2,000 m3 of water per capita in 1960 to 600 nowadays.[281] Additionally, access to freshwater is uneven: while some large cities receive freshwater without restrictions, water is rationed in most remote villages and towns.[282] The situation is even more distressing for farmers, who must increasingly choose between basic necessities (cooking and cleaning) and means of subsistence (agriculture as an economic activity) or food security.[283] This directly affects Morocco's agriculture-reliant economy, as agriculture accounts for 87% of water use.[284] Water thus becomes a

[274] Paul A. David, 'Clio and the Economics of QWERTY,' *The American Economic Review* 75, no. 2 (1985), https://www.jstor.org/stable/1805621, this is also called path dependence: the outcome depends on the path taken and related switching costs (e.g. re-training), not the quality of the alternatives.

[275] Bossuyt and van Elsuwege, *Principled pragmatism in practice*, 370-382.

[276] Joint Research Centre, *Photovoltaïcs in the European Union: Status report on technology development, trends, value chains & markets* (Publications Office of the European Union, 2023), 3.

[277] Von der Leyen, 'Europe's Choice – Political Guidelines', 27.

[278] *Ibid.*

[279] European Commission, 'Communication on a hydrogen strategy for a climate-neutral Europe,' COM(2020)301 final, August 7, 2020, 19. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301.

[280] Samantha Kuzma, Liz Saccoccia and Marlena Chertock (World Resource Institute), '25 Countries, Housing One-Quarter of the Population, Face Extremely High Water Stress,' *World Resource Institute website*, August 16, 2023, accessed Jan 13, 2026, https://www.wri.org/insights/highest-water-stressed-countries.

[281] Jihane Ziyan, 'Water Crisis in Morocco – Response and Challenges,' *EcoMENA*, January 5, 2026, accessed Jan 13, 2026. https://www.ecomena.org/water-crisis-in-morocco-response-and-challenges/

[282] Ziyan, 'Water Crisis in Morocco'.

[283] *Ibid.*

[284] *Ibid.*

potential source of political, social and geographical tensions.

Serving as a blueprint for subsequent Green Partnerships, the EU-Morocco Green Partnership does acknowledge the need for sustainable water management under the heading 'climate change adaptation and resilience'. However, its priority work for green hydrogen focuses exclusively on developing production, export and the necessary infrastructure.[285] The Green Partnership explicitly mentions increasing desalination capacity under the heading 'energy transition and decarbonising the Moroccan economy', yet it is not specified whether green hydrogen projects should be built with desalination plants, as is the general practice.[286] The negative effect of green hydrogen ambitions on freshwater availability for agriculture or basic necessities thus remains unaccounted for.

By failing to clearly identify the energy-water nexus underpinning hydrogen production in its diversification strategies, the EU effectively reproduces its extractivist dynamics in its external energy engagement. Local value creation aspects related to green hydrogen trade do appear in the Green or Hydrogen Partnerships; yet, these remain largely focused on job and revenue creation. This may disproportionately benefit central authorities in contexts of weak labour protections and high corruption, at the expense of the local population. Furthermore, an extractivist logic that falls short of water considerations could trigger political instability in water-stressed countries in the face of diminishing public support for the governments that allowed for further depletion of their already scarce water sources.[287] In turn, these shortcomings fuel accusations of neo-colonialism, green and water grabbing at the expense of local ecosystems and increase energy-rich countries' reluctance to trade hydrogen with the EU.[288] Consequently, the blindspot of the EU's hydrogen ambitions – water availability – threatens all areas of life, from basic drinking needs to food production and economic life, and therefore the very political stability which the EU's external energy engagement has always relied on.

Additionally, water is a growing weapon of conflict worldwide, representing 105 of the 1428 water conflicts since 2020.[289] Export-oriented hydrogen infrastructure and their power plants could become targets of protests and sabotages from local populations whose water supplies will be affected by green hydrogen production.[290] Conversely, water-stressed partner countries' elites (facing growing public discontent) could cut water supplies to these facilities for (geo)political or economic gains, similar to Russia's weaponisation of pipeline natural gas supplied to the EU.[291] Thus, across its initial green partnerships, the EU risks locking in a familiar assumption in nascent green hydrogen markets – one that has failed to ensure its energy security: that economic interdependence alone can prevent the weaponisation of strategic resources.[292]

3) A true local value – Addressing water constraints in hydrogen partnerships

---

[285] European Commission, 'Annex to the Commission Implementing Decision on the EU-Morocco Green Partnership,' C(2022)7308 final, October 17, 2022. https://enlargement.ec.europa.eu/system/files/2022-11/C_2022_7308_F1_ANNEX_EN_V3_P1_2128231.PDF.

[286] Ivon Ivanova, 'Hydrogen's Potential in Desalination: Providing Clean Water for Communities,' *Hydrogenera*, October 2, 2024, accessed Feb 5, 2026,: https://hydrogenera.eu/tpost/6ebz9l9ii1-hydrogens-potential-in-desalination-prov , examples include the NEOM Green Hydrogen Project in Saudi Arabia or the Port of Rotterdam's green hydrogen desalination initiative.

[287] United Nations Water, 'Water and Peace,' *UN Water*, n.d, accessed Jan 12, 2026, https://www.unwater.org/water-facts/water-and-peace.

[288] Ammar Saber, "Green hydrogen, old colonialism," *CETRI*, May 22, 2025, accessed Jan 14, 2026. https://www.cetri.be/Green-hydrogen-old-colonialism?lang=fr.

[289] Water Conflict Chronology Timeline List, accessed Feb 5, 2026, https://www.worldwater.org/conflict/list/.

[290] Kitty van der Heijden and Callie Stinson, 'Water is a growing source of global conflict. Here's what we need to do,' *WeForum*, March 18, 2019. https://www.weforum.org/stories/2019/03/water-is-a-growing-source-of-global-conflict-heres-what-we-need-to-do/; Madani, *Global Water Bankruptcy*, a key reason would be the lack of a justice lens in water management.

[291] Yazan Ibrahim et al., 'The socio-political factors impacting the adoption and proliferation of desalination: A critical review,' *Elsevier* 498 (2021), https://doi.org/10.1016/j.desal.2020.114798, relying on water imports from neighbouring countries is a potential threat to national security; Madani, *Global Water Bankruptcy*, 53-55

[292] Bossuyt and van Elsuwege, *Principled pragmatism in practice*, 370-382, returning to business-as-usual (interdependence) in EU-Russia relations is not possible and a qualitatively different and more constructive long-term strategy is needed.

Green Hydrogen Won't Flow Without Water: Rethinking EU Energy Security for Resilient Trade with Water Scarce Partners

External engagement based on extractivism and economic interdependence is no longer a winning strategy to create new and secure markets, particularly for green hydrogen. Yet, the EU already lags behind other international powers on this realisation: in 2023, the China International Energy Group already discussed water treatment plants and desalination with the Egyptian President during negotiations on a green hydrogen project worth billions in Egypt.[293] On a larger scale, China pours billions into projects to be the first mover in green hydrogen markets, notably through its Belt and Road Initiative, In this context, energy suppliers and the European Court of Auditors are calling for the EU to downscale its hydrogen ambitions;[294] yet, a hands-off policy would leave the EU at a double loss. Firstly, the EU would risk losing another key market, perhaps its only opportunity to establish true win-win standards in an emerging energy market and fix its reputation as a trading partner. Secondly, the EU would leave its strategic vulnerabilities infinitely more exposed by exacerbating the EU's dependency on Chinese technologies and firms for its energy transformation.

Inaction and business-as-usual offer no solution to mitigating the threats to the EU's energy security. Therefore, the EU's most promising way to successfully challenge China is to quickly deliver on its promise for truly mutually beneficial partnerships in emerging green hydrogen markets, where the market taker is not (yet) defined as that which has the greatest financial capacity – markets in which the EU, due its current financial constraints, would lose to China. Doing so will thus require the EU to set an actionable agenda for local value creation going beyond job and wealth creation in its Green and Hydrogen Partnerships with water-stressed countries, starting with recognising the intertwined nature of hydrogen ambitions and water management. Its hydrogen trade must then be anchored in shared water resilience, for instance, by:

- **Integrating requirements** on water source disclosure and limiting freshwater withdrawals in water-stressed countries;
- **Including binding commitments to shared water governance and local ecosystem resilience**, such as local communities' priority access to freshwater, ensuring that agricultural activities do not suffer significant negative effects due to green hydrogen projects, or establishing participatory monitoring bodies with local representatives to oversee water usage and allocation in case of droughts or depletion caused by hydrogen production and affecting locals;
- **Supporting partner countries in establishing transparent water accounting systems and in cross-sectoral planning** linking water, energy (infrastructure) and land;
- **Investing more in R&D in developing viable models to use saline, waste or seawater water** for green hydrogen production, reducing both freshwater needs and water treatment costs;[295]
- **Engaging in technological and knowledge transfers and capacity building for water treatment** as the EU is at the forefront of cutting-edge technologies for wastewater management (e.g. smart water networks, advanced filtration systems);
- **Ensuring that desalination capacities are not hijacked by industrial or export-oriented energy projects**, by co-financing new desalination plants that supply freshwater for both hydrogen production and local needs.

Conclusion

While setting new local value creation standards in existing renewable markets is challenging, the EU can do so by taking the lead in green hydrogen markets that are yet to emerge. However, being well-

[293] Njenga Hakeenah, 'Egypt's Chinese Green Hydrogen Project Could be a Blueprint for Africa,' *China Global South*, March 26, 2023, accessed Jan 13, 2026. https://chinaglobalsouth.com/2023/03/26/china-green-hydrogen-egypt-africa-blueprint/.

[294] European Court of Auditors, *Special report 11/2024: The EU's industrial policy on renewable hydrogen – Legal framework has been mostly adopted – time for a reality check*, (Publications Office of the European Union, 2024), https://www.eca.europa.eu/en/publications?ref=SR-2024-11.

[295] OECD, *Towards a Renewable Hydrogen Strategy for Mongolia*, 110.

equipped and positioned to both benefit from and shape them is not enough. It will require the EU to correct its default approach to energy security when seeking to meet its green hydrogen import targets – turning from an extractivism logic blind to water constraints to true win-win synergies that effectively address water scarcity issues in EU hydrogen trade. This would create a momentum for the EU to revise its external energy engagement and diversification strategy in line with the derisking principle and its promise to deliver long-term, mutually beneficial partnerships.

Thus, tapping into the full transformative potential of the EU's ambitious green hydrogen targets, rather than downscaling or simplifying them, could mitigate the threats to the EU's energy security – by addressing not just market and structural barriers to transformation, but also local water challenges. Through market-stimulation, the EU could set a new standard of local value creation in its hydrogen partnerships, starting with its own neighbours and then relying on market expansion for a domino effect. This approach could help move beyond the winner–loser dynamic that makes the EU's dependencies dangerous and place the EU's energy transition on a more resilient and sustainable trajectory. ■

Death in the Shadow of the Dam: A Critical Political Ecology Perspective on the Lesotho Highlands Water Project

Galen Miller

Galen Miller is a second year Master in Environmental Policy at the Paris School of International Affairs. He is highly interested in water and water related-challenges, specifically the nexus between water and global climate change. He recently completed his semester « Hors les Murs » in Cambodia, conducting interviews with rural households and analyzing water use and perception patterns in the context of climate change and Cambodia's water management strategy. In addition, he has recently worked on research with the Environmental Investigation Agency (EIA) regarding marine microplastic

The Lesotho Highlands Water Project (LHWP) is the product of a treaty[296] signed in 1986 between Lesotho and the apartheid government of South Africa.[297] The LHWP ranks among the largest water transfer schemes in Africa, incorporating three complete dams in the Mulati Mountains: Katse Dam and 'Muela Dam (completed 1996) and Mohale dam (2002), administered by the Lesotho Highlands Development Authority (LHDA).[298] The water from these dams is directed towards the Vaal Reservoir in Gauteng Province, South Africa.[299] How did different actors produce the idea of water abundance and a dire need for development in Lesotho and water scarcity in South Africa to justify, implement, and measure the success of the LHWP?

The application of a critical political ecology lens allows a dissection of these questions and lends itself to an uncomfortable conclusion: the LHWP is the manifestation of a dominant, water-centric development imaginary with roots in British imperialism and supply-trap water policy which has had deleterious impacts on the livelihoods of Basotho highlanders.

Life and Land Before the Dam

Lesotho is an ethnically homogeneous state with most of the country identifying as Basotho. 70% of Lesotho is highlands, home to 20% of Lesotho's 2.2 million people.[300,301] Different legal systems provide different lenses for understanding Basotho land tenure, codified in 1903 by the Laws of Lerotholi. Under these laws, land was held in trust by the King of Lesotho, chiefs, and community leaders, who allocated land to individuals and households. The 1993 Lesotho Constitution attempts to honor this customary system by vesting all land in the Basotho nation while also providing for some commodification. However, the 2010 Land Act rattled the foundations of customary law and gave primacy to a system of commodification which is far less protective of communal land.[302,303]

---

[296] See Republic of South Africa, & Kingdom of Lesotho. (1986, October 24). *Treaty on the Lesotho Highlands Water Project Between the Government of the Kingdom of Lesotho and the Government of the Republic of South Africa*.

[297] Lesotho Highlands Development Authority, "Lesotho Highlands Development Authority," n.d., https://www.lhda.org.ls.

[298] Yvonne Braun, "Lesotho's White Gold: The Political Ecology of Temporality and the Economy of Anticipation in Resource Extraction and Large Dam Infrastructural Projects," *Journal of Political Ecology* 27, no. 1 (September 5, 2020).

[299] Andre Lombard, "Lesotho-South Africa Water Project: The 'White Gold' Controversy," Bbc.com (BBC News, August 22, 2024).

[300] Colin Hoag, "'Water Is a Gift That Destroys': Making a National Natural Resource in Lesotho," *Economic Anthropology* 6, no. 2 (March 25, 2019).

[301] Colin Hoag, "Scratching about (Fato-Fato): Erosion, Governance, and the Commodification of Water in Lesotho" (2017), https://www.proquest.com/docview/1940251132?pq-origsite=gscholar&fromopenview=true&sourcetype=Dissertations%20&%20Theses.

[302] C. C. Ngang et al., "Land Entitlement and the Right to Development in Lesotho," *Africa Insight* 53, no. 1 (2024).

[303] C. C. Ngang et al., "Right to Development Governance: A Policy Proposition for the Kingdom of Lesotho," *African Journal of Legal Studies* 15, no. 3 (July 3, 2023): 393–421.

The hegemonic discourse of commodification has rendered invisible the ways in which water and rivers were central to highland life before the LHWP. Under the communal land system, almost all highland land was commonly owned.[304] Agriculture was a networked process of multiple families or communities, with tools and equipment often treated as shared goods. Farmers staggered crop production throughout the year, insulating themselves from unpredictable rainfall patterns. Social systems are reliant on trust and social capital built up and preserved through systems of mutual assistance and exchange.[305] Many communities did not emphasize monetary income.[306] Families in the highlands generally practiced multiple livelihood activities, involving subsistence agriculture and livestock herding; brewing beer; and using locally available river sand and grasses for building. According to residents of the Mohale area, the land was rich before the LHWP. Manure from livestock pens would wash down into the flatlands, excluding the need for external inputs of fertilizer. Snowmelt stored in the porous mountains fed rivers, springs, streams, and wetlands even during periods of less rain.[307,308]

Although not captured or controlled, the flow of water from mountaintops to rivers provides for highlanders before ending up in the fluvial systems of South Africa. This water was often dangerous and unpredictable: "metsi ke mahlopha-a-senya," or "the gift that destroys".[309] This is juxtaposed with the vision for water employed by the LHWP: a commodified engine for development.[310,311]

Creation of Abundance: Necessitating the Dam

How did the LHWP create a construction of Lesotho's water as abundant and underutilized, a fact so opposed to the lived reality of many Lesotho highlanders? It is a tension between two overarching imaginaries: "...capitalism must be able to control and profit from resources…[as opposed to] resources must be in control of the people and used to support and sustain life for all".[312] The framing of Lesotho as "water abundant," a necessary prerequisite to posture water as a driver of development, began when British imperial authorities noticed that Lesotho's water was "underused".[313] The idea was resurrected in the 1980s when apartheid South Africa realized that Johannesburg was demanding more water than accessible.[314,315] During this same period, the development priorities of international institutions touted privatization and neoliberal development models, including the treatment of water as a commodity. In this context, South Africa decided to pursue Lesotho's "underused" water, and Lesotho began to conceptualize their water resources as a tool for development.[316]

Aggressively reacting against Lesotho's initial resistance to the idea of a water transfer scheme, South Africa imposed an economic blockade on the country in 1985 and orchestrated a coup the next

[304] Jess L. Delves et al., "Scrutinising Multidimensional Challenges in the Maloti-Drakensberg (Lesotho/South Africa)," *Sustainability* 13, no. 15 (January 1, 2021).
[305] E. R. Lehema, "Large Dam Development and Displacement : Understanding Reasons and Dynamics for Conflict over Construction of Polihali Dam in Mokhotlong District" (2020), https://www.proquest.com/openview/f02d3d1caeba0af3607770faa8a955cb/1?cbl=20263%2066&diss=y&parentSessionId=Jio4%2BnlRcyKPFydGnK6Vrcu6sB%2FNjXfcr6idYuH%%202BiOA%3D&pq-origsite=gscholar&parentSessionId=SjeTHoWp0Rt0z9nJJNa6logGNY%20a%2FfFDd3x1i7F5iomA%3D.
[306] Moeketsi Kali, "Causes and Solutions of Poverty in Lesotho," *European Journal of Behavioral Sciences* 3, no. 2 (December 30, 2020): 23–38.
[307] Lehema, *Large Dam Development and Displacement : Understanding Reasons and Dynamics for Conflict over Construction of Polihali Dam in Mokhotlong District*
[308] M. J. Liphoto, "Exploring the Impacts of the Lesotho Highlands Water Project on the Sustainable Livelihoods of Resettled Communities " (2020), https://scholar.sun.ac.za/items/30910379-4cf0-4370-8750-ad77549218f9.
[309] Hoag, *Scratching about (Fato-Fato): Erosion, Governance, and the Commodification of Water in Lesotho*, 88
[310] Hoag, *Water Is a Gift That Destroys': Making a National Natural Resource in Lesotho*
[311] Hoag, *Scratching about (Fato-Fato): Erosion, Governance, and the Commodification of Water in Lesotho*
[312] Caitlin Schroering, *Global Solidarities against Water Grabbing* (Manchester University Press, 2024): 51
[313] Oscar Gakuo Mwangi, "Hydropolitics versus Human Security: Implications of South Africa's Appropriation of Lesotho's Highlands Water," *Daedalus* 150, no. 4 (2021): 181–93.
[314] Braun, *Lesotho's White Gold: The Political Ecology of Temporality and the Economy of Anticipation in Resource Extraction and Large Dam Infrastructural Projects*
[315] EIB, "Lesotho Highlands Water Project," European Investment Bank, November 26, 2002, https://www.eib.org/en/press/news/lesotho-highlands-water-project.
[316] Braun, *Lesotho's White Gold: The Political Ecology of Temporality and the Economy of Anticipation in Resource Extraction and Large Dam Infrastructural Projects*

year.[317] The Lesotho Highlands Water Project treaty was signed in 1986 between South Africa and a Lesotho puppet government.[318,319] The treaty subverted Lesotho's domestic water use to the obligation to provide South Africa with set amounts of water.[320] In 1988, with international sanctions against apartheid South Africa blocking the financing necessary to continue construction of the LHWP, King Moshoeshoe II urged the international community to reconsider, presenting Lesotho as being blessed with endless water and desperately needing the revenue from water sales for development.[321]

How was this social, economic, and political process of water seizure justified? The role of water gained a different meaning in the imaginary underpinning the LHWP. Water was no longer something critical to the survival of highland communities, unevenly distributed across the state, or a powerful force to be negotiated in highland life. It was white gold, necessary to generate revenue for development.[322] This framing of water as a commodified mechanism was further supported by a regime of representation portraying highlanders as an impoverished demographic badly in need of development.[323] This representation can be traced through official reports and contemporary academic work: the residents of the highlands were "disadvantaged"[324]; they were not using the water "efficiently";[325] they were stuck in poverty and unable to fully participate in the real economy;[326,327] and preserving or restoring the lifestyles of rural river communities is a "non-starter" development strategy.[328] These notions of development can be totally at odds with the reality of local highland economies, where a standard of living is secured through agriculture, community networks, and available natural resources.[329] However, once the highlands are labelled as "disadvantaged," a dam comes with a host of benefits: "A huge benefit to conserve the water and make use for agricultural purposes";[330] attracting the private sector and making more efficient use of resources[331]; and improving standards of living.[332]

The construction of dams and other infrastructure is thereby portrayed as the solution to a double "crisis": a development crisis in Lesotho and a water crisis in South Africa. This second crisis was produced across the border in Gauteng, South Africa, the industrial and mining hub of the country[333]. According to LHWP funders, Gauteng faced serious and persistent water shortages before the LHWP.[334] This is an inappropriate conflation of socioeconomic demand for water and water need.[335] This conflation and the resulting "solution"– a massive water transfer scheme enabled by complex physical infrastructure– is an example of supply-trap water policy: taking Guateng's water demands at face value and attempting to meet them, no matter the cost.

[317] F Darroch et al., "Dams, Displacement, and Communal Compensation: A Lesotho Highlands Legal Case," University of Botswana Law Journal, 2020.
[318] ibid.
[319] Mwangi, Hydropolitics versus Human Security: Implications of South Africa's Appropriation of Lesotho's Highlands Water
[320] C Vinti, "Hydrocolonisation in the Lesotho Highlands Water Project Treaty: Legitimate Treaty or Murky Waters? " (2021), https://wiredspace.wits.ac.za/server/api/core/bitstreams/9f9d401f-73f9-42be-8053-9028d%209c791c0/content.
[321] Hoag, Water Is a Gift That Destroys': Making a National Natural Resource in Lesotho
[322] Lombard, Lesotho-South Africa Water Project: The 'White Gold' Controversy
[323] A Escobar, Encountering Development: The Making and Unmaking of the Third World (Princeton University Press, 2011).
[324] Delves et al., Scrutinising Multidimensional Challenges in the Maloti-Drakensberg (Lesotho/South Africa), 12
[325] EIB, Lesotho Highlands Water Project
[326] Ngang et al., Land Entitlement and the Right to Development in Lesotho
[327] Ngang et al., Right to Development Governance: A Policy Proposition for the Kingdom of Lesotho
[328] L. J. M. Haas, L. Mazzei, and O'Leary D.T., "Lesotho Highlands Water Project: Communications Practices for Governance and Sustainability Improvement" (World Bank Group, 2010).
[329] Escobar, Encountering Development: The Making and Unmaking of the Third World
[330] N. L. Skefu, "Impact Assessment for Lesotho Highlands Water Project and Sustainable Livelihoods: A Case Study of Community around Katse Dam" (2018): 45 https://scholar.ufs.ac.za/server/api/core/bitstreams/547753c7-09ef-41b0-b1a1-f79d49919%20028/content.
[331] AfDB, "South Africa - Lesotho Highlands Water Project (LHWP), Phase II," African Development Bank Group, 2024, https://mapafrica.afdb.org/en/projects/46002-P-ZA-EA0-004.
[332] Haas, Mazzei, and O'Leary, Lesotho Highlands Water Project: Communications Practices for Governance and Sustainability Improvement
[333] C. Vinti, "An Evaluation of Lesotho's Right to 'Expropriate' the Water in the Treaty on the Lesotho Highlands Water Project in a "Conflict of Uses," Obiter 43, no. 1 (March 24, 2022).
[334] EIB, Lesotho Highlands Water Project
[335] Julie Trottier, "Water Crises: Political Construction or Physical Reality?," Contemporary Politics 14, no. 2 (June 2008): 197–214.

Presenting Lesotho is a water-rich state barely using abundant water, home to a largely impoverished population in desperate need of development, and Gauteng is a water-stressed region in desperate need of ever-growing amounts of water contributes to the interpretive scheme of "national water," which continues to justify the LHWP.[336] It is an interpretive scheme in which water is a "...locally emplaced, abundant resource…national water…largely unintelligible to ordinary people".[337,338] It relies on statistics such as the notion that Lesotho "only uses" 5%[339] or 6%[340] of their water. This vision of a nationally abstracted, abundant resource clashes with the lived realities of many Basotho, where water supply varies vastly across regions and seasons.[341,342,343,344] It is likewise an ideological tool: the pain caused to local communities by the LHWP is a necessary sacrifice for the national good.[345,346]

Hegemonic Implementation: Building the Dam

These same black boxes informed the implementation of the project and the compensation schemes applied to local communities. Mandated to compensate affected communities, the LHDA established a series of quickly abandoned agencies designed to oversee compensation. The under-resourced Ministry of Agriculture was left to handle the environmental and social impacts.[347] The LHDA did not consider the cultural relationship to the land held by the Basotho, the spiritual value of place, or the social networks embedded in the highlands, compensating land based on the amount of grain which could be grown on it.[348,349] This scheme was disastrous: the purely corrective approach to justice ignored the concentrated war waged on the ecological and social fabric of the highlanders.[350]

Residents in communities affected by the dam were frequently denied information regarding the details of planning or construction. At times, armed force was used to keep protests to a minimum.[351] Youth on the payroll of the LHDA were used to advocate for the project from within communities and further reduce dissent.[352] Implementing agencies failed to research the potential environmental impacts of Phase I and no benchmark studies were conducted to evaluate ecological impacts.[353] The World Bank itself ignored in-house environmental and social guidelines in the financing of Phase I.[354] The first environmental impact statement for the Katse Dam was published in 1997, the year after the dam was completed, and noted that the dam had caused immense and potentially permanent damage to the river system.[355] Local springs ran dry and massive degradation downstream and upstream quickly became apparent.[356] Overall, Phase I resulted in the relocation of 664 households and impacted 27,400 individuals, or 1.5% of the entire population of Lesotho.[357,358]

336 Delves et al., Scrutinising Multidimensional Challenges in the Maloti-Drakensberg (Lesotho/South Africa)
337 Hoag, Scratching about (Fato-Fato): Erosion, Governance, and the Commodification of Water in Lesotho, 184
338 Hoag, Water Is a Gift That Destroys': Making a National Natural Resource in Lesotho
339 Mwangi, Hydropolitics versus Human Security: Implications of South Africa's Appropriation of Lesotho's Highlands Water
340 EIB, Lesotho Highlands Water Project
341 Hoag, Scratching about (Fato-Fato): Erosion, Governance, and the Commodification of Water in Lesotho
342 Hoag, Water Is a Gift That Destroys': Making a National Natural Resource in Lesotho
343 Vinti, Hydrocolonisation in the Lesotho Highlands Water Project Treaty: Legitimate Treaty or Murky Waters?
344 Mwangi, Hydropolitics versus Human Security: Implications of South Africa's Appropriation of Lesotho's Highlands Water
345 Liphoto, Exploring the Impacts of the Lesotho Highlands Water Project on the Sustainable Livelihoods of Resettled Communities
346 Braun, Lesotho's White Gold: The Political Ecology of Temporality and the Economy of Anticipation in Resource Extraction and Large Dam Infrastructural Projects
347 Darroch et al., Dams, Displacement, and Communal Compensation: A Lesotho Highlands Legal Case
348 Delves et al., Scrutinising Multidimensional Challenges in the Maloti-Drakensberg (Lesotho/South Africa)
349 Darroch et al., Dams, Displacement, and Communal Compensation: A Lesotho Highlands Legal Case
350 R Kuehn, "A Taxonomy of Environmental Justice," Environmental Law and Reporter 30, no. 9 (2000).
351 Lehema, Large Dam Development and Displacement : Understanding Reasons and Dynamics for Conflict over Construction of Polihali Dam in Mokhotlong District
352 Esha Shah et al., "Environmental Justice Movements in Globalising Networks: A Critical Discussion on Social Resistance against Large Dams," The Journal of Peasant Studies 48, no. 5 (November 25, 2019): 1–25.
353 Darroch et al., Dams, Displacement, and Communal Compensation: A Lesotho Highlands Legal Case
354 ibid.
355 Delves et al., Scrutinising Multidimensional Challenges in the Maloti-Drakensberg (Lesotho/South Africa)
356 Mwangi, Hydropolitics versus Human Security: Implications of South Africa's Appropriation of Lesotho's Highlands Water
357 Darroch et al., Dams, Displacement, and Communal Compensation: A Lesotho Highlands Legal Case
358 T. Sekamane et al., "Community Perceptions of the Social Impacts of the Metolong Dam and Reservoir in Lesotho," Land Use Policy 125 (2023).

Devastating Legacies: After the Dam

Understood through the imaginary of water-driven development, the LHWP is a success. According to the LHDA and international funding agencies, the compensation of local communities has been legally sound and materially sufficient.[359] The LHWP had the intended impact of boosting Lesotho's GDP.[360,361,362,363] 10% of Lesotho's GDP now comes from LHWP water sales.[364] These measures of success fit neatly into a neoliberal development paradigm.[365] On these terms, the EIB concluded that local communities were better off resettled, and the World Bank called it a stellar example of mutually beneficial development and poverty reduction– in a report that defined positive outcomes entirely in nationally abstracted empirical terms.[366,367] The EIB sees the project as a success story, saying the LHWP undertook "specialized research" to understand potential impacts and that the compensation framework was "comprehensive".[368] Similarly, the World Bank finds the LHWP exemplary for learning and improvement between Phase I and Phase II.[369]

Basotho highlanders suffered extreme adverse impacts from Phase I. LHDA policies resulted in every indicator of poorly managed displacement: landlessness, joblessness, homelessness, marginalization, food insecurity, increased mortality, reduced access to common property, and social disarticulation.[370] For those communities directly relocated, the promised rise in living standards has often been a facade. Rural self-sufficiency has been replaced by urban wage labor and economic instability. In the words of a resident from the Mohale region: "... [before the LHWP] there was no formal employment. Food was always in abundance; one would never go hungry".[371] The unexpected costs of keeping up a larger urban home have drained compensation payments. Before the LHWP, many could access services for free– they did not have electricity, but could repair their homes with freely accessible materials, and never paid a water bill.[372] Land, previously a source of generational livelihood security, was replaced with lump sums of cash which, in many cases, quickly ran out.[373,374]

Highland social structures were obliterated. The complex system of mutual agriculture, resource sharing, and social structures that built life in the highlands was given no value by the LHDA and World Bank: "The LHWP dismantled our neighborly ties and partnerships…Prosperity is now only a dream".[375] Another resident in an affected community put it this way: "They cannot determine what we have lost. They do not know the pain of losing because they are not us".[376] The consequences for communities only indirectly affected by the dam, and therefore ineligible for compensation, have been severe and often overlooked: the desecration of burial grounds, the loss of springs, the destruction of animal biodiversity, and the severing of physical links between communities. Communities are now unable to exchange food and other products, and

359 Darroch et al., Dams, Displacement, and Communal Compensation: A Lesotho Highlands Legal Case
360 ibid.
361 Liphoto, Exploring the Impacts of the Lesotho Highlands Water Project on the Sustainable Livelihoods of Resettled Communities
362 Ngang et al., Land Entitlement and the Right to Development in Lesotho
363 Ngang et al., Right to Development Governance: A Policy Proposition for the Kingdom of Lesotho
364 Vinti, Hydrocolonisation in the Lesotho Highlands Water Project Treaty: Legitimate Treaty or Murky Waters?
365 Escobar, Encountering Development: The Making and Unmaking of the Third World
366 EIB, Lesotho Highlands Water Project
367 Haas, Mazzei, and O'Leary, Lesotho Highlands Water Project: Communications Practices for Governance and Sustainability Improvement
368 EIB, Lesotho Highlands Water Project
369 Haas, Mazzei, and O'Leary, Lesotho Highlands Water Project: Communications Practices for Governance and Sustainability Improvement
370 Darroch et al., Dams, Displacement, and Communal Compensation: A Lesotho Highlands Legal Case
371 Liphoto, Exploring the Impacts of the Lesotho Highlands Water Project on the Sustainable Livelihoods of Resettled Communities, 47
372 D. G. Marrs, "Involuntary Displacement and Urban Resettlement in the Lesotho Highlands Water Project" (2018), https://nmbu.brage.unit.no/nmbu-xmlui/handle/11250/2586563.
373 Liphoto, Exploring the Impacts of the Lesotho Highlands Water Project on the Sustainable Livelihoods of Resettled Communities
374 Sekamane et al., Community Perceptions of the Social Impacts of the Metolong Dam and Reservoir in Lesotho
375 Liphoto, Exploring the Impacts of the Lesotho Highlands Water Project on the Sustainable Livelihoods of Resettled Communities, 75
376 Lehema, Large Dam Development and Displacement: Understanding Reasons and Dynamics for Conflict over Construction of Polihali Dam in Mokhotlong District, 74

neighborly relationships have been decimated.[377,378] These new forms of insecurity have led to higher levels of anxiety and depression.[379] These injustices are not taken into account by compensation schemes which relied on narrowly defined and commensurative corrective measures.[380]

There are concerns that the damage will be reproduced in the coming years by Phase II. The African Development Bank claims that locals are excited about the project and the new opportunities that will arrive alongside.[381] The realities of the Katse Dam decades after its completion questions this assertion: the village of Ha Ramokoatsi has lacked even basic access to potable water since the dam's completion.[382] The reservoir a stone's throw from the village is not a reliable water source, as local communities are often prohibited from accessing the water for subsistence agriculture.[383] 8,000 people are threatened with forced relocation and have been offered the equivalent of 1 USD as compensation for resettlement as the construction of Pohali Dam proceeds.[384] Residents report that the LHDA has turned "consultation" meetings into sans-participation information sessions: "The LHDA knew what they were going to offer, they only came here to waste our time. The LHDA is treating us like children…"[385].

Under the LHWP, domestic water use is ancillary to the sale of water, and the Disaster Management Authority of Lesotho has admitted that Lesotho faces water shortages.[386,387] Climate change has changed rainfall patterns in the country, with rivers unseasonably reduced to a trickle and LHWP reservoirs far below capacity.[388] Lesotho may soon be unable to meet its water supply obligation to South Africa. Yet the image of Lesotho as "water-rich" continues to drive the LHWP and the building of more infrastructure to move water to South Africa. The idea of "water shortage" no longer has relevance to the actual water needs of those in Lesotho but indicates a situation in which Lesotho cannot meet its own water needs and the demands of urban areas in South Africa. The urban and industrial demand for water from the Orange River Basin will double by 2040 (from 2012 levels), driven by "...population and economic development, urbanization, ineffective use, and modified lifestyles…".[389] As long as the double crisis framing and supply-trap mindset dominate water management in Lesotho, the LHDA will continue to feed South African urban sprawl, as hundreds of thousands of Basotho face an increasingly precarious water situation. South Africa holds immense enforcement power in this dynamic, including the legal and technical ability to slash 50% of Lesotho's electricity generation by stopping the flow of water through the hydroelectric turbines of LHWP dams.[390]

Lastly, community resistance to these projects is fraught with barriers. Activists have challenged the World Bank and the findings of their studies.[391] Some communities affected by Phase I have formed Survivors of Lesotho's Dams (SOLD), and are fighting for better compensation. However, many

[377] Darroch et al., Dams, Displacement, and Communal Compensation: A Lesotho Highlands Legal Case
[378] Liphoto, Exploring the Impacts of the Lesotho Highlands Water Project on the Sustainable Livelihoods of Resettled Communities
[379] Cassandra L. Workman and Heather Ureksoy, "Water Insecurity in a Syndemic Context: Understanding the Psycho-Emotional Stress of Water Insecurity in Lesotho, Africa," Social Science & Medicine 179 (April 2017): 52–60.
[380] Kuehn, A Taxonomy of Environmental Justice
[381] Delves et al., Scrutinising Multidimensional Challenges in the Maloti-Drakensberg (Lesotho/South Africa)
[382] Lombard, Lesotho-South Africa Water Project: The 'White Gold' Controversy
[383] Skefu, Impact Assessment for Lesotho Highlands Water Project and Sustainable Livelihoods: A Case Study of Community around Katse Dam
[384] Amnesty International, "Lesotho: 8000 People at Risk of Displacement in Lesotho due to Water Deal with South Africa," Amnesty International, February 6, 2020, https://www.amnesty.org/en/latest/news/2020/02/lesotho-polihali-dam-construction-putsnearly-8000-people-at-risk-of-displacement/.
[385] Lehema, Large Dam Development and Displacement : Understanding Reasons and Dynamics for Conflict over Construction of Polihali Dam in Mokhotlong District, 74
[386] Vinti, An Evaluation of Lesotho's Right to 'Expropriate' the Water in the Treaty on the Lesotho Highlands Water Project in a "Conflict of Uses
[387] Kali, Causes and Solutions of Poverty in Lesotho
[388] Mwangi, Hydropolitics versus Human Security: Implications of South Africa's Appropriation of Lesotho's Highlands Water
[389] Vinti, An Evaluation of Lesotho's Right to 'Expropriate' the Water in the Treaty on the Lesotho Highlands Water Project in a "Conflict of Uses
[390] Hoag, Scratching about (Fato-Fato): Erosion, Governance, and the Commodification of Water in Lesotho
[391] Braun, Lesotho's White Gold: The Political Ecology of Temporality and the Economy of Anticipation in Resource Extraction and Large Dam Infrastructural Projects

residents were directed towards the statutory justice system in response to questioning resettlement and compensation contracts. Lacking the resources to challenge the LHDA in court, they had little option but to sign.[392]

Conclusion

This paper highlights two different understandings of water and land– those of the Basotho highlanders and that presented by the Lesotho Highlands Water Project– and the conflict between the two during the implementation of the LHWP. By dissecting these competing ideas, the paper tells the story of a dominant imaginary of development fueled by abundant and commodified water. This vision of water was used in the necessitation, implementation, and evaluation of the LHWP. It further explains how the dominant narratives continue to overwrite local relationships with water as the LHWP grinds onward.

The LHWP has failed as an effective water management regime for Lesotho. The Phase I dams had catastrophic impacts on the ecology and social fabric of the highlands, and the duty of the LHDA to provide compensation that maintained the livelihoods of highland communities was abandoned. To this day, the LHDA is avoiding responsibility for solving problems related to Phase I compensation plans, despite court orders and directions from the Lesotho Ombudsman to do so.[393,394] Many of the touted benefits of the dam are only applicable in a nationally abstracted context and have little relevance to the lived experiences of local communities. The double crisis framing and supply-trap approach of Gauteng's hydro-insecurity and Lesotho's water wealth remain unquestioned and the LHWP is now heralded as a success story in development discourse, portrayed as indispensable to the Lesotho economy.[395] This issue is becoming increasingly urgent as climate change impacts rainfall patterns and water in both Lesotho and Gauteng, South Africa. Lesotho has continued implementing the LHWP, with Phase II currently in progress. To avoid additional harm to Basotho highland communities, Lesotho should endeavor to renegotiate the LHWP treaty with South Africa and prioritize the needs of highland communities over the sale of commodified water. This reposturing could have important implications for development discourse more broadly, questioning the oft-unchallenged legitimacy of resource commodification, supply-trap water policy, and neoliberal growth models. ■

[392] Lehema, Large Dam Development and Displacement: Understanding Reasons and Dynamics for Conflict over Construction of Polihali Dam in Mokhotlong District
[393] Darroch et al., Dams, Displacement, and Communal Compensation: A Lesotho Highlands Legal Case
[394] Oscar Mwangi, "Hydropolitics, Ecocide and Human Security in Lesotho: A Case Study of the Lesotho Highlands Water Project *," Journal of Southern African Studies 33, no. 1 (March 2007): 3–17.
[395] Delves et al., Scrutinising Multidimensional Challenges in the Maloti-Drakensberg (Lesotho/South Africa)

Addressing Africa's Energy–Water–Food Challenges Simultaneously with an Agrivoltaics Nexus Approach

Christopher Hegadorn

Christopher Hegadorn : Chris Hegadorn is Adjunct Professor of Global Food Politics at Sciences Po University in Paris where he teaches graduate courses on food security, food systems and the complex linkages between agriculture, climate and nutrition. Mr. Hegadorn is President of the Consortium for Sustainable Agrivoltaics (C4SA) Foundation – a Paris-based non-profit promoting uptake of agrivoltaic solutions in Africa and other developing markets. He custom designs food system crisis simulations ("Food Alert" Workshops) for policy-makers and other experts to foster systemic resilience in the food sector. A retired U.S. diplomat, Mr. Hegadorn spent more than three decades in international development and multilateralism, serving tours in Asia, Africa, the Near East and the United Nations, including nearly four years as Executive Secretary of the UN's Committee on World Food Security (CFS) in Rome.

Ivan Gligorov

Ivan Gligorov is a Master's student in Environmental Policy at Sciences Po (PSIA), with a strong interest in agri-food and environmental public policies. He is particularly interested in policy instruments that support innovation in the agri-food sector. He has worked at the French Ministry of Agriculture on mapping and analysing public support schemes and innovation projects, and at INRAE on public policy analysis related to food systems and inequalities. He also has research experience at CNRS on methane emissions linked to biogas.

Introduction: Turning a triple crisis into a nexus opportunity

Across much of Africa, a triple crisis of inadequate energy access, rising food insecurity and intensifying water stress is constraining development and fueling socio-economic fragility. Sub-Saharan Africa accounts for roughly 80% of the 760 million people worldwide who still lack access to electricity, and overall electrification rates in the region remain below 50%.[396,397] Access is even more uneven when one compares urban centers to rural areas, where grid extension is costly and reliability is often poor.[398]

At the same time, Africa has the highest prevalence of moderate or severe food insecurity of any region, driven by rapid population growth, low agricultural productivity, biodiversity loss and growing exposure to climate extremes.[399,400] Climate projections suggest that, without adaptation, yields of major crops in parts of Eastern and Southern Africa could decline by 8–45% by 2050 as a result of heat and drought stress.[401]

In addition, agriculture accounts for around 80–95% of water consumption in many African countries, yet more than 80% of cultivated land is still under

396 W. S. Ebhota and P. Y. Tabakov, "Leveraging Agrivoltaics to Increase Food, Energy, and Water Access in the Global South: A Case Study Sub-Saharan Africa," *Nigerian Journal of Technology* 43, no. 2 (2024): 364–380, https://doi.org/10.4314/njt.v43i2.20.

397 Suleiman Ibrahim Abubakar et al., "Deploying Agrivoltaics in Sub-Saharan Africa—A Sustainable Pathway Toward Energy-Food Security-Challenges and Opportunities: A Review," *IEEE Access* 13 (2025): 87810–87833, https://doi.org/10.1109/ACCESS.2025.3568717.

398 *Ibid*

399 Ebhota and Tabakov, "Leveraging Agrivoltaics to Increase Food, Energy, and Water Access," 364–380.

400 Aurup Ratan Dhar, "Building Climate-Resilient Food Systems Through the Water–Energy–Food–Environment Nexus," *Environments* 12, no. 5 (2025): 167, https://doi.org/10.3390/environments12050167.

401 R. J. Randle-Boggis et al., "Harvesting the Sun Twice: Energy, Food and Water Benefits from Agrivoltaics in East Africa," *Renewable and Sustainable Energy Reviews* 208 (2024): 115066, https://doi.org/10.1016/j.rser.2024.115066.

low-input, rainfed systems, and only about 3% of cropland in Sub-Saharan Africa is irrigated.[402,403] This makes livelihoods extraordinarily vulnerable to rainfall variability and multi-year droughts, as illustrated by recent emergencies in the Horn of Africa, and by El Niño-induced droughts in Southern Africa that sharply reduced hydropower output and in turn constrained irrigation and food processing.[404] Despite the close links between energy, water and food in Africa, policy responses on the continent remain largely siloed: energy ministries are tasked with delivering megawatts, agriculture ministries with increased yields, water authorities with allocating a declining resource, and land-use agencies often arbitrate among these demands too late in the process.[405]

In this triple crisis context, agrivoltaics – the co-location of agricultural production and solar photovoltaic (PV) generation on the same land – offers African countries a rare opportunity to tackle all three dimensions simultaneously. By deliberately sharing sunlight between crops or livestock and PV modules, agrivoltaic systems can increase land-use efficiency, buffer agriculture against heat and drought, and enable sustainable PV deployment where land competition is acute.[406,407] Critically, these benefits interact: by improving water productivity and reducing evapotranspiration, agrivoltaics links electrification to water savings and food security, making it a concrete energy–water–food nexus strategy. This article argues that agrivoltaics should move rapidly from experimental pilots to a strategic pillar of African energy, agriculture, and water policy.

1. Africa's intertwined energy–water–food challenge

1.1 Energy access and climate-vulnerable power systems

Roughly 600 million people in Sub-Saharan Africa lack access to electricity, and even among those connected, reliability is often poor and tariffs volatile.[408,409] Centralized grid infrastructure struggles to reach sparsely populated rural areas, where most of the population depends on subsistence agriculture.[410,411] In many countries, hydropower and large thermal plants dominate the power mix. Both are increasingly exposed to climate risk: hydropower to multi-year droughts, and fossil fuel plants to volatile fuel prices and foreign-exchange constraints.[412,413] Thermal power plants are also vulnerable to drought where they rely on freshwater cooling: reduced water availability (and higher water temperatures during heatwaves) can constrain cooling and force output reductions, which has pushed utilities in water-stressed systems to consider dry or hybrid cooling despite efficiency penalties. The 2015–2016 El Niño event in Southern Africa provides a stark example: reduced rainfall caused sharp declines in hydropower output, which in turn limited electricity available for irrigation pumping and food processing, amplifying food price spikes across the region.[414,415] Such episodes are likely to become more frequent as climate change alters rainfall patterns and raises temperatures.[416]

---

402 Segbedji Geraldo Favi et al., "Agrivoltaic Systems Offer Symbiotic Benefits across the Water-Energy-Food-Environment Nexus in West Africa: A Systematic Review," *Energy Research & Social Science* 117 (2024): 103737, https://doi.org/10.1016/j.erss.2024.103737.
403 FAO, *Renewable Energy and Agri-food Systems: Advancing Energy and Food Security towards Sustainable Development Goals* (IRENA and FAO, 2021), https://doi.org/10.4060/cb7433en.
404 Dhar, "Building Climate-Resilient Food Systems," 167.
405 Richard George Lawford, Rabi Mohtar, and Jill A. Engel-Cox, "Achieving Water-Energy-Food Nexus Sustainability: A Science and Data Need or a Need for Integrated Public Policy?" *Frontiers Research Topics* (2020), https://doi.org/10.3389/978-2-88966-105-3.
406 Randle-Boggis et al., "Harvesting the Sun Twice," 115066.
407 IEA PVPS Task 13, *Dual Land Use for Agriculture and Solar Power Production: Overview and Performance of Agrivoltaic Systems*, Report IEA-PVPS T13-29:2025 (IEA Photovoltaic Power Systems Programme (IEA PVPS), 2025), https://iea-pvps.org/wp-content/uploads/2025/03/IEA-PVPS-T13-29-2025-REPORT-Dual-Land-Use.pdf.
408 Ebhota and Tabakov, "Leveraging Agrivoltaics to Increase Food, Energy, and Water Access," 364–380.
409 Abubakar et al., "Deploying Agrivoltaics in Sub-Saharan Africa," 87810–87833.
410 *Ibid*
411 Favi et al., "Agrivoltaic Systems Offer Symbiotic Benefits," 103737.
412 Dhar, "Building Climate-Resilient Food Systems," 167.
413 W. S. Ebhota and P. Y. Tabakov, "Leveraging Agrivoltaics to Increase Food, Energy, and Water Access in the Global South: A Case Study Sub-Saharan Africa," *Nigerian Journal of Technology* 43, no. 2 (2024): 364–380, https://doi.org/10.4314/njt.v43i2.20.
414 Dhar, "Building Climate-Resilient Food Systems," 167.
415 Mohammed E. B. Abdalla et al., "A Pathway to Food and Energy Security: Agrivoltaic Potential in the MENA Region," *Energy Nexus* 21 (2025): 100610, https://doi.org/10.1016/j.nexus.2025.100610.
416 Dhar, "Building Climate-Resilient Food Systems," 167.

1.2 Water scarcity and climate-sensitive agriculture

Africa's agricultural systems are both the largest user of water resources and the most vulnerable sector to climate change. In West Africa, for example, about 95% of agricultural land depends on seasonal rainfall, and agricultural production is the primary driver of rural incomes.[417] Yet, projected demographic growth, urbanization and climate change are all expected to intensify pressure on limited water resources and increase the volatility of both river flows and shallow aquifers.[418,419] Rainfed smallholders have limited capacity and resilience to deal with dry spells. Without access to affordable, low-carbon energy for irrigation and on-farm water management, farmers in arid and semi-arid lands face a high risk of repeated crop failures, livestock losses and forced displacement.[420,421] For example, drought emergencies in the Horn of Africa, including Somalia, show how quickly failed rains, insufficient storage and weak social protection systems can translate into acute hunger, mass displacement and heightened conflict risk.

1.3 Food insecurity and the limits of business-as-usual

Food insecurity in Africa is not simply a function of low yields. It is also a product of volatile production, underdeveloped value chains and limited access to energy for storage, processing and transport.[422] Many African countries already rely heavily on food imports and are among the most severely impacted by conflict and climate-induced shocks to global grain markets. These factors, combined with currency depreciation and rising logistics costs can rapidly translate into unaffordable staples and further loss of food sovereignty.[423,424,425] Continuing with a business-as-usual approach, expanding irrigation powered by diesel pumps, or developing vast ground-mounted PV parks that displace fertile land, risks further exacerbating the trade-offs between energy, water and food needs. In practice, this can mean more water consumption for irrigation at the expense of ecosystems and domestic supply, more energy used (and paid for) to pump and distribute that water, and less land available for food production where solar competes with agriculture. Furthermore, diesel-based irrigation raises greenhouse-gas emissions and exposes farmers to fuel price volatility, while large PV parks can exacerbate local land conflicts if they are perceived as displacing food production or traditional land rights.[426,427,428] What is needed instead is a shift toward integrated solutions that explicitly pursue energy, water and food objectives together, and that leverage Africa's structural advantages: high solar irradiance, a young workforce, abundant marginal land and a rapidly growing demand for electricity.

2. Why agrivoltaics is especially suited to Africa?

Agrivoltaics directly responds to the core shortcomings of siloed policy in Africa by integrating food, energy and water objectives at the level of the field.[429] It does so in four main ways:

1. **Optimising land use and reducing land-use conflict.** By stacking energy and food production vertically, agrivoltaics decouple PV deployment from the conversion of agricultural land to energy-only uses. Land-equivalent-ratio (LER) analyses from multiple regions show that combined crop-plus-electricity productivity per hectare can exceed that of either use alone, often by 20–70% or more, depending on crop choice and

[417] Favi et al., "Agrivoltaic Systems Offer Symbiotic Benefits," 103737.
[418] *Ibid*
[419] Lawford, Mohtar, and Engel-Cox, "Achieving Water-Energy-Food Nexus Sustainability?"
[420] Favi et al., "Agrivoltaic Systems Offer Symbiotic Benefits," 103737.
[421] FAO, *Renewable Energy and Agri-food Systems*.
[422] Ebhota and Tabakov, "Leveraging Agrivoltaics to Increase Food, Energy, and Water Access," 364–380.
[423] *Ibid*
[424] Lawford, Mohtar, and Engel-Cox, "Achieving Water-Energy-Food Nexus Sustainability?"
[425] The right of peoples and nations to define their own sustainable, culturally appropriate food and agricultural policies.
[426] Ebhota and Tabakov, "Leveraging Agrivoltaics to Increase Food, Energy, and Water Access," 364–380.
[427] Dhar, "Building Climate-Resilient Food Systems," 167.
[428] Mohammad Abdullah Al Mamun et al., "A Review of Research on Agrivoltaic Systems," *Renewable and Sustainable Energy Reviews* 161 (2022): 112351, https://doi.org/10.1016/j.rser.2022.112351.
[429] Ambe Emmanuel Cheo et al., "Agrivoltaics across the Water-Energy-Food-Nexus in Africa: Opportunities and Challenges for Rural Communities in Mali" (Springer Science and Business Media LLC, 2022), https://doi.org/10.21203/rs.3.rs-1503422/v1.

system design.[430,431,432]

2. **Improving crop microclimates and water-use efficiency.** Elevated PV modules partially shade crops, reducing heat stress and evapotranspiration, which can improve yields for shade-tolerant species and increase crop-per-drop (kg/m³) in water-limited environments, thereby reducing irrigation requirements and overall consumptive water use.[433,434]

3. **Providing decentralised, low-carbon electricity for rural areas.** Agrivoltaic arrays can be configured as off-grid mini-grids or grid-tied systems, supplying power for irrigation, cold storage, processing and rural services, thereby raising farm incomes and improving the resilience of local food systems.[435,436]

4. **Creating new income streams and jobs in rural communities.** When properly structured, agrivoltaic projects provide farmers with dual income streams (from crops and from electricity sales or lease payments) while creating skilled jobs for installation, operation and maintenance. [437,438,439]

These features make agrivoltaics particularly attractive for African contexts where: (i) solar resources are abundant (4–7 kWh/m²/day in much of East and West Africa); (ii) most agriculture is rainfed and climate-sensitive; and (iii) central grids are weak or absent.[440,441,442]

3. Emerging evidence: what agrivoltaics can deliver

Although agrivoltaics in Africa remains at an early stage, the first generation of experiments and case studies is promising and aligns with findings from more mature markets. Early evidence is now coming from operational systems in Tanzania and Kenya, emerging pilots and modelling in West Africa/the Sahel (including Niger), and policy and technical lessons from Europe and Asia (France, Germany, Italy, Japan). Together suggesting strong potential, but also the need for context-specific crop and system design.

3.1 East Africa: field evidence from Tanzania and Kenya

A landmark multi-season study in Tanzania and Kenya assessed two fully operational agrivoltaic systems: a 36.6 kWp off-grid array in semi-arid Tanzania and a 62.1 kWp grid-tied system at a commercial agribusiness in Kenya.[443] Key findings include:

- **Water savings and rainwater harvesting.** At the Tanzanian site, soil moisture under the panels was substantially higher than in open control plots, and total irrigation water use was reduced by 12.6% over the study period, with seasonal savings of up to 21.7% in the driest season.[444] A simple guttering system on the lower edges of the panels channeled runoff into a 10,000 liter tank; harvested rainwater provided around 12–13% of the agrivoltaic plot's irrigation during one season and reduced demand on the central irrigation system by about 14%.[445]

- **Yield and water-productivity gains for specific crops.** Beans and Swiss chard grown under the agrivoltaic structures produced significantly higher yields than in open fields, while requiring less irrigation water per kilogram of output.[446] Leafy greens grown during a dry period showed particularly large improvements in yield-per-unit-water, underscoring the potential of agrivoltaics to stabilise the production of nutritious crops under drought stress.[447]

- **Energy access and cost savings.** The off-grid Tanzanian system generated around 12.5 MWh

[430] Randle-Boggis et al., "Harvesting the Sun Twice," 115066.
[431] Ebhota and Tabakov, "Leveraging Agrivoltaics to Increase Food, Energy, and Water Access," 364–380.
[432] R. K. Chopdar et al., "Comprehensive Review on Agrivoltaics with Technical, Environmental and Societal Insights," *Renewable and Sustainable Energy Reviews* 197 (2024): 114416, https://doi.org/10.1016/j.rser.2024.114416.
[433] Randle-Boggis et al., "Harvesting the Sun Twice," 115066.
[434] Chopdar et al., "Comprehensive Review on Agrivoltaics," 114416.
[435] Randle-Boggis et al., "Harvesting the Sun Twice," 115066.
[436] FAO, *Renewable Energy and Agri-food Systems*.
[437] Randle-Boggis et al., "Harvesting the Sun Twice," 115066.
[438] Ebhota and Tabakov, "Leveraging Agrivoltaics to Increase Food, Energy, and Water Access," 364–380.
[439] Uzair Jamil and Joshua M. Pearce, "Energy Policy for Agrivoltaics in Alberta Canada," *Energies* 16, no. 1 (2022): 53, https://doi.org/10.3390/en16010053.
[440] Randle-Boggis et al., "Harvesting the Sun Twice," 115066.
[441] Favi et al., "Agrivoltaic Systems Offer Symbiotic Benefits," 103737.
[442] FAO, *Renewable Energy and Agri-food Systems*.
[443] Randle-Boggis et al., "Harvesting the Sun Twice," 115066.
[444] *Ibid*
[445] *Ibid*
[446] *Ibid*
[447] Randle-Boggis et al., "Harvesting the Sun Twice," 115066.

per year, providing sufficient power for irrigation and farm operations and offsetting diesel costs that would otherwise have been incurred for pumping. The grid-tied Kenyan system supplied roughly 58% of the farm's electricity consumption, reducing operating expenses and enabling reinvestment in training facilities.[448]

Crucially, the study emphasized that not all crops benefit equally; shade-tolerant vegetables and legumes performed better than some solanaceae crops, underscoring the importance of context-specific crop selection and system design.[449]

3.2 West Africa and the Sahel: potential and early pilots

In West Africa, agrivoltaics is beginning to move from concept to practice. A systematic review of the water–energy–food–land nexus in the region concludes that agrivoltaic systems can mitigate competition between solar development and agriculture, support solar-powered irrigation and provide clean electricity for agrifood processing.[450] Emerging pilot projects in countries such as Ghana, Togo, Benin and Mali are exploring different configurations, including full-density panel arrays with rainwater collection and checkerboard layouts above vegetables.[451]

Economic modelling from Niger provides an instructive example. A 0.15 ha agrivoltaic system was compared to three alternatives: traditional rainfed farming, diesel-powered irrigation and solar-pumped irrigation.[452] Under realistic assumptions, the agrivoltaic case achieved a land-equivalent ratio between 1.13 and 1.33 (depending on assumed shading-induced yield losses) - an LER >1 indicating that the yields are higher in comparison to an *ex ante* scenario. Moreover, it could supply electricity to roughly 400 nearby households, assuming typical rural consumption levels.[453,454] All economic indicators (gross margin, benefit–cost ratio and net present value) were positive for the agrivoltaic and solar-irrigation cases, but negative for diesel-based irrigation, illustrating both the financial and environmental advantages of coupling PV with farming rather than relying on fossil fuel pumps.[455]

3.3 Lessons from more mature markets

Experience from Europe and Asia can inform African policy design, even though agro-ecological and socio-economic conditions differ. In France, Germany, Italy and Japan, agrivoltaics has evolved from pilot projects to a recognized class of dual-use infrastructure, often supported by dedicated incentives or regulatory frameworks.[456]

Studies in temperate regions have documented significant improvements in water-use efficiency and microclimate regulation under elevated PV arrays, alongside modest yield gains for some shade-tolerant crops and minor yield penalties for others, depending on panel density. [457,458] Evidence from European orchards and vineyards shows that agrivoltaics can protect high-value fruits from hail, sunburn and extreme heat, while producing substantial electricity and maintaining farm viability.[459,460,461]

For Africa, international experience demonstrates that robust legal definitions and performance standards can prevent "green-washing" of conventional PV farms as agrivoltaics; feed-in premiums or auction bonuses tied to agricultural performance criteria can steer investment toward genuine dual-use projects; and farmer engagement

[448] *Ibid*
[449] *Ibid*
[450] Favi et al., "Agrivoltaic Systems Offer Symbiotic Benefits," 103737.
[451] Randle-Boggis et al., "Harvesting the Sun Twice," 115066.
[452] Srijana Neupane Bhandari et al., "Economic Feasibility of Agrivoltaic Systems in Food-Energy Nexus Context: Modelling and a Case Study in Niger," *Agronomy* 11, no. 10 (2021): 1906, https://doi.org/10.3390/agronomy11101906.
[453] Bhandari et al., "Economic Feasibility of Agrivoltaic Systems," 1906.
[454] Diego Soto-Gómez, "Integration of Crops, Livestock, and Solar Panels: A Review of Agrivoltaic Systems," *Agronomy* 14, no. 8 (2024): 1824, https://doi.org/10.3390/agronomy14081824.
[455] Diego Soto-Gómez, "Integration of Crops, Livestock, and Solar Panels: A Review of Agrivoltaic Systems," *Agronomy* 14, no. 8 (2024): 1824, https://doi.org/10.3390/agronomy14081824.
[456] IEA PVPS Task 13, *Dual Land Use for Agriculture and Solar Power Production*.
[457] Randle-Boggis et al., "Harvesting the Sun Twice," 115066.
[458] Chopdar et al., "Comprehensive Review on Agrivoltaics," 114416.
[459] Ebhota and Tabakov, "Leveraging Agrivoltaics to Increase Food, Energy, and Water Access," 364–380.
[460] Abdalla et al., "Pathway to Food and Energy Security," 100610.
[461] IEA PVPS Task 13, *Dual Land Use for Agriculture and Solar Power Production*.

and community co-ownership models improve social acceptance and distribution of benefits.[462,463,464]

4. What is needed for agrivoltaics to flourish in Africa?

Realizing agrivoltaic opportunities in Africa will require deliberate policy and governance innovations rather than a simple transfer of hardware. Several key enabling conditions stand out as areas for focus, especially in Africa.

4.1 Clear definitions and land-use rules

First, African governments need to define what counts as agrivoltaics in their own legal and planning frameworks, distinguishing it clearly from conventional ground-mounted PV.[465] International practice suggests that meaningful dual use requires agriculture to remain the primary land use, with PV a secondary activity that enhances rather than replaces production. [466]

Regulatory criteria can include: minimum thresholds for agricultural yield (for example, a percentage of historical yields or a minimum LER); limits on the share of land that can be rendered uncultivable by foundations or service roads; panel-height and spacing requirements to allow machinery, livestock or manual labour to operate under and between rows; and obligations for long-term monitoring of both PV and agricultural performance.[467] Such definitions help preserve food production, give clarity to developers and financiers, and reduce the risk of backlash from farmers and civil society.

4.2 Cross-sector coordination and nexus-oriented planning

Second, agrivoltaics must be anchored in cross-sectoral planning that aligns energy, agriculture, water and land-use goals.[468] This has happened elsewhere: in Japan, "solar sharing" has been enabled through an explicit coupling of agricultural land-use permissions with energy policy instruments, while France's recent agrivoltaics framework similarly reflects joint agricultural–energy governance by tying PV deployment on farmland to continued agricultural activity and performance. The water–energy–food nexus literature underscores that uncoordinated investments, such as subsidized solar pumps without groundwater governance, or irrigation schemes powered by emissions-intensive electricity, can create new risks even as they solve old ones.[469,470]

Practical steps include: establishing inter-ministerial task forces or "nexus units" with a mandate to design agrivoltaic strategies; integrating agrivoltaics into national electrification plans, agricultural development programs and water-resource strategies; and, using spatial planning tools to map zones where agrivoltaics would deliver the highest combined benefits (for example, irrigated horticulture belts, peri-urban food-sheds or drought-prone semi-arid lands). [471,472]

4.3 Economic instruments and financing

Third, economic incentives must reflect agrivoltaics' contributions to energy, water and food systems. Evidence from Europe and Japan shows that targeted feed-in premiums, tender bonuses or investment grants can successfully steer capital toward agrivoltaic projects, especially in the early stages of market development.[473,474]

For African countries, hybrid incentives drawing on energy, water and agriculture budgets could offer higher tariffs or auction scoring for projects that meet specified agricultural performance benchmarks (for example, yield retention or LER thresholds); provide capital subsidies or concessional loans for agrivoltaic mini-grids that serve off-grid farming communities; and, support farmer-led cooperatives or public-private partnerships that keep a significant

[462] Randle-Boggis et al., "Harvesting the Sun Twice," 115066.
[463] IEA PVPS Task 13, *Dual Land Use for Agriculture and Solar Power Production*.
[464] André Alves, Eduarda Marques da Costa, and Igor Sirnik, "The Policy Landscape of Agrivoltaics: A Systematic Review," *Energy, Sustainability and Society* (2025), https://doi.org/10.1186/s13705-025-00555-7.
[465] IEA PVPS Task 13, *Dual Land Use for Agriculture and Solar Power Production*.
[466] *Ibid*
[467] *Ibid*
[468] Cheo et al., "Agrivoltaics across the Water-Energy-Food-Nexus in Africa."
[469] Dhar, "Building Climate-Resilient Food Systems," 167.
[470] Lawford, Mohtar, and Engel-Cox, "Achieving Water-Energy-Food Nexus Sustainability?"
[471] Randle-Boggis et al., "Harvesting the Sun Twice," 115066.
[472] IEA PVPS Task 13, *Dual Land Use for Agriculture and Solar Power Production*.
[473] Randle-Boggis et al., "Harvesting the Sun Twice," 115066.
[474] Alves, Costa, and Sirnik, "Policy Landscape of Agrivoltaics."

share of project value in rural areas.[475,476] Given that agrivoltaics directly advance multiple SDGs such as: Zero Hunger (SDG 2), Affordable and Clean Energy (SDG 7), Climate Action (SDG 13) and Sustainable Water Management (SDG 6). They are strong candidates for green bonds, climate funds and adaptation finance.[477,478,479]

4.4 Capacity-building, social acceptance and political economy

Fourth, agrivoltaic deployment will be shaped by political-economy dynamics: ministries may guard their mandates; large solar developers may prefer simpler, single-use projects; and farmers may fear loss of land or control.[480,481] Research from Europe and North America highlights that social acceptance hinges on transparent benefit-sharing, visible continuation of farming and genuine participation of local stakeholders in system design.[482]

In Africa, this implies systematic awareness-raising among farmers, extension agents, financial institutions and local authorities; integration of agrivoltaics into agricultural extension services and vocational training; participatory design processes that respect customary land-tenure systems and gender dynamics; and business models that give farmers an active, remunerated role rather than relegating them to passive land-lessors.[483,484]

Finally, governance of water is critical. Solar-powered irrigation can dramatically lower the marginal cost of pumping, and without safeguards it may lead to groundwater over-abstraction.[485,486] Coupling agrivoltaics with smart irrigation (for example, drip systems and soil-moisture sensors) and with community-based water-allocation rules reduces this risk and aligns projects with long-term resource sustainability.[487,488,489]

Conclusion: From niche innovation to strategic pillar

Agrivoltaics is not a silver bullet, but it is one of the most compelling practical embodiments of the energy–water–food nexus currently available. By harvesting the sun twice, agrivoltaic systems can: expand clean, decentralized electricity access in rural Africa; reduce crop exposure to heat and drought stress while improving water-use efficiency; (similar benefits for livestock, poultry, beehives, and/or fish ponds that are maintained underneath panels); lower pressure to convert forests or high-value farmland into single-use energy infrastructure; and, create new income streams and employment opportunities in places where alternatives are scarce.[490,491,492]

For African governments and their development partners, agrivoltaics should no longer be treated as an experimental niche but as a strategic pillar of energy, agricultural and water policy. The building blocks are clear: define agrivoltaics in law, align incentives with dual-use outcomes, strengthen cross-sector coordination, and invest in pilots and capacity-building that demonstrate benefits for farmers and communities.[493]

If these steps are taken, agrivoltaics can help African countries navigate an increasingly volatile climate, reduce long-term land-use conflicts between food and energy, and accelerate progress toward food sovereignty, water security and universal access to modern energy.[494,495,496] ■

475 Bhandari et al., "Economic Feasibility of Agrivoltaic Systems," 1906.
476 IEA PVPS Task 13, *Dual Land Use for Agriculture and Solar Power Production*.
477 Randle-Boggis et al., "Harvesting the Sun Twice," 115066.
478 Walston, Leroy J. et al.. "Opportunities for agrivoltaic systems to achieve synergistic food-energy-environmental needs and address sustainability goals." Frontiers in Sustainable Food Systems 6 (2022). https://doi.org/10.3389/fsufs.2022.932018.
479 FAO, *Renewable Energy and Agri-food Systems*.
480 Jamil and Pearce, "Energy Policy for Agrivoltaics," 53.
481 IEA PVPS Task 13, *Dual Land Use for Agriculture and Solar Power Production*.
482 *Ibid*
483 Favi et al., "Agrivoltaic Systems Offer Symbiotic Benefits," 103737.
484 Jamil and Pearce, "Energy Policy for Agrivoltaics," 53.
485 Dhar, "Building Climate-Resilient Food Systems," 167.
486 Lawford, Mohtar, and Engel-Cox, "Achieving Water-Energy-Food Nexus Sustainability?"
487 Dhar, "Building Climate-Resilient Food Systems," 167.
488 FAO, *Renewable Energy and Agri-food Systems*.
489 Lawford, Mohtar, and Engel-Cox, "Achieving Water-Energy-Food Nexus Sustainability?"
490 Randle-Boggis et al., "Harvesting the Sun Twice," 115066.
491 Ebhota and Tabakov, "Leveraging Agrivoltaics to Increase Food, Energy, and Water Access," 364–380.
492 Favi et al., "Agrivoltaic Systems Offer Symbiotic Benefits," 103737.
493 IEA PVPS Task 13, *Dual Land Use for Agriculture and Solar Power Production*.
494 Randle-Boggis et al., "Harvesting the Sun Twice," 115066.
495 Ebhota and Tabakov, "Leveraging Agrivoltaics to Increase Food, Energy, and Water Access," 364–380.
496 IEA PVPS Task 13, *Dual Land Use for Agriculture and Solar Power Production*.