

Social and Environmental Trade-Offs and Safeguards in Hydrogen Production in the Middle East and North Africa Region

Insights from Morocco and Oman

Tobias Zumbraegel



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Preface

The adoption of hydrogen strategies by Germany (*Nationale Wasserstoffstrategie*, NWS) and the European Union (EU) in 2020, and follow-up strategy papers such as the update of the NWS in 2023 and the Hydrogen Import Strategy in 2024 have triggered manifold research activities by academic and policy-oriented research institutions in Germany and beyond. The German Institute of Development and Sustainability (IDOS) has been involved in these activities from the outset; among other things, it contributed to the multi-institutional “HyPat project (H₂ Potential Atlas)”. In line with its mandate, IDOS has so far focused primarily on the question of what potential an evolving global hydrogen economy could have for low- and middle-income countries, and what policy and international cooperation can do to help unfold the potential of such an economy and minimise possible risks. IDOS has conducted a series of country case studies (Costa Rica, South Africa, Turkey, Namibia); most of these can be downloaded from the HyPat project’s website. A research team from the IDOS postgraduate programme also conducted studies on Argentina and Uruguay.

It is apparent that a fully fledged hydrogen economy in Europe and Germany cannot be conceptualised without far-reaching changes to international energy trade patterns and supply chains. Europe has neither enough space nor renewable energy potential to produce the quantities of green hydrogen and derivatives that would be required to decarbonise its energy-intensive industries (refineries, iron and steel) and long-distance and heavy goods transport. A win–win scenario would be for countries in the Global South to produce hydrogen as a commodity, and for Germany and the rest of Europe to provide the required technologies and then to import hydrogen. However, this is by no means a given.

Whether hydrogen trade becomes a win-win scenario depends on how its benefits and costs are distributed. Some research in Germany has focused more strongly on issues of justice, power dynamics, and distribution, as well as on the potential environmental consequences of a hydrogen economy that may emerge, and has sought to proactively identify potential problems and challenges in this area. Although IDOS policy-oriented research has, in some respects, had a different focus so far, and we may not agree with all the conclusions drawn in publications in this field, we consider them to be very important. Against this background, the present study on the future development of the hydrogen economy in Oman and Morocco has been commissioned. As with our other publications, we invite critical discussion. We kindly ask you to direct any enquiries to the author.

Abstract

Several countries in the Middle East and North Africa (MENA) have launched initiatives to produce green hydrogen for their own use and for export, raising the question of what environmental and social effects such initiatives may generate, and how these can be anticipated and mitigated. Oman and Morocco are among the region's frontrunners. Because all projects in these countries are still in the preparatory phase and no large-scale facility is yet in commercial operation, they offer the unusual opportunity to observe how safeguards, stakeholder participation and risk management are being configured before build-out, that is, before conditions are created that may not be easily reversed, thereby creating path dependencies.

Drawing on desk-based analysis, a comparative media review, and stakeholder interviews conducted in both countries, this study examines the environmental and social impacts of hydrogen projects in the two countries through the lens of four inter-related dimensions: (i) resource endowments, (ii) environmental risks, (iii) decision-making and governance arrangements, and (iv) social equity dynamics. It finds that the two states have developed different institutional settlements.

While environmental and social safeguards are increasingly integrated into hydrogen development, often drawing on international standards, their practical implementation often remains shaped by complex and fragmented institutional arrangements. This raises questions about the allocation of mandates, the distribution of responsibilities, the consistency of procedures and the capacity for long-term monitoring and traceability. The study therefore argues that institutional design is central to sustainable hydrogen development, as environmental and social risks may otherwise evolve faster than regulatory capacities, highlighting the need for robust impact assessment, monitoring frameworks and transparent reporting mechanisms.

Keywords: Low-carbon hydrogen; sustainability tradeoffs; safeguards; Oman; Morocco; resources; decision-making; governance; social equity; local value creation

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Abbreviations

CCS	carbon capture and storage
CCUS	carbon capture, utilisation and storage
CSP	concentrated solar power
CO ₂	carbon dioxide
EGR	enhanced gas recovery
EOR	enhanced oil recovery
EIA	environmental impact assessment
EIB	European Investment Bank
ESIA	environmental and social impact assessment
EMP	environmental management plan
FEED	front-end engineering and design
FID	final investment decision
GIZ	German Agency for International Cooperation
H ₂	hydrogen
Hydrom	Hydrogen Oman
IRESN	Institute for Research in Solar Energy and New Energies
kWh/m ²	kilowatt-hours per square metre
MASEN	Moroccan Agency for Sustainable Energy
MEM	Ministry of Energy and Minerals (Oman)
MENA	Middle East and North Africa
m/s	metres per second
OQGN	OQ Gas Networks (Oman)
PDO	Petroleum Development Oman
SEZ	special economic zone
SEZAD	Special Economic Zone Authority Duqm
SMEs	small and medium-sized enterprises
UV	ultraviolet

1 Introduction

There's this general assumption that more environmental protection is automatically bad for business because it makes everything more expensive. And that's obviously particularly problematic in a market [the hydrogen market] that doesn't really exist yet. So, of course, that's a clear conflict of goals.¹

This quote from one of the interviews conducted for this study captures a central tension in the emerging hydrogen economy: while green hydrogen is promoted as a major business opportunity and a cornerstone of the low-carbon transition, its commercial viability is often perceived to depend on minimising costs, potentially at the expense of broader environmental and social objectives. Oman and Morocco provide particularly useful test cases because both seek to establish themselves as leading production, and potentially export, hubs for green hydrogen, while facing constraints related to scarce water resources, land availability, ecological vulnerability and institutional capacity. At the same time, key export clients and financiers, particularly the EU, continue to emphasise sustainability requirements, even as growing competitive pressure raises concerns about the cost of compliance. This tension has become increasingly visible in Brussels, where policymakers are debating whether previously ambitious sustainability regulations should be simplified, softened or postponed in order to accelerate the low-carbon hydrogen ramp up and reduce regulatory burdens (Monciardini, 2025).

Against this backdrop, this study examines how the imperative to rapidly scale up a commercially viable hydrogen economy may reinforce trade-offs between economic competitiveness and robust environmental and social safeguards. By analysing these tensions, the study investigates how efforts to establish a globally competitive hydrogen sector intersect with questions of environmental protection, governance quality, resource justice and the equitable distribution of costs and benefits.

Throughout its more than 200-year history, hydrogen has repeatedly experienced cycles of intense enthusiasm followed by periods of disillusionment and reassessment (Heymann & Wengenroth, 2009). The present moment is no exception. After a surge of global interest in recent years, the hydrogen economy has entered a more sober phase, characterised by growing scepticism, delayed final investment decisions, and recalibrated demand forecasts (Kalt & Cezne, 2026). Technical, logistical and safety challenges compound the uncertainty: hydrogen is colourless, odourless and highly mobile, requiring careful handling, storage and transport (Griffiths et al., 2021; Hine et al., 2024). These technical complexities intersect with environmental and social considerations, making it essential to examine not just economic viability but also potential impacts on communities, ecosystems and regional resource governance.

At the same time, many of the currently discussed hydrogen projects are still in very early planning or pilot stages, meaning that many of their environmental, social and political risks cannot yet be fully assessed. As a result, the findings of this study must also be seen as anticipatory. They may be helpful, though, because it is important to identify potential negative repercussions at an early stage in order to make efforts in time to find more socially and environmentally sustainable governance pathways before harmful lock-ins and long-term impacts become entrenched.

So far, research on hydrogen has primarily focused on techno-economic assessments, including energy efficiency and production pathways, where the “colour taxonomy” is used to distinguish different forms of hydrogen according to their production methods and associated carbon intensity. For example, grey and brown hydrogen is produced from fossil fuels, as is blue hydrogen, which minimises greenhouse gas emissions with carbon capture and storage. Green

1 Interview with an international hydrogen financing expert

hydrogen is produced through electrolysis powered by renewable energy (Chew et al., 2023; Howarth & Jacobson, 2021; Staffell et al., 2019). While these analyses remain important, they often neglect social and environmental consequences and pressure, particularly in resource-limited and export-oriented contexts.

Only recently, some studies have begun to fill this gap, highlighting how hydrogen projects, especially in the Global South, can exacerbate existing inequalities and create new environmental pressures (Dillman & Heinonen, 2022; Kalt et al., 2023; Tunn et al., 2024). Large-scale green hydrogen production entails substantial trade-offs, including land-use pressures, freshwater consumption in arid regions, potential biodiversity loss, and social displacement, all of which complicate the promise of a “clean” energy transition (Fladvad, 2023; Gasparatos et al., 2017; Sovacool, 2021; Sovacool et al., 2019, 2020).

This study focuses on Oman and Morocco, two countries positioned as frontrunners in hydrogen development and potential export in the MENA region. Both countries benefit from exceptional renewable energy endowments, political commitment and regulatory frameworks aligned with international standards. Yet their development pathways illustrate that resource abundance alone does not guarantee equitable or environmentally sustainable outcomes. Early observations reveal that regulatory rigour, participatory planning and local capacity building are decisive in determining whether hydrogen projects foster inclusive and sustainable development or entrench existing vulnerabilities.

The present research examines three interrelated questions: What are the potential environmental and social effects associated with emerging hydrogen development in the MENA region? How significant are these potential effects? And what practical interventions could mitigate risks and promote socially and environmentally sustainable hydrogen projects?

Methodologically, the study combines desk-based analysis, including a comprehensive media review, with field research, including stakeholder interviews, to capture anticipated impacts. The remainder of the study proceeds in a deliberately progressive manner, moving from the general analytical framework to the regional context and, finally, to the two country cases. Chapter 2 establishes the analytical framework, introducing four interrelated aspects of social and environmental development – resource endowments, environmental risks, governance dynamics and social equity dynamics – to be studied in subsequent chapters. Chapter 3 provides the substantive foundation for this framework by reviewing potential social and environmental effects and safeguards across the hydrogen value chain. Chapter 4 sets out the research questions and methods. Chapter 5 applies the framework to the MENA region. Chapter 6 examines how these dynamics play out in the specific contexts of Oman and Morocco. Chapter 7 synthesises comparative lessons, and Chapter 8 concludes.

2 Conceptual framework: sustainability trade-offs and the hydrogen transition

The global sustainability transformation is marked by profound and persistent tensions between goals. Conflicts arise, for example, between climate change mitigation and social justice, between the use of a technique and its potential environmental effects, and between aspirations for national energy sovereignty and the imperatives of global cooperation. Policies addressing climate change have never followed a linear or technocratic path; rather, they unfold within complex interdependencies and competing objectives that generate overlaps, trade-offs and difficult political choices. As knowledge expands and societal assumptions evolve, decision-making often becomes even more intricate. What may once have appeared to be a clear or “optimal” pathway can, in light of new evidence or shifting normative frameworks, reveal hidden costs, distributional effects or long-term environmental risks: interactions among sustainability

goals frequently produce synergies but also entail significant trade-offs, complicating efforts to define a singular “right” approach (Nilsson et al., 2016).

The production of hydrogen reproduces the structural trade-offs already known from electricity systems (security, sustainability, sovereignty) and adds a fourth pressure: the geographic externalisation of environmental costs to producer regions. Thaler and Hofmann (2022) speak of an “impossible energy trinity” in which no country can fully achieve security, sustainability and sovereignty at once. For hydrogen production, the trinity becomes a quadrilemma, since the costs of pursuing one combination tend to fall on host communities far from the consuming markets. This externalisation is what the four analytical dimensions below are designed to make visible: where the costs of hydrogen development are located (resource endowments), what form these costs and associated risks take (environmental risks), who decides how they are allocated (governance dynamics), and who ultimately bears them (social equity dynamics). Against this backdrop, the rollout of hydrogen production forces governments to deal with trade-offs across four dimensions, which this study uses as its analytical spine: resource endowments (land, water, minerals, renewable potential); environmental risks (emissions, hydrogen and methane leakage, brine, ammonia handling, ecosystem disruption); governance dynamics (planning, regulation, transparency, coordination, parliamentary review); and social equity dynamics (exclusion, benefit-sharing, labour conditions, displacement, distributional justice) (Cezne & Otsuki, 2025; Hine et al., 2024; Lehmann & Wiertz, 2025; Virens, 2024).

The four categories are not independent of one another. Resource endowments determine where pressure on water, land and biodiversity concentrates. Environmental risks emerge from how that resource use is operationalised. Governance dynamics shape who gets to assess, monitor and mitigate those risks. Social equity dynamics shape who carries the residual burden when assessment and monitoring fall short (Cezne & Otsuki, 2025; DeBoom, 2025; Müller et al., 2022; Zumbraegel, 2025b). Causality runs across the categories in both directions: weak governance amplifies environmental risk; concentrated environmental risk produces equity damage; and unequal benefit distribution erodes the political space needed for stronger governance.

Resource endowments in hydrogen are not just about how much sun, wind or water a country has. They also concern infrastructure inheritance (deep-water ports, gas pipelines, ammonia plants, refineries), mineral availability for electrolyzers and fuel cells (notably platinum group metals; lithium and cobalt matter more for batteries than for hydrogen-specific equipment), and the institutional capacity to manage these assets. Continuity from the fossil-fuel era matters: early hydrogen and renewable rollouts in the MENA region already reproduce many of the same patterns – state-coordinated, capital-intensive, export-oriented projects – while being steered by many of the same actors. Rather than a break with the hydrocarbon order, hydrogen strategies in the Gulf and wider MENA increasingly function as a diversification of that order: using oil and gas rents to finance large-scale, centrally planned energy projects that preserve the strategic importance of incumbent state and corporate actors (Koch, 2022; Zumbraegel, 2022, 2025b).

Environmental risks span the full value chain. Hydrogen leakage matters because hydrogen is an indirect greenhouse gas. In the case of blue hydrogen, methane leakage along the natural-gas chain undermines the climate case for it. Underperforming carbon capture storage (CCS) or carbon capture, utilisation and storage (CCUS) does the same. Desalination produces brine; ammonia produces toxicity exposure; large-scale renewable installations alter habitats. None of these are certainties; they are risks whose materialisation depends on technology choice, operational rigour and regulatory enforcement, which is why this study labels them risks rather than outcomes.

Governance dynamics concern how hydrogen-related decisions get made, monitored and adjusted. Three elements recur in the empirical chapters: degree of centralisation, transparency of contracts and of environmental and social impact assessments (ESIAs), and the strength of

independent oversight (parliamentary, judicial, civil society). Centralisation per se is not the problem; centralisation without procedural rights for affected communities is.

Finally, social equity dynamics concern who benefits and who bears residual costs. Availability of skills among the workforce, local content requirements and benefit-sharing mechanisms are the variables that determine whether hydrogen rollout broadens economic opportunity or concentrates it among existing elites.

3 Social and environmental effects and safeguards in the hydrogen economy

Social and environmental pressure points are distributed unevenly across the hydrogen value chain, but four moments concentrate most of the risk: planning and governance, upstream materials, production and operation, and downstream distribution. This chapter walks through each and identifies which safeguards are realistic at each stage.

The planning phase is where most of the distributional damage gets locked in. Once concession blocks, offtake terms and land-use rights are signed, communities have very little leverage to claw back their voice. Anticipated benefits risk being captured by political and economic elites, while local communities are excluded from siting, investment and technology decisions (Kalt & Cezne, 2026; Virens, 2024). Negotiations over project development and financing frequently take place primarily between international investors and government representatives, with limited transparency (Gabor & Sylla, 2023; Lindner, 2023; Zumbraegel, 2025b). Without participatory governance mechanisms, economic gains may therefore concentrate among investors, corporations and state actors, with limited local spillovers. The absence of harmonised rules further increases the likelihood that projects prioritise short-term gains over long-term safety, environmental and social considerations (Bade & Tomomewo, 2024; Griffiths et al., 2021; Hancher & Suciu, 2024).

Upstream, the hydrogen value chain is characterised by new forms of energy resource appropriation rather than mineral extraction in the conventional sense. Hydrogen is not a naturally occurring resource; it is produced, so the upstream politics are about renewable electricity, electrolyser manufacturing, and the few minerals (notably platinum group metals) that hydrogen-specific equipment requires (Cezne & Otsuki, 2025; Dillman & Heinonen, 2022). Manufacturing, disposal and recycling of solar panels and wind turbines do generate hazardous waste streams, and supply-chain labour conditions in critical-mineral mining can be a concern in the Global South (Chigbu & Nweke-Eze, 2023; Forget & Bos, 2022; Koch, 2019; Lehmann & Wiertz, 2025; Marín & Goya, 2021).

In water-scarce export contexts (as pertains in the MENA context), the binding constraint on green hydrogen production is fresh water, brine management and land. Where desalinated seawater is used, brine discharge, marine-ecosystem stress, chemical residues and additional energy load can be challenges. Likewise, although green hydrogen is a new sector, its rollout is already being prepared through large-scale land allocations and infrastructure plans that reproduce familiar dynamics from renewable and extractive megaprojects: land acquisition and enclosure, restrictions on pastoral and agricultural use, and risks of displacement for local communities. Early case material from Namibia or South Africa shows that hydrogen ‘scapes’ are emerging through the same spatial and governance patterns – state-led land earmarking, investor-driven enclosure and marginalisation of customary land users – that have been documented for large solar, wind and mining projects (Chigbu & Nweke-Eze, 2023; Lehmann & Wiertz, 2025; Melber et al., 2025).

Blue hydrogen pathways involve a different set of risks. Beyond the quite common argument that blue hydrogen bears the risk of extending the economic life of fossil assets (Griffiths et al., 2021; Szabo, 2021; Unruh, 2000), there can be additional implicit and explicit social and environmental impacts. Communities located near fossil fuel extraction sites may continue to experience environmental degradation (e.g. soil erosion and eutrophication of water resources), negative health impacts and land-use pressures associated with oil and gas operations (Dillman & Heinonen, 2022; Roefs et al., 2019). Methane leakage along the natural-gas supply chain and potential underperformance of CCUS technologies may also undermine expected climate benefits (Howarth & Jacobson, 2021; Longden et al., 2022; in contrast: Bauer et al., 2022). Furthermore, economic risks may arise if investments in blue hydrogen infrastructure become stranded assets in the course of rapid decarbonisation, potentially affecting workers and regional economies dependent on fossil fuel industries (Ansari & Holz, 2020).

Pipelines, ports and ammonia handling are where local accident risk concentrates. Linear infrastructure fragments habitats and can affect indigenous or rural communities reliant on intact landscapes (Dillman & Heinonen, 2022; Gasparatos et al., 2017; Rehbein et al., 2020). Pipeline leaks or storage failures may contaminate soils, groundwater or marine environments, while hydrogen's mobility introduces detection and safety requirements that any deployment region must meet (Cezne & Otsuki, 2025; Falcone et al., 2021; Khan & Al-Ghamdi, 2023). Hydrogen's nearly invisible flame makes detection sensors a standard safety feature in virtually all hydrogen systems (Griffiths et al., 2021). Ammonia, the leading proposal for hydrogen export, is highly toxic (Klerke et al., 2008; Kojima, 2024). In addition, uncontrolled ammonia leakage and emissions contribute to acid deposition and ecosystem acidification: atmospheric ammonia reacts to form ammonium salts that, after deposition and nitrification in soils and waters, release protons and lower pH, thereby acidifying sensitive ecosystems (in addition to driving eutrophication and particulate-matter formation). Large volumes of conventional ammonia are already handled safely in agricultural and industrial applications, but scaling ammonia as a global energy carrier would substantially increase the stakes of any leakage or emission (Yu et al., 2024).

Downstream, the open question is who pays the cost premium of hydrogen-derived steel, chemicals and fuels. Early adoption of hydrogen mobility or industrial applications may primarily benefit high-income consumers and firms, while associated costs flow through to households via higher prices for energy-intensive goods and services, a pattern documented for decarbonisation policies more broadly, where relative increases in energy expenditures tend to be highest for low-income households (Ascari et al., 2026; Carley & Konisky, 2020; Dillman & Heinonen, 2022). In export-oriented producer countries the effect of hydrogen production on domestic energy prices depends on how electrolysis is integrated into the power system; under some designs, exports raise domestic electricity costs, while under others they leave domestic prices largely unchanged or even lower them (Schumm et al., 2025).

At the same time, the geopolitical reconfiguration of resource dependencies, from hydrocarbons to sun, wind and minerals, can produce new hierarchies that map unevenly onto existing development gaps: countries and firms that control key nodes in hydrogen value chains (renewable sites, electrolyser manufacturing, shipping, certification) may capture disproportionate value, while others risk being locked into raw-material or feedstock roles. Rather than assuming a clean break with fossil-fuel geopolitics, this suggests that hydrogen trade may reproduce and reconfigure, rather than erase, core-periphery dynamics in the global energy system (Kalt & Cezne, 2026; Scholten et al., 2020; Van de Graaf et al., 2020).

Table 1: Overview of potential social and environmental harm across the hydrogen value chain

Stage/ dimension	Main possible social and environmental risks	Typical mechanisms/examples
Planning & governance	Elite capture, exclusion of communities, unequal benefit sharing, regulatory uncertainty	Closed negotiations between governments and investors, limited transparency, weak participatory mechanisms, profits concentrating among corporations and state actors
Upstream materials & technologies (including green/blue hydrogen production as well as transport and infrastructure)	Environmental degradation and labour exploitation in supply chains including land disturbance, water pollution, hazardous waste, unsafe work and child labour	Critical mineral extraction causing habitat loss and water pollution, hazardous waste from solar and wind, unsafe work, low wages, child labour in Global South supply chains
	<u>Green hydrogen production</u> : Land and water conflicts, ecosystem pressure, agricultural displacement, and desalination-related impacts from brine, chemicals and additional energy demand.	Large solar/wind projects displacing agriculture, competing with food production, high water demand for electrolysis and desalination impacts (brine, chemicals, extra energy)
	<u>Blue hydrogen production</u> : Fossil lock-in, methane leakage, local air & water pollution, CCS underperformance, and stranded-asset risk.	Continued oil and gas extraction impacts on communities, methane leakage along gas chains, CCS not capturing as planned
	Hydrogen transport and infrastructure can cause habitat fragmentation, land-use conflicts, and public/worker safety risks across pipelines, storage, ports and terminals.	Pipeline corridors cutting through ecosystems and indigenous/rural lands, leak risks (soil, water, marine), explosion/asphyxiation hazards, centralised ownership and weak community participation
Downstream use & distribution	Distributional inequalities, energy poverty, new geopolitical dependencies	High technology and fuel costs passed to consumers, burden on low-income households, unequal access to hydrogen services, new hierarchies around sun, wind and mineral endowments

Source: Mainly based on Dillman & Heinonen, 2022

Despite highlighting the potential social and environmental risks associated with hydrogen development, it is equally important to recognise that there are potential abatement strategies and safeguards emerging (Fladvad, 2023) and that not all risks are necessarily imminent and acute, nor applicable to every region or specific location. Moreover, the extent of these effects may differ significantly depending on whether they manifest at the local, regional or global level.

Three safeguards keep recurring across the literature, but the evidence on whether they shift outcomes in practice is mixed. First, transparency on energy systems, investment structures

and environmental impacts is necessary for informed public debate and accountability (Dillman & Heinonen, 2022). Second, comprehensive ESIAAs are necessary to anticipate and manage potential risks (see below). Third, collaborative and participatory decision-making processes have been proposed as a way to give affected communities formal channels to shape project design and benefit-sharing arrangements, although evidence on whether such processes actually shift outcomes in their favour remains mixed: well-organised local interest groups can dominate consultation processes in ways that disadvantage less-organised communities, and even where public participation is legally mandated, empirical studies highlight persistent gaps in timing, access to information, and the substantive influence of public comments on final decisions (Dillman & Heinonen, 2022; Geißler et al., 2019; Suškevičs et al., 2023).

Box 1: Environmental and social impact assessments (ESIA)

Environmental and social impact assessments (ESIAs) are standard requirements for projects financed by various multilateral institutions. ESIAAs are a core requirement of international financial institutions (IFIs) and multilateral development banks (MDBs), and are implemented to screen, categorise and manage the environmental, social and climate-related risks of proposed projects in line with the institutions' safeguard frameworks and performance standards. IFI ESIAAs follow a structured process: screening and categorisation, scoping, baseline studies, impact prediction and evaluation, mitigation hierarchy (avoidance, minimisation, restoration, offset/compensation), preparation of an environmental and social management plan (ESMP), and monitoring and adaptive management, and are intended to be proportionate to the project's risk and to the receiving-country context.

Most hydrogen projects in the MENA and elsewhere are still at the planning or early-development stage, which makes the decision-making phase the critical moment for shaping the future (Kalt & Cezne, 2026). The following empirical investigation examines the social and environmental effects and safeguards of hydrogen production in two countries: Oman and Morocco. It focuses primarily on green hydrogen, while also considering blue hydrogen in one of the cases. The analysis concentrates mainly on the national context and on planning and governance processes, as most hydrogen facilities and infrastructure in these contexts are still in early, pre-operational stages.

4 Research questions and methods

The study answers three linked questions, each pitched at a different level: what are the potential social and environmental effects of hydrogen in MENA, how might they be distributed across places and social groups, and which safeguards could realistically address them. The three, layered questions cause the analysis to shift from a generic risk inventory towards concrete, country-specific intervention points.

The first question (potential environmental and social effects) covers emissions, land requirements, water demand, ecosystem impacts and social implications for local communities and labour markets, across green, blue and grey hydrogen pathways. The second question examines how potential environmental and social risks may be distributed across places and social groups, with particular attention to local and national dynamics and their connections to international trade and finance flows. The third question (safeguards) reviews existing and emerging governance instruments, including ESIAAs, regulatory oversight, monitoring systems and transparency requirements, and asks which can realistically be made effective in the regulatory and political conditions of the case-study countries.

To answer these questions, the research adopts a comparative case study approach focusing on Morocco and Oman. Both countries were selected for their strategic roles in the emerging global hydrogen economy, their ambitious energy transition targets, and their contrasting energy models. Despite these differences, they share important commonalities, including reliance on natural resources for economic sustainability, comparable total emissions, energy transition targets, and constrained fiscal spaces that warrant closer comparison (Shehabi, 2024). In terms of its potential as a new “hydrogen destination”, Morocco is frequently highlighted (Ersoy et al., 2024; Müller et al., 2022; Plank et al., 2023; Tanchum, 2024). Similar claims can be found regarding the Gulf states, particularly Saudi Arabia, the United Arab Emirates, and Oman (Abdelshafy et al., 2024; Marzouk, 2024). However, Oman has not so often been included in some earlier studies, as the development of its hydrogen governance only began to accelerate significantly in the last two years.

The research follows a three-phase methodological approach. First, the desk research provides a comprehensive overview of hydrogen strategies and sustainability issues in Morocco and Oman. This includes a systematic review of academic literature, government plans and reports by international organisations, with particular attention to geophysical conditions, renewable energy capacity, infrastructure, and environmental impacts such as emissions, water use and ecosystem pressures. In addition, the desk research incorporated a qualitative media analysis based on approximately 100 newspaper articles (around 50 for each case study) identified through targeted Google searches. This component served to capture dominant public narratives, policy framings, and the visibility of environmental and social concerns in national discourses. Second, ethnographic field research and semi-structured interviews with 33 key stakeholders, ranging from government agencies and research institutions to industry actors and civil society, were conducted in the two focus countries.² These interviews aim to capture stakeholder interests, governance dynamics, and the perceived effectiveness of sustainability safeguards. Finally, a comparative analysis synthesises the findings to identify shared challenges and divergent pathways in hydrogen development. It assesses the adequacy of existing safeguards, explores risks to vulnerable groups, and examines how civil society and critical researchers contribute to shaping a more just and ecologically sound hydrogen transition.

Together, these methodological steps are designed to produce a rich, empirically grounded understanding of the environmental and social dimensions of hydrogen economies in the MENA region, contributing to both academic debates and policy design for sustainable energy futures.

2 During one field research trip to Oman from 29 May to 6 June 2025, 17 interviews were conducted with a diverse range of stakeholders from the public and private sectors, as well as from academia. Among the interviewees were representatives from key institutions involved in shaping Oman’s hydrogen economy. A second field research trip was conducted in Morocco from 28 August to 5 September 2025. During this visit, it was possible to engage with key public and private stakeholders, decision-makers, representatives of external financial institutions, and members of environmental civil society organisations.

5 Environmental and social effects of hydrogen in the Middle East and North Africa (MENA): green saviour or shallow tech fix?

MENA's hydrogen production prospects sit on a familiar regional pattern: high renewable endowment, severe water scarcity, centralised energy governance, and weak independent oversight. That combination produces a specific risk profile, different from northern European or Latin American hydrogen contexts, which this chapter unpacks across the four analytical dimensions introduced in Chapter 2 (conceptual framework). The chapter focuses on what is regionally specific; cross-regional findings are addressed in Chapter 3.

Table 2: Overview of key analytical categories guiding the empirical analysis

Dimension	Core topics
Resource endowments	Upstream materials & technologies; transport and infrastructure siting; land, water, minerals, and renewable potential
Environmental risks	Potential damaging aspects include habitat loss, water pollution, methane leakage, CCS/CCUS underperformance (i.e. insufficient capture efficiency or net climate benefits), brine discharge, ecosystem fragmentation
Decision-making and governance arrangements	Planning and governance, regulatory uncertainty, transparency, coordination failures, certification, state–investor relations
Social equity dynamics	Elite capture, exclusion, labour exploitation, displacement, energy poverty, unequal access, limited local value creation

Source: Author

5.1 Resource endowments

A first dimension is access to and management of key resources related to hydrogen. The same structural features that underpinned the region's prominence in the fossil-fuel era – favourable geographic conditions, state-dominated energy sectors, and highly centralised political economies – may also shape its role in emerging low-carbon energy systems (Zumbraegel, 2025a). The MENA region benefits from some of the highest solar irradiation levels globally and significant wind resources. In addition, existing hydrocarbon revenues and infrastructure could be mobilised to finance renewable energy deployment and facilitate the integration of new technologies, while also supporting transitional pathways such as blue hydrogen in countries with substantial oil and gas resources (Hafner et al., 2023; Khan & Al-Ghamdi, 2023; Wolff & Young, 2024).

For green hydrogen in MENA, water availability is often the more immediate binding constraint than electricity access, especially in arid and hyperarid settings (Helerea et al., 2023). Green hydrogen production requires approximately 9 litres of demineralised water per kilogram of hydrogen at the electrolyser, which amounts to 18–25 litres of raw water intake once purification and process losses are included (Ersoy et al., 2024). Blue hydrogen production requires 13–24 litres per kilogram on a comparable intake basis (Alshawaf et al., 2025). Electrolysis processes may also require additional cooling, often relying on water-intensive systems that further increase consumption (Weipert-Fenner, 2025). These demands are particularly significant in the MENA region, which holds only around 1.4 % of global freshwater resources and already faces mounting pressures from demographic growth, industrial development and climate change

(Sadiq et al., 2023; Weidner et al., 2023). Renewable installations themselves add water load, since photovoltaic systems require frequent cleaning in dusty desert environments, though waterless robotic systems and floating solar are increasingly deployed where fresh water is constrained (Pouran, 2022). Concentrated solar power (CSP) technologies may require further cooling water depending on their configuration (Alshawaf et al., 2025).

Desalination, the “miracle in the desert” (Hamblin, 2019, p. 1), is frequently presented as a key solution to water scarcity in the MENA region, but it is not yet a fully sustainable solution. While it can improve water security in highly arid environments, it also creates environmental and energy costs that limit its sustainability. In this regard, some scholars caution that it can foster the perception of an effectively inexhaustible water supply, thereby obscuring the structural limits and environmental implications associated with the technology (Günel, 2016; Naderi Beni et al., 2021; Omerspahic et al., 2022). The Middle East, particularly the hyperarid Gulf region, has become the global centre of desalination activity (Khanzada et al., 2026). Together with its Gulf neighbours, Saudi Arabia alone accounts for a substantial share of global desalination output, and the wider region contributes more than half of the world’s desalinated water production (Low, 2020; Zumbraegel, 2026).

Reverse osmosis has improved operational efficiency relative to thermal methods, but it remains energy intensive and does not eliminate the dominant concern of brine discharge: more than 90 per cent of seawater desalination plants worldwide discharge brine directly into open water bodies, a pattern especially widespread across the Arabian Peninsula (Khanzada et al., 2026). Highly concentrated brine alters salinity gradients, contains chlorine, copper and pre-treatment chemicals, and produces hypersaline plumes extending several kilometres from release points. In parts of the Gulf, weakened buffering capacity, reduced freshwater inflow from upstream dam construction on the Tigris–Euphrates system, low precipitation, and limited water exchange with the Indian Ocean intensify these effects (Ben-Hasan & Christensen, 2019; Lachkar et al., 2019). Brine post-treatment, zero-liquid discharge and seawater electrolysis are active research areas but not yet at industrial scale (Khan et al., 2021; Khanzada et al., 2026; Omerspahic et al., 2022). The logistical layer adds further pressure: desalinated water transported over hundreds of kilometres risks heavy-metal leaching into pipes, and supply tends to favour major metropolitan areas, tourist centres and industries while remote regions get less (Al-Hamzah & Fellows, 2024; Gazzeh & Abubakar, 2018; Zumbraegel, 2026).

Although direct land conflict is less common in many arid areas of MENA than in more densely populated regions, indirect tensions recur wherever hydrogen projects are seriously planned. Large solar and wind installations, electrolysis facilities and pipelines do require substantial land, and can contribute to habitat fragmentation, biodiversity loss, and degradation of fragile desert and coastal ecosystems (Sola et al., 2024). Indirect tensions arise where projects are developed on agriculturally productive or otherwise valuable land, for instance, debates in Tunisia have flagged concerns that large renewable or hydrogen projects could occupy fertile agricultural areas (Weipert-Fenner, 2025), and where customary tenure or politically sensitive territory is involved, as in the Moroccan case study below.

5.2 Environmental risks

Any climate benefits from producing hydrogen in the MENA region are conditional, not guaranteed. Hydrogen leakage along the value chain, methane leaks in feedstock chains for blue hydrogen, and underperforming CCS/CCUS can erode the emissions advantage that hydrogen is meant to deliver. This is particularly acute in oil- and gas-exporting countries where blue hydrogen is positioned as a transition pathway (Khan & Al-Ghamdi, 2023; Koch, 2022). Hydrogen (H₂) itself is an indirect greenhouse gas: when H₂ escapes to the atmosphere it prolongs the lifetime of methane and increases tropospheric ozone and water vapour, generating near-term warming even though its combustion does not emit carbon dioxide (CO₂).

Therefore, hydrogen leakage itself indirectly increases warming by affecting atmospheric chemistry and the methane sink, highlighting the need for rigorous system integrity and operational standards (Cooper et al., 2022; Ocko & Hamburg, 2022; Suleman et al., 2015)

Blue hydrogen's climate credibility hinges on several challenges: the deployment of carbon sequestration technologies, methane leakage rate of the upstream gas chain and the actual CO₂ capture rate of the CCS plant; and current MENA projects do not publish either reliably. First, one recent investigative analysis finds that, globally, the amount of CO₂ permanently stored each year remains lower than the annual emissions of a single large power plant (Propublica, 2026). Second, only the most modern carbon-sequestration facilities achieve 90–95 per cent capture; many other plants operate at around 60 per cent (Bauer et al., 2022; Hafner et al., 2023; Suleman et al., 2015). Third, greenhouse gas emissions can also occur across the value chain through leakage, venting or purging. Because hydrogen is a very small molecule, it can leak from electrolyzers, compressors, pipelines, storage tanks, liquefaction units, transport vessels and refuelling infrastructure; in addition, operational procedures such as maintenance, startup/shutdown and safety relief routinely involve deliberate venting and purging of hydrogen (Goita et al., 2025). In the case of blue hydrogen and CCS/CCUS pathways, additional greenhouse gas risks arise from CO₂ leakage. Pilot projects have encountered challenges such as leakage through fractured rock formations and CO₂ escape via abandoned oil and gas wells. These experiences underscore the need for long-term monitoring and verification, which further increases the costs of an already expensive technology (Propublica, 2026). Distinguishing CCS from CCUS matters here: in oil- and gas-exporting Gulf countries, CCUS is often applied in enhanced oil recovery (EOR) or enhanced gas recovery (EGR), which currently represents the only commercially profitable form of CO₂ sequestration in oil-and-gas geographies (Koch, 2022; Shabaneh et al., 2024; Zumbraegel, 2025b). In EOR/EGR, captured CO₂ is separated and pressurised first, then injected to extract additional oil or gas; the climate benefit depends on whether the CO₂ remains permanently stored or eventually escapes, and on the lifecycle emissions of the additional hydrocarbons recovered. This is a separate question from CCS at greater depth for permanent sequestration (Koch, 2022; Roefs et al., 2019).

Ammonia is the leading proposal for hydrogen export, and its toxicity profile puts coastal and port communities directly in the operational risk perimeter. Several Middle Eastern countries, particularly Saudi Arabia and Morocco, are key producers and exporters of ammonia, with extensive operating experience. Annually, around 20 million tons of NH₃ are traded internationally, mostly as feedstock for nitrogen fertilisers. In 2020, Saudi Aramco shipped 40 tons of blue ammonia to Japan, marking the world's first demonstration of a blue ammonia supply chain, encompassing both production and international transport (Piotrowski et al., 2021). Two years later, in 2022, both Saudi Aramco and the petrochemical giant Saudi Basic Industries Corporation (SABIC) received the world's first independent certifications from TÜV Rheinland for the production of blue hydrogen and of blue ammonia (Shabaneh et al., 2024). Ammonia offers advantages over hydrogen in terms of storage and transport, as it can be liquefied at relatively moderate conditions. At the same time, it presents distinct safety considerations. Unlike hydrogen, ammonia is not highly flammable, but it is toxic and corrosive, requiring careful handling and established safety protocols (Klerke et al., 2008; Kojima, 2024). However, these risks should be viewed in context. Conventional ammonia is handled safely at scale under established industrial standards; the hydrogen-export case differs in volume, in the concentration of handling at a small number of ports, and in the absence of hydrogen-specific safety regulation in either country. The risk is therefore not novel in kind but unprecedented in scale and unregulated in form.

Across the region, coastal desalination at the scale required to generate hydrogen for export poses the largest marine-ecosystem risk, though its severity varies sharply with hydrography: enclosed basins such as the Gulf concentrate hypersaline plumes, whereas open-ocean coastlines like that of Oman and of Morocco's Atlantic seaboard permit greater dispersion (Omerspahic et al., 2022; Sharifinia et al., 2019). This variation is examined in the case studies.

5.3 Decision-making and governance arrangements

In many MENA countries, hydrogen policy is being developed within governance arrangements that remain strongly shaped by the region's hydrocarbon era: decision-making is concentrated in executive bodies and line ministries, parliamentary scrutiny is limited, and responsibilities for water, energy and environment are often divided across separate ministries and agencies. This institutional setup can deliver rapid, large-scale project approvals and align with existing patterns of state-led investment, but it also complicates the integrated water–energy–food–climate planning that large-scale hydrogen deployment arguably requires. Rather than assuming a clean institutional break, early hydrogen governance in the region appears to be layered onto and mediated through these more centralised, sectorally fragmented structures, with implications for how trade-offs are assessed, who is consulted, and how risks are allocated.

Hydrogen-specific legal frameworks are still largely absent or incomplete across the region. Developers operate under overlapping energy, environmental and maritime law that was not designed for integrated electrolysis–desalination–renewables projects (Khan & Al-Ghamdi, 2023; Olawuyi & Aryanpour, 2024; Piotrowski et al., 2021). Technical standards for low-carbon certification, safety and guarantees of origin are often absent or opaque, hindering trade and infrastructure integration (Hussein & Schuetze, 2024; Sadiq et al., 2023). Environmental and social assessments for integrated hydrogen–desalination–renewables projects are insufficiently defined, weakly enforced, or not publicly accessible, with few exceptions, such as large renewable-energy projects in Morocco (Terrapon-Pfaff et al., 2015). Legal frameworks governing CCS/CCUS liability in blue-hydrogen projects remain ambiguous, leaving responsibilities unclear and ecological risks largely unmitigated (Alshawaf et al., 2025; Ersoy et al., 2024; Koch, 2022).

Public data on emissions, water use and contractual arrangements is scarce or unpublished, which makes both market credibility and domestic accountability hard to construct. Parliamentary review mechanisms and independent regulatory authorities are often weak or absent, reducing capacity to scrutinise concessions, ensure compliance or monitor environmental performance (Zumbraegel, 2022). Project approval, licensing, permit procedures, or compliance with certain certification mechanisms for low-carbon hydrogen and ammonia are also uneven and/or opaque, affecting both market credibility and the ability to integrate projects into global supply chains (Terrapon-Pfaff et al., 2024). Heavy reliance on state funding, unclear financing frameworks, and inconsistent subsidies, carbon pricing, and offtake contracts impede the development of bankable models, constraining private and domestic participation (Aljamal et al., 2022; Hanieh, 2018; Olawuyi & Aryanpour, 2024; Piotrowski et al., 2021; Vermeulen, 2018; Vidican, 2014; Zumbraegel, 2022). Industrial policies often insufficiently align with local value creation, skills development and just transition objectives (Hanieh, 2018; Richards & Waterbury, 1996), and enforcement of environmental and social safeguards is oftentimes weak, with limited participatory environmental impact assessments and minimal inclusion of marginalised groups (Weipert-Fenner, 2025). Diplomatic and economic risks remain even in countries with stable EU relations (Hafner et al., 2023; Plank et al., 2023).

Macro-level governance quality, corruption and rule-of-law risks, shape the overall environment for hydrogen development (Terrapon-Pfaff et al., 2024). Lower-ranked countries face medium-level challenges in legal enforcement, contract execution and regulatory consistency; states affected by conflict or concentrated market power face significantly higher risks that undermine investor confidence, distort markets and exacerbate environmental and social vulnerabilities. The cumulative effect of these governance features – fragmented authority, weak transparency, coordination failures, opaque state–investor relations – is that environmental, social and economic outcomes of hydrogen production become difficult to shape, predict or hold to account. They determine how effectively safeguards can be implemented, how local communities participate, and how risks to ecosystems are managed.

5.4 Social equity dynamics

Hydrogen development in MENA may not deliver broad-based local benefit without explicit policy intervention. Empirical evidence from Tunisia, Morocco and the Gulf shows that capital-intensive green megaprojects can concentrate economic gains among state actors, domestic elites and foreign investors, while local communities often receive limited direct benefit (Henderson, 2023; Hussein & Schuetze, 2024; Kalt & Cezne, 2026; Tunn et al., 2024). For instance, construction-phase jobs tend to be short-lived and operational roles require imported expertise (Irrarazaval et al., 2026; Namaganda, 2023; Weipert-Fenner, 2025). Hydrogen development is embedded in patterns of uneven development, meaning that different social groups and territories do not benefit equally from the projects, and that the associated gains, costs and risks are distributed unevenly across space and society (Ersoy et al., 2024; Houdret et al., 2017; Pinto et al., 2025; Tunn et al., 2024; Weipert-Fenner, 2025).

The countries most likely to capture local employment from hydrogen are probably the ones that already have strong technical education systems or oil-and-gas talent pipelines. Jordan, Morocco, Iran and Tunisia have established renewable sectors and technical institutions producing engineers and chemists (Terrapon-Pfaff et al., 2024). Some Arab Gulf states could build on existing hydrocarbon technical capacities (Ansari, 2022; Khan & Al-Ghamdi, 2023); by contrast, countries that depend heavily on foreign labour may face greater workforce challenges (Terrapon-Pfaff et al., 2024). This is better framed as a likely challenge than as a settled fact. These challenges are compounded by a global shortage of skilled workers in the energy transition, which may limit local capacity building and the localisation of higher-skilled jobs (Hafner et al., 2023).

Public–private partnerships are so far the dominant financing model for hydrogen projects and critics document a recurring pattern: such partnerships, which look like infrastructure investment in policy text, often function as soft privatisation in implementation (Ersoy et al., 2024; Schuetze & Hussein, 2023; Weipert-Fenner, 2025; Zumbraegel, 2022). The role of external actors is also particularly contested (Hussein & Schuetze, 2024). In Tunisia, this has been described as a pattern in which external investors and development actors are seen as reproducing dependency through finance, technology, market access and decision-making power, rather than creating fully autonomous domestic value chains (Weipert-Fenner, 2025). Similar concerns extend to intra-regional investments from Gulf countries (Amouzai & Haddioui, 2023; Müller, 2024; Müller et al., 2022; Plank et al., 2023; Zumbraegel & Sons, 2024).

Marginalised populations (e.g. rural communities, low-income households, migrant workers and other populations with weaker bargaining power and less access to formal decision-making processes) may bear disproportionate burdens from hydrogen rollout if land, water and coastal resources are redirected toward export-oriented production, while access to consultation remains limited. Available studies suggest that these groups may be especially exposed to environmental degradation and resource competition, but longer-term distributional effects will depend on project design, regulation and enforcement (Amouzai & Haddioui, 2023; Bengezi, 2022; Hussein & Schuetze, 2024; Irrarazaval et al., 2026; Terrapon-Pfaff et al., 2019; Weipert-Fenner, 2025). Hydrogen production can also generate possible co-benefits for local communities, where the right enabling conditions exist, but these benefits are not automatic and should be framed as conditional. For instance, desalination capacity linked to hydrogen projects could improve water availability if it is designed for multiple users rather than only for industrial supply, and hydrogen value chains could support industrial upgrading, fertiliser production, and job creation if local-content requirements, benefit-sharing, and public oversight are in place (Ersoy et al., 2024). At this stage, however, it is more accurate to say that such gains are potential rather than already demonstrated outcomes.

6 Case studies from the Middle East & North Africa (MENA)

Having set out the principal social and environmental risks of a hydrogen build-out in the MENA region, this chapter turns from the conceptual to the empirical. It examines how those risks, and the governance arrangements meant to contain them, are taking shape in the two countries that have moved furthest toward a green hydrogen economy: Oman and Morocco. Both are widely cast as regional frontrunners; both pair exceptional solar and wind endowments with an explicitly export-oriented strategy directed at European and Asian markets; and both, despite considerable political momentum, remain in the planning and early-works phase, with no large-scale project yet in commercial operation. This makes them less a test of hydrogen's realised impacts than a window onto how risks, safeguards and participatory mechanisms are being configured *before* build-out; a governance-in-the-making whose path dependencies later phases will find difficult to reverse. The two cases are analysed along the same dimensions developed above: resource endowments (notably water and land), decision-making and governance arrangements, environmental risks, and social equity dynamics. Read together, they also invite comparison. Oman has built the most procedurally structured hydrogen governance in the region, centralising auctions, land allocation and permitting within a single technocratic channel (Hydrom); Morocco's rollout is more politically embedded, steered from the royal court (Makhzan) and coordinated through the Moroccan Agency for Sustainable Energy (MASEN), yet institutionally more fragmented. Each configuration accelerates investment in its own way, and each, as the following sections show, forecloses local participation in its own way. The analysis draws on expert interviews, policy and legal documents, and the emerging grey and academic literature.

6.1 Oman's energy recast: from fossil dependence to hydrogen ambitions

So far, Oman has developed one of the most procedurally structured hydrogen governance frameworks in the MENA region. By centralising key functions such as project allocation, land access, permitting, and investor coordination within a single governance architecture, it has replaced ad hoc bilateral negotiations with a more standardised and coordinated process. Whether this institutional architecture is equally accountable to local communities, environmental oversight, and public scrutiny, however, remains a separate question.

Oman possesses considerable potential to emerge as a leading hydrogen exporter, with the vast majority of announced volumes (close to 85%) currently earmarked for foreign markets. Oman is pursuing an ambitious scale-up of green hydrogen, aiming for annual output of around 1 million tons by 2030 and expanding to roughly 8 million tons by mid-century (Calabrese, 2025). With the establishment of Hydrogen Development Oman (Hydrom) in 2022, Oman has centralised and formalised its hydrogen governance, introducing a more structured, transparent, and investor-friendly tendering and land allocation process. This shift replaces ad hoc negotiations with standardised auction mechanisms, enhancing planning consistency, price clarity and contractual certainty (Schulkes, 2025).³ At the project level, the country is still largely in Phase 1 of its national hydrogen build-out, understood here as the planning and design phase, which covers master planning, land allocation, regulatory design and the auctioning of large integrated hydrogen blocks. Within this framework, Hydrom has completed the first two competitive auction rounds and launched a third round in Duqm in April 2025, which for the first time employs more flexible, two-sided auction features and is closely aligned with emerging downstream uses

3 Interview with a senior official of the national hydrogen authority

such as green steel. These auctions mark the transition from pure planning to early implementation, as awarded consortia are now preparing sites, arranging infrastructure connections, and moving selected projects into Phase 2, the early works and construction stage, with initial physical construction expected to start on several projects from 2026 onwards (Hydrom, 2025). However, full commissioning of large-scale hydrogen and ammonia export facilities is not anticipated before around 2030, meaning that Oman's hydrogen strategy remains in an extended first project phase, even as auctioned projects and legacy developments gradually advance toward operation (Al Maimani, 2025).⁴ Some experts even suggest it will be post-2030 before most large-scale hydrogen projects in Oman become operational, given typical four- to five-year timelines from final investment decision and current delays or lack of specified deadlines (Schulkes, 2025). In addition to some social and environmental implications that will be examined in greater detail below, Oman's hydrogen ambitions face structural constraints that are characteristic of this early stage of development, and are common across emerging hydrogen markets. These include a pronounced reliance on imported electrolyser technologies, limited domestic technical expertise, and persistently high production costs (Amoatey et al., 2024; Schulkes, 2025). Without supportive policy instruments, such as international subsidies, robust regulatory frameworks or effective carbon pricing mechanisms, green hydrogen is likely to struggle to achieve cost competitiveness vis-à-vis competing hydrogen-exporting countries and, especially in the near term, against fossil-based hydrogen and other incumbent "dirty" alternatives (Calabrese, 2025).

Integrating hydrogen into the domestic energy system could generate significant socio-economic and environmental gains, provided that current export-oriented strategies are complemented by deliberate efforts to anchor value creation within the country. Hydrogen could serve as a key input for future low-carbon industries, including green steel (as envisioned in Duqm projects) and direct reduced-iron processes (Calabrese, 2025), and hydrogen derivatives offer pathways to decarbonise and expand domestic fertiliser production. Realising these opportunities requires embedding hydrogen strategies within broader industrial policy and ensuring export ambitions link systematically to domestic manufacturing, workforce development, and downstream value chains (Al Maimani, 2025; Tian et al., 2024).⁵

The country's hydrogen economy is rapidly emerging as one of the most ambitious and strategically positioned in the world, leveraging its exceptional natural endowments and a proactive policy environment (Amoatey et al., 2024; Ansari, 2023; Calabrese, 2025; Schulkes, 2025). In addition to the country's favourable geographic positioning and energy transition ambitions, "developers find a government that wants to do business", a sentiment echoed by international investors and project consortia (Schulkes, 2025).⁶ At the same time, the country places strong emphasis on expanding knowledge production and capacity building in the field of the hydrogen economy, including the development of dedicated academic programmes.⁷

Oman's leadership, through the establishment of Hydrom and a series of regulatory reforms, has set clear targets: at least one million tons of renewable hydrogen annually. The Sultanate's location, between Europe and Asia, with deep-water ports and existing energy export infrastructure, further strengthens its appeal as a future global hydrogen hub (Ansari, 2023; Calabrese, 2025; Marzouk, 2024). A series of large-scale hydrogen-related projects have already been awarded, meaning that dedicated land and resource blocks have been allocated

4 Interview with an independent hydrogen expert

5 Interview with a senior official of the national hydrogen authority

6 Interview with a port and special economic zone official and interview with a senior official of the national hydrogen authority

7 Interviews with a senior official from a national hydrogen think tank, a university-based hydrogen scientist and an academic researcher and hydrogen expert

to hydrogen developers, or are in advanced stages of planning, involving a broad and diverse range of stakeholders, including international energy majors such as Électricité de France (EDF), Shell, and BP, as well as Oman's national energy company, OQ, among others (see Table 3) (Amoatey et al., 2024; Calabrese, 2025). Summarised by a high representative of Hydrom:

So, in total now we have nine [green hydrogen] projects, the expectations of those projects are that they will come online by 2030, and production in total is around 1.5 million tons of green hydrogen. So, we're on target with the 2030 production number.⁸

Another official from the same authority stated in a rather sober assessment that of the nine green hydrogen projects currently in the pipeline, it remains uncertain how many will ultimately be realised, with perhaps only half expected to proceed to implementation.⁹ The projects cluster around three core regions, with five in Duqm, three in Dhofar and one in Al Wusta (Calabrese, 2025; Piotrowski et al., 2021; Schulkes, 2025). Oman also has one blue hydrogen project, Blue Horizons, executed by Shell as lead developer in Duqm Special Economic Zone in close coordination with the Ministry of Energy and Minerals (MEM), outside Hydrom's umbrella.¹⁰ So far, not much is revealed in terms of concrete steps and status. As one interviewee mentioned: "There is no news because it is nothing to report".¹¹ A more recent assessment that also includes the blue hydrogen project suggests that progress has been uneven: only two projects remain on schedule, while three have been cancelled, three have unclear status, and two are believed to have been cancelled (Schulkes, 2025). Beyond dedicated hydrogen projects, Petroleum Development Oman has identified CCUS, applied to EOR/EGR and prospectively to synthetic fuels, as a decarbonisation pathway. Official and independent accounts of project attrition therefore diverge sharply. The following table provides an overview of the hydrogen projects identified in Oman. It includes projects at different stages of development, although the current status of some initiatives remains unclear and it is uncertain whether all announced projects will ultimately reach construction and operation.

8 Interview with a senior official from the national hydrogen authority

9 Interview with a senior official from the national hydrogen authority

10 Interview with a senior official from the national hydrogen authority

11 Interview with a government policy advisor

Table 3: Overview of current hydrogen projects and involved stakeholders in Oman

#	Project	Consortium	Location	Block	Selection date	Purpose
1	Hyport Duqm	OQ, Deme, BP	Duqm	Duqm Freezone	June 2023	Ammonia export
2	GEO (Green Energy Oman)	OQ, EnerTech, InterContinental Energy, Shell	Al Wusta	Block Z1-04	June 2023	Ammonia export
3	BP Oman	BP Oman	Duqm	Block Z1-03	June 2023	Ammonia export
4	Amnah Green Hydrogen Project	Amnah, Copenhagen Infrastructure Partners (CIP), Blue Power Partners, Al Khadra Partners	Duqm	Block Z1-01	June 2023	Green steel production
5	HyDuqm, Posco-Engie	Posco, Samsung, Engie, EWP, ICOSPO	Duqm	Block Z1-02	June 2023	Ammonia export
6	SalalaH ₂	OQ, Marubeni, Dutco Energy & Samsung C&T	Dhofar	Unknown	Dec. 2023	Ammonia export
7	ACME Green Hydrogen Project	ACME Group (India)	Duqm	unknown	March 2023	Ammonia export
8	EDF-J-POWER-Yamna Project	EDF Renewables, J-POWER, YamnaCo	Dhofar	Unknown	April 2024	Ammonia export
9	Actis & Fortescue Project	Fortescue, Actis	Dhofar	unknown	April 2024	Ammonia export
10	Blue Horizons	Shell, OQGN, PDO	Duqm	unknown	Sept. 2023	Large-scale blue hydrogen and ammonia production facility

Source: Author

So far, most of Oman's hydrogen projects remain in pre-FEED (front-end engineering and design) phase, with Final Investment Decisions (FID) not expected before 2026–2027 for the leading projects. Land has been formally allocated to developers through Hydrom's auction process and associated long-term usufruct or lease arrangements, and project development agreements have been signed and feasibility studies launched, but large-scale construction and commercial operation have not begun. Hydrogen production, based on electricity from dedicated wind and solar assets followed by electrolysis, is planned upstream within designated concession blocks, with the partial exception of earlier projects such as Hyport Duqm, which were initiated before the current regulatory framework was established. Here, upstream renewables and downstream hydrogen and ammonia facilities are spatially separated between inland areas and the port zone. Downstream processes, conversion into derivatives such as green ammonia, are intended to be located near ports, specifically within the special economic zones (SEZs).¹²

12 Interviews with a policy advisor/hydrogen expert and with a state-owned energy company representative

The scale and complexity of these projects, covering hundreds of square kilometres and requiring substantial water and material inputs, underscore the need for early and robust environmental and social assessment. Initial scoping studies have informed site selection and auction design, but full project-specific impact assessments are generally prepared later in the permitting process, after land allocation and concession agreements and before construction permits. In Oman, the general legal basis for environmental permitting and environmental impact assessment is set out in Royal Decree 114/2001 and related implementing regulations, rather than in a hydrogen-specific statutory regime (Sultanate of Oman, 2001). Comprehensive official environmental impact assessment (EIA) or ESIA documents for hydrogen projects in Oman could not be located during this research. An Omani environmental consultant captured the gap:

Research on green hydrogen has the following obstacles in terms of risks, socioenvironmental consequences, and the general public's perception. The first is a lack of studies on the environmental and social impacts of hydrogen on the local population and indigenous communities, as well as a lack of local government authorities in related areas. Although some studies evaluated the environmental consequences of green hydrogen, the social dimension evaluation is lacking.¹³

Moreover, several interviewees emphasised that Oman has taken environmental and social concerns into account from the very beginning, building its hydrogen governance framework “from scratch” with socioeconomic and environmental topics in mind.¹⁴ For instance, this includes pre-siting and scoping studies conducted prior to auctions, such as sensitivity mapping for wind and solar sites, and assessments of water availability and biodiversity constraints. Yet, while hydrogen developers must comply with a wide range of Hydrom auction requirements, environmental and social assessment is not currently a core element of those auction criteria (Hydrom, 2024).¹⁵

Box 2: Requirements for Hydrom's hydrogen auctions

Hydrom's auction framework places strong emphasis on commercial readiness and project delivery. Developers must demonstrate full value-chain integration, commit to large-scale land and capacity development, participate in consortia, and provide binding offtake arrangements together with robust financial and technical qualifications. By contrast, environmental and social assessment is addressed mainly through separate permitting and approval processes, rather than as a central auction requirement.

The current environmental permitting process in Oman, particularly in light of ongoing discussions about a potential transition to a single-permit system overseen by Hydrom, operates as follows. Environmental permitting is governed by Royal Decree 114/2001 and ministerial decisions 187/2001 and 48/2017 (concerning the regulation, issuance and approval of environmental permits). Under this framework, the Environment Authority classifies proposed activities into predefined categories “according to the materials used in production, production capacity and the degree of their impact on the environment” (Sultanate of Oman, 2017). For example, oil and gas projects are classified as Category A activities. Projects within this category are required to submit a comprehensive EIA as part of the environmental permitting process. The EIA must be prepared by a qualified environmental consultancy in accordance with the applicable regulations and technical requirements established by the Environmental Authority. A more recent regulation, the Public Authority for Special Economic Zones and Free Zones Decision

13 Interview with an independent environmental consultant

14 Interview with an official from the energy ministry

15 Interviews with a senior official from the national hydrogen authority, an energy ministry official and an official from the government hydrogen programme

17/2021, further specifies that not only environmental but also social impact assessments (ESIAs) are conducted on behalf of the Public Authority for Special Economic Zones and Free Zones through its environmental monitoring department (Sultanate of Oman, 2021).¹⁶ For instance, the guidelines of the Special Economic Zone Authority Duqm (SEZAD) states that the authority “shall have the sole authority of issuing environmental permits and applicable licenses” (Special Economic Zone Authority at Duqm (SEZAD) n.d., p. 2).

The recent proposed introduction of a “single permit” system, administered by Hydrom, represents a major shift in project approval. The reform is intended to streamline development by reducing bureaucratic hurdles. While many interviewees emphasised that environmental safeguards will remain intact,¹⁷ a more critical view holds that the new process may dilute oversight and reduce transparency, particularly within special zones that operate under their own regulatory frameworks.¹⁸ The process is currently described as “phased”, with “environmental and social standards intended to be addressed at a very early stage”. Internationally, despite growing concerns about weakening hydrogen targets in parts of the EU,¹⁹ interviewees do not expect a general race to the bottom in Oman.²⁰ Oman’s approach is widely seen as proactive, shaped early to meet international expectations: ACME’s Duqm project received the world’s first TÜV Rheinland “Green Hydrogen and Green Ammonia Certificate” (TÜV Rheinland, 2022). Nonetheless, policymakers continue to track EU developments closely, including recent proposals to ease sustainability reporting under the Taxonomy Regulation.²¹ Following this brief contextualisation of Oman’s broader hydrogen ambitions and strategic objectives, the analysis now turns to the four analytical categories that structure the framework of this study.

Resource endowment

Oman possesses exceptionally favourable conditions for the production of low-carbon hydrogen. The country benefits from high solar irradiance across its entire territory, averaging around 2,450 kWh/m² per year, as well as steady wind speeds between 7 and 9 m/s along its southern and eastern coasts, particularly in the Al Wusta and Dhofar regions. Stronger wind patterns at night and during winter months help balance the variability of solar energy, contributing to a more stable and continuous supply of renewable electricity (Al-Mamari et al., 2024). These factors place Oman among the leading countries globally in terms of renewable energy potential. Indeed, Oman ranks among the top 20 countries in terms of photovoltaic potential (Ahshan, 2021; Al Bulushi et al., 2024). Its geographic position between Europe, Africa and Asia, plus deep-water ports, natural gas pipelines, refineries and existing methanol and ammonia production, can be leveraged to support a hydrogen economy (Calabrese, 2025; Schulkes, 2025).²²

16 Interviews with a hydrogen expert and economic development official, a state-owned energy company representative

17 Interviews with two senior officials from the national hydrogen authority and with a state-owned energy company representative

18 Interview with a policy advisor/hydrogen expert

19 Interview with an independent hydrogen expert

20 Interviews with a representative of the national oil company/hydrogen project developer and a senior official of the national hydrogen authority

21 Interviews with an independent hydrogen expert, an energy ministry official and a port authority and free zone official

22 Interviews with an independent hydrogen expert and a policy advisor/hydrogen expert

Water availability is frequently cited as a critical challenge (Al-Mamari et al., 2024; Amoatey et al., 2024), but is considered a manageable one (Schulkes, 2025).²³ Stakeholders emphasise that hydrogen water will come from desalination²⁴ (“groundwater reserves are not touched”²⁵) coordinated with Hydrom by developers. As Dhofar illustrates, additional energy and infrastructure are needed: hydrogen production upstream within inland concession blocks means water must be transported, partially over long distances and rocky mountains, via pipelines from coastal desalination plants.²⁶ More desalination plants are needed, and are expected to operate using renewable energy (Al Bulushi et al., 2024).²⁷ While the issue of brine discharge remains insufficiently resolved, it has not emerged as a critical concern in Oman.²⁸ This is partly attributed to the country’s open coastline, which allows for continuous water exchange with the Indian Ocean and is therefore perceived to mitigate localised environmental impacts, particularly in contrast to more enclosed marine environments such as Kuwait, where rising salinity levels are becoming an increasing concern.²⁹ While large-scale solutions to address brine discharge remain limited, ongoing research into the direct use of seawater or treated wastewater in electrolysis could substantially reduce, or even eliminate, reliance on freshwater resources (Amoatey et al., 2024).³⁰ In addition, in some instances, automated robotic systems are used to clean solar panels, particularly following sand and dust storms, thereby minimising surface damage while avoiding the use of scarce freshwater resources. However, their deployment has not yet occurred at scale.³¹

Land governance for hydrogen development follows a markedly different trajectory. Hydrom’s mapping identified roughly 50,000 square kilometres of land available for possible renewable hydrogen development across Duqm, Al-Jazir and Dhofar (Hydrom, 2024). Under Royal Decree 10/2023, Hydrom may receive usufruct rights to designated state land and award subdivided blocks through auctions. This process can simplify allocation, but it raises questions about community participation and the transparency of land-use decisions, particularly where land tenure is weak or contested as one interviewee mentioned.³² According to another interviewee:

In Oman, there are many protected areas, and these are highly vulnerable. The development of hydrogen projects is taking place very close to these areas. As a result, there is strong attention to environmental requirements to ensure that these projects do not negatively affect the environment or the protected zones. So far, no specific regulations have been developed, but authorities are actively looking into it, as there is significant concern about the environmental impact of hydrogen facilities.³³

23 Interviews an energy ministry official and an academic researcher/hydrogen expert

24 Interview with a representative of the national oil company/hydrogen project developer

25 Interview with a senior official of the national hydrogen authority

26 Interview with a representative from the state-owned energy company

27 Interviews with a senior official from the national hydrogen authority, an official from the port and special economic zone and a representative of the national oil company/hydrogen project developer

28 Interviews with a representative of the national oil company/hydrogen project developer and a senior official from the national hydrogen think tank

29 Interviews with a representative of the national oil company/hydrogen project developer and a senior official from the national hydrogen think tank

30 Interviews with an official from the port and special economic zone and a senior official from the national hydrogen think tank

31 Interview with a representative of the national oil company/hydrogen project developer

32 Interview with a senior official from the national hydrogen authority

33 Interview with an independent hydrogen expert

At present, Oman has only one piece of legislation specifically regulating land use for clean energy and green hydrogen: Royal Decree No. 10/2023 on the Allocation of Some Lands for the Purposes of Renewable Energy and Clean Hydrogen Projects (Amoatey et al., 2024; Schulkes, 2025; Sultanate of Oman, 2023). The Decree allocates certain state-owned land parcels for renewable energy and green hydrogen projects, granting usufruct rights over these areas, subject to approval by the MEM.³⁴ Under the Decree, these usufruct rights are first granted to Hydrom, which holds the authority to sub-divide the land and allocate it to project developers through competitive auctions, open to both Omani and international investors and operated on the principles of openness, equal opportunity, non-discrimination and free competition. The precise contractual duration of land use for individual projects is set in the head usufruct agreement between the MEM and Hydrom and in subsequent project-specific contracts, typically structured as long-term arrangements aligned with project financing and offtake structures.

However, the socio-environmental concerns associated with land use may be somewhat less pronounced in Oman compared to other contexts, as many of the designated areas, particularly around Duqm, are comparatively sparsely populated. Nevertheless, local populations have been steadily increasing, suggesting that future project expansion may create new pressures on land use, resources and local communities. According to one high-level representative from a SEZ, the current social and environmental implications of hydrogen projects remain limited:

When it comes to deploying massive solar panels and wind turbines, these are being installed on non-agricultural land; in fact, it's a rocky desert that isn't being used by anyone. Even in terms of fisheries, activity is minimal; along the shore, we're talking about maybe 2,300 people involved, so it's not a large or flourishing industry.³⁵

The situation in Dhofar, by contrast, is more complex, and land allocation may involve more delicate trade-offs.³⁶ Given Dhofar's rich wildlife, ecotourism potential, and natural attractions, which contribute substantially to the country's GDP (Shehabi, 2024), it is essential to ensure that different economic diversification goals do not come into conflict or undermine one another.³⁷

Finally, power production in Oman faces a significant challenge. Meeting the country's ambitious hydrogen targets would require installing renewable capacity at unprecedented rates: Oman aims to obtain 30 per cent of its electricity from renewable sources by 2030 and 60 per cent by 2040 (Calabrese, 2025). In 2025, however, renewables still accounted for only a small share of the national power mix, indicating a substantial gap between current levels and medium-term targets (Calabrese, 2025; Zumbraegel, 2026). Even with accelerated construction, Oman would likely fall short of its 2050 targets, creating a risk of energy shortfalls and potential energy poverty if demand outpaces supply (Schulkes, 2025). However, as previously envisaged plans for hydrogen cooperation between Oman and Europe have been put on hold, including, for example, the offtake agreement between Hyport Duqm and Germany-based Uniper,³⁸ a broader question arises as to whether a potential conflict between domestic energy transformation priorities and externally driven hydrogen demand will materialise at all.

34 Interviews with two senior officials from the national hydrogen authority

35 Interview with an official of the port and special economic zone

36 Interviews with a policy advisor/hydrogen expert and a representative of the state-owned energy company

37 Interview with a government policy advisor

38 Interview with a senior official of the national hydrogen authority.

Environmental risks

Oman's environmental review system for hydrogen exists largely on paper and is mediated through project developers and a small set of local consultancy firms. Public ESIA documents for hydrogen projects could not be located during this research, which may partly reflect the fact that several projects only began in 2023/24 and are still at an early stage of development. Environmental governance is overseen by the Environment Authority, which is responsible for environmental policy, permitting and compliance, while the proposed Hydrom Single Permit System is intended to streamline approvals for green hydrogen developers and may, over time, centralise parts of the permitting chain. However, the exact allocation of tasks between the Environment Authority, Hydrom, and the relevant SEZ authority is still not fully transparent in public sources.³⁹

Oman's environmental governance rests on framework legislation from the 1990s and on later implementing regulations, but it still lacks a comprehensive hydrogen-specific regulatory framework covering production, storage, transport, safety and export. Key gaps include water management and environmental safeguards for large-scale electrolysis driven by desalination, brine-discharge management, thermal pollution from desalination cooling, circular-economy and lifecycle standards, safety protocols for storage and pipeline blending, and regulations for liquefaction, derivative transport and maritime exports (Amoatey et al., 2024).⁴⁰

The Environment Authority is formally responsible for environmental permits and EIA review for many project types, including industrial and infrastructure projects. Projects are classified into different categories based on their potential environmental impact.⁴¹ In practice, much of the technical work is carried out by developers and registered environmental consultancies, while permit procedures can also vary across SEZs, where zone authorities retain specific environmental (and social) permitting competences.⁴² Furthermore, some interview partners suggested that developers may at times operate with a notable degree of autonomy.⁴³ Furthermore, an important question concerns the extent to which such procedures will account for geographical variation in ecological sensitivity and how these differences will be assessed. For instance, Dhofar is generally considered more ecologically sensitive than Duqm due to its greater biodiversity and natural richness, potentially requiring more stringent environmental safeguards than the arid and sparsely populated landscapes of Duqm.⁴⁴

Another environmental concern was raised regarding the blue hydrogen project led by Shell, for which detailed information on procedures, standards and reporting practices is not publicly available.⁴⁵ While interviewees emphasise that a minimum carbon capture rate of 95 per cent is targeted, specific implementation details remain unclear.⁴⁶ Consequently, the currently

39 Interviews with an independent hydrogen expert and a policy advisor and hydrogen expert, a representative of the national oil company/hydrogen project developer, an independent hydrogen expert and an independent environmental consultant

40 Interviews with a hydrogen expert/economic development official, a policy advisor/hydrogen expert, an independent environmental consultant, a representative of the state-owned energy company and a representative of a logistic company

41 Interviews with a representative of the national oil company/hydrogen project developer, an independent hydrogen expert and an independent environmental consultant

42 Interview with an independent environmental consultant

43 Interview with a hydrogen expert/economic development official and a representative of the state-owned energy company

44 Interview with a policy advisor/hydrogen expert

45 Interview with a policy advisor/hydrogen expert

46 Interview with an independent hydrogen expert

immature state of carbon sequestration technologies, their underperformance relative to expectations, and the limited experience and expertise available in Oman suggest that expectations surrounding this technology may be overly optimistic (Propublica, 2026). Insights from interviews indicate that carbon sequestration is at risk of being framed as a solution with a level of potential that it may ultimately be unable to deliver.⁴⁷

A shared concern for both Duqm and Dhofar is the environmental impact of expanding green ammonia production powered by renewable electrolysis. While Oman has longstanding experience with conventional ammonia production (especially in Duqm, Sohar, Salalah and Sur) and has developed advanced monitoring and mitigation systems (Al-Mamari et al., 2024),⁴⁸ the new green ammonia mega-projects in Duqm and Salalah operate at a fundamentally different scale (Schulkes, 2025). This is primarily due to the extensive land requirements of associated renewable energy infrastructure, whereas the ammonia plants themselves maintain a comparatively limited footprint. Industrial land-use transformation at this scale entails habitat fragmentation, ecosystem disruption, and broader land-use shifts, requiring more comprehensive and spatially integrated regulatory approaches than conventional site-bound ammonia. Concerns have been raised particularly about marine ecosystems. As one representative from a logistics company involved in hydrogen transport put it:

It is a ticking time bomb for ports. One mistake, and you can create a disaster.⁴⁹

He continued, emphasising both the technical and knowledge gaps:

There's a lack of infrastructure right now for green ammonia. There's a lack of engines that can run on it. And there's a lack of understanding of what green ammonia really is, except among the academics who study its volatility.⁵⁰

These remarks reflect a degree of scepticism about the rapid expansion of green ammonia infrastructure, particularly in the absence of established safety practices, infrastructure and end-use technologies at scale. They should not, however, be interpreted as evidence that Oman lacks the capacity to handle ammonia or that the risks are unique to the country. Oman already exports conventional (grey) ammonia and has established handling facilities at several ports. Rather, the concerns relate to the scale-up and technological complexity of green ammonia exports, not to a fundamental lack of capacity. Oman already has established ammonia infrastructure and a statutory framework for environmental permitting, alongside an official commitment to ensuring that hydrogen development does not come at the expense of environmental protection.

Overall, Oman has a defined statutory basis for environmental permitting and a broad official commitment that hydrogen should not come at the environment's expense. What remains to be established is who exercises that mandate for hydrogen projects specifically, and whether any assessment produced under it will be publicly disclosed. At the same time, the emerging system of environmental accountability around large-scale hydrogen projects still appears mixed: although environmental impact assessments are formally required and subject to review by the competent authorities, much of the day-to-day preparation and implementation remains driven by project developers, and the overall process is not yet fully transparent to external observers. An independent review or oversight mechanism that would ensure greater comparability, consistency, and transparency across projects has not yet been fully established. Depending on their leverage and capacities, developers may therefore pursue different priorities and levels

47 Interview with a senior official of the national hydrogen think tank

48 Current ammonia refineries exist in Duqm, Sohar, Salalah and Sur.

49 Interview with a representative of a logistic company

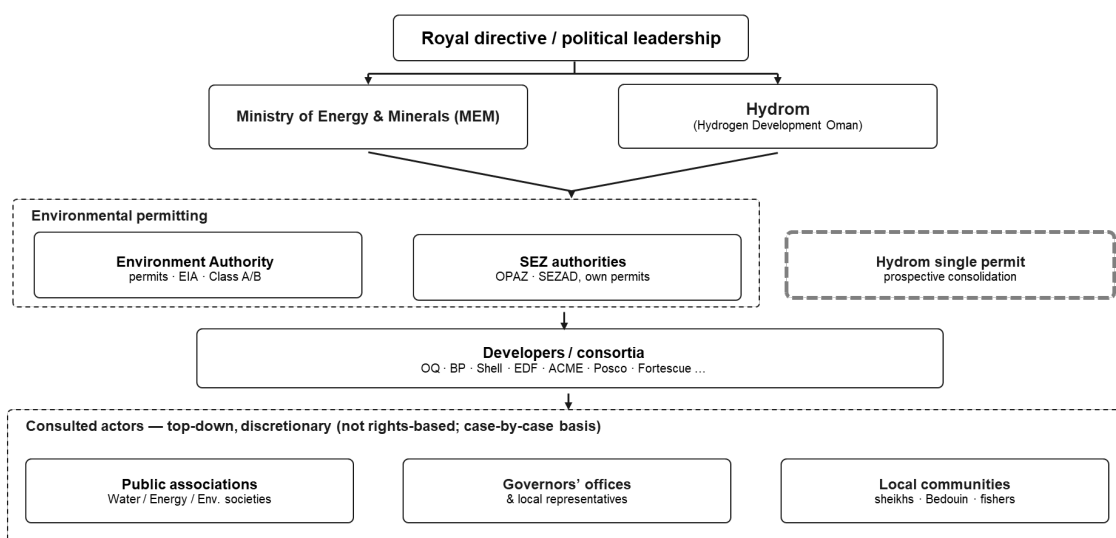
50 Interview with a representative of a logistic company

of ambition in implementation. Moreover, the environmental costs associated with the large-scale hydrogen rollout, including water consumption, potential leakage risks, and the ecological side effects of a major expansion of ammonia production, cannot yet be fully or reliably assessed at this early stage.

Decision-making and governance arrangements

As already indicated in the introduction of this in-depth case study, Oman's hydrogen governance is state-led and highly centralised, with strategic decisions concentrated in the MEM and Hydrom. Formal entry points for nongovernmental actors and potentially affected communities appear limited, although Hydrom has emphasised community engagement, local-content development, and coordination with governors' offices and local representatives. This suggests that consultation exists, but it is more top-down and discretionary than rights-based or institutionally entrenched. Adaptive responsiveness does exist, for example through consultations and adjustments in specific projects, but it currently seems to depend more on executive prioritisation and political visibility than on a stable set of procedural participation rights. Centralisation itself is not unusual in energy governance, but Oman appears to sit at the stronger end of the regional spectrum in terms of executive control and the limited role of independent regulatory oversight and formal public participation in hydrogen decision-making (Al Bulushi et al., 2024; Ansari, 2023; Marzouk, 2024).⁵¹ While environmental permitting procedures and regulatory requirements exist on paper (although their specific application to large-scale hydrogen projects is still evolving), the governance of emerging hydrogen developments involves a complex institutional landscape with overlapping competencies among state entities, SEZs, and other relevant authorities. Decisions concerning project allocation, land use, investment conditions, and the integration of environmental and social safeguards are often shaped through negotiations among government actors and project developers. In some cases, the strategic importance of attracting investment and securing project commitments may provide developers with considerable leverage. Particularly in the absence of binding offtake agreements and under conditions of uncertainty regarding project implementation, there is a risk that the consistent application of rigorous environmental and social standards could face challenges. Moreover, opportunities for broader stakeholder engagement, public debate, and independent interest articulation remain relatively limited within the country's wider governance framework. The following graphic seeks to unpack the current decision-making procedures governing the consideration of social and environmental aspects within Oman's emerging hydrogen landscape. It illustrates the key institutional actors, regulatory pathways, and points of interaction through which environmental and social considerations are incorporated into project development and approval processes.

51 Interview with a policy advisor/hydrogen expert

Figure 1: Overview of hydrogen decision-making & stakeholders in Oman

Source: Author

Hydrom's establishment and the introduction of a single permit system is intended to streamline regulatory procedures for large-scale hydrogen and renewable energy projects. However, this centralisation of authority can also concentrate decision-making power on a narrow set of actors, and rapid implementation risks reinforcing technocratic governance structures, potentially at the expense of broader stakeholder engagement and transparency. Major investment and infrastructure decisions are often taken without robust public consultation, creating structural barriers to inclusive engagement, especially for communities near project sites.⁵² Despite these constraints, interview data suggest that efforts are being made to foster a degree of transparency and public awareness. For instance, one interviewee stated:

Everything is transparent here in Oman, and they are talking about these projects and the benefits from these projects, so this is how they try to engage with locals.⁵³

Although it is acknowledged that these are not civil society actors in the conventional sense, given the limited space for independent civil society in Oman, public associations like the Oman Water Society, Oman Energy Association, or the Environmental Society are reportedly invited to participate.⁵⁴ Beyond environmental considerations, as discussed above, social aspects have also been addressed in some instances. Several interviewees pointed to cases where hydrogen projects were planned on land traditionally used by local sheikhs for camel rearing, herding and racing. In these instances, generous compensation was reportedly provided.⁵⁵ Yet, as with environmental impact procedures, there is no clear or consistent approach in place to ensuring meaningful participatory practice.⁵⁶

Two illustrative cases bear closer attention. First, the ESIA Guideline issued by SEZAD provides a transparent and well-structured framework for integrating environmental and social considerations into project planning, even though no hydrogen-specific version of such guidance

⁵² Interview with a policy advisor/hydrogen expert

⁵³ Interview with an independent hydrogen expert

⁵⁴ Interviews with a senior official of the national hydrogen authority and a policy advisor/hydrogen expert

⁵⁵ Interviews with an independent hydrogen expert, an independent environmental consultant and an energy ministry official

⁵⁶ Interview with a policy advisor/hydrogen expert

currently exists (Duqm, s.a.). The document outlines a screening system that classifies projects according to their potential impacts, and determines whether a full ESIA, a simplified EMP, or no assessment is required. A detailed scoping process requires developers to compile baseline data, identify potential impacts, and propose mitigation strategies before a full ESIA can be undertaken. Once a project has received final approval, project developers must submit a comprehensive ESIA report and an EMP that covers mitigation, monitoring and compliance measures across construction, operation and decommissioning phases. The guideline also emphasises cumulative impact assessment, hazardous waste and risk management, and, where necessary, biodiversity offsets. Finally, it mandates public disclosure by requiring non-technical summaries of approved assessments to be made available in Arabic and English on SEZAD's website, although such reports could not be located during this research.

A second example, primarily concerning the upstream value chain of hydrogen production, is a publicly disclosed Stakeholder Engagement Plan for a renewable energy project by the Saudi developer ACWA Power (Yahya Engineering & 5 Capitals, 2020), which offers a rare and detailed insight into how social safeguards and participatory practices are approached in Oman.⁵⁷ The project, in commercial operation for over four years, included a Stakeholder Engagement Plan reflecting the standards required by its main investor, the Asian Infrastructure Investment Bank, broadly aligned with IFC Performance Standard 1, which provides an internationally recognised framework for identifying and managing environmental and social risks, engaging affected stakeholders, disclosing relevant information, and providing grievance mechanisms. The plan covered identification of stakeholders, structured consultation, feedback channels, and a formal grievance mechanism. Cultural and social sensitivities were addressed, for example, preserving communal camel racing tracks by adjusting project layout, and a resettlement action plan was prepared where land access or displacement was unavoidable.

These two cases illustrate that robust participatory planning and social due diligence are both possible and, in some cases, already practised in Oman.⁵⁸ Several interviewees mentioned similar processes in current hydrogen projects, though detailed insights have not been shared.⁵⁹ The absence of a fully systematic and structured approach reflects responsibilities still in transition between the Environmental Authority and arrangements under Hydrom. Given that many projects are still at an early stage, it is expected that ESIA's will be conducted in later phases. However, their implementation remains questionable in the absence of a formalised and publicly available framework.

Social equity dynamics

The hydrogen transition in Oman presents both significant opportunities and serious social risks. If managed equitably, it could contribute to inclusive development, though the assumptions underlying projected benefits remain largely unspecified. Government projections suggest that the green economy could account for up to 55 per cent of Oman's new jobs by 2050, including an estimated 70,000 positions in the hydrogen sector alone (Schulkes, 2025), driven by investments in renewable energy and hydrogen infrastructure (Al Bulushi et al., 2024; Marzouk, 2024).⁶⁰ However, these figures remain uncertain and could not be independently verified, and, under current trajectories, appear rather optimistic and difficult to reconcile with the scale and pace of hydrogen development observed to date.

57 Interview with a policy advisor/hydrogen expert

58 Interview with a policy advisor/hydrogen expert

59 Interviews with an independent hydrogen expert, a senior official of the national hydrogen authority, an independent environmental consultant and an academic researcher/hydrogen expert

60 Interviews with an academic researcher/hydrogen expert, a policy advisor/hydrogen expert and a government hydrogen programme official

Public acceptance of these developments appears relatively high, with several interview partners emphasising that communities are eager to participate and benefit.⁶¹ For instance, the transformation of Duqm into a key energy and industrial hub was cited as an example where development occurred with minimal public resistance, due to the perceived social and economic benefits. According to one conversation partner:

We have seen, for example, in the development of Duqm that there weren't any objections because the people benefit from it and want to be engaged. [...] Oman is also looking for capacity building – to employ their own people and to engage them in all these developments.⁶²

However, more critical voices also point out that labour and workforce acceptance should not be taken for granted. Several well-educated Omanis, including engineers, are reportedly reluctant to take up positions in remote industrial zones like Duqm, citing a lack of social infrastructure and quality of life beyond the workplace.⁶³ In addition, if employment effects are concentrated in the construction phase, temporary housing clusters can create secondary social and gender-related challenges, such as pressure on local services and informal economies, as has been observed in similar large-scale resource-based projects in other countries.

Workforce development has nonetheless emerged as a central pillar of Oman's hydrogen strategy, with several initiatives designed to strengthen local capacity and align with future labour market needs. The Ecosystem Readiness Lab, a specific initiative by like-minded stakeholders to map key issues and bottlenecks, identified workforce development as one of five strategic focus areas, advocating for the establishment of skills incubators, targeted training programmes, and even dedicated housing for workers. Accordingly, the established academic master's programme (Master of Science in Hydrogen Economy and Technology) at the German University of Technology in Oman (GUtech) is designed as a flagship initiative to build national hydrogen capabilities by developing local expertise across the entire value chain, thereby complementing physical infrastructure with a dedicated knowledge base. It combines interdisciplinary training in engineering, economics and governance with strong international collaboration, while maintaining local ownership to ensure relevance for Oman's strategic priorities.⁶⁴ Hydrogen development may offer some social advantages relative to fossil-fuel industries, especially where it reduces exposure to combustion-related pollution and some extraction-related hazards, but it does not automatically deliver better social outcomes. New risks remain, especially in storage, transport, and outdoor construction and maintenance work, and the quality of employment depends on regulation and project design rather than on the fuel itself (Al Bulushi et al., 2024).

As emphasised in other sections, Oman maintains high standards and regulatory frameworks; however, these are not always uniformly applied, as illustrated by the case-by-case approach employed by SEZAD. One interviewee noted that some developers, though no specific names were mentioned, already account for "existing rights" during the project design phase, for example by recognising the presence of homes or farmland and committing to respect these rights throughout project implementation. In one case, wind turbines had to be placed at least 300 meters away from residential property based on such pre-established conditions.⁶⁵ Compensation mechanisms are in place when projects encroach on actively used land, such as

61 Interviews with a hydrogen expert/economic development official and a port authority and free zone official

62 Interview with an independent hydrogen expert

63 Interview with a government policy advisor

64 Interview with a university-based energy and hydrogen scientist and an academic researcher and hydrogen expert.

65 Interview with a senior official of the national hydrogen authority

camel-racing tracks, culturally significant in some communities.⁶⁶ Government representatives also pointed to cases where individuals made false land-ownership claims to receive compensation. Verification procedures have been introduced to balance accuracy with avoidance of local conflict.⁶⁷

Broader questions remain about who ultimately benefits from hydrogen development and under what conditions those benefits are shared. Because formal participation channels remain limited and the socio-political dimensions of the transition are still underexplored, there is a risk that gains accrue disproportionately to investors, central state institutions, and already advantaged groups unless more inclusive governance mechanisms are put in place. As one local source put it: “In Duqm, Bedouin started talking to the government and complained that they never came to us and asked us what we need.”⁶⁸ While families attempted to assert usage rights over government-owned land, the initial planning process excluded them. Wind and solar projects in Salalah sparked public concerns about displacement and disruption, described by one informant as a classic “not in my backyard” response: “What is it [i.e. energy transition] going to do with us?”⁶⁹

Officials acknowledged that they had underestimated the level and nature of public input and were initially unprepared for such responses. The government subsequently adjusted its approach by consulting affected communities through repeated rounds of direct dialogue across multiple ministries (housing, energy). One source emphasised that “his Majesty is keen that general society gets what it is owed – people first.”⁷⁰ This responsiveness suggests that Omani authorities are willing to accommodate societal needs, but adaptive engagement does not replace the need for institutionalised, transparent mechanisms of participation, particularly for rural and marginalised communities. Royal Decree No. 10/2023 contains no explicit requirements for public consultation, community engagement or participation mechanisms (Sultanate of Oman, 2023). Oman’s general Public–Private Partnership law requires that projects demonstrate “social or economic returns” but contains no specific mechanisms for community participation, consultation timelines or grievance procedures (Al Kalbnai et al., 2025; Sultanate of Oman, 2019).

Capacity-building and workforce development initiatives may unintentionally favour individuals with higher education or better institutional access. Several insiders suggest Oman may replicate its oil-sector approach for hydrogen: initially relying on foreign specialists while it builds home-grown expertise. As one source explained, citing discussions with the Minister of Finance, “the priority is to secure the investments first; job creation will follow later” (Schulkes, 2025). Oman’s reliance on migrant labour and the associated sponsorship-based labour regime pose additional concerns. Labour exploitation, wage disparities and unsafe working conditions have been documented in large infrastructure projects, including in Duqm (Valeri, 2017). If left unaddressed, similar dynamics could emerge or be exacerbated within the hydrogen economy, underscoring the need for enforceable labour protections and participatory oversight.

66 Interview with a hydrogen expert and economic development official

67 Interview with a senior official from the national hydrogen authority

68 Interview with a hydrogen expert and economic development official

69 Interview with a hydrogen expert and economic development official

70 Interview with a hydrogen expert and economic development official

6.2 Morocco's hydrogen turn: who will benefit from the energy leap?

Morocco's hydrogen rollout is politically centralised and hierarchically steered from the top, but institutionally fragmented in implementation. Strategic direction comes from the royal level and the central government, while several ministries share responsibilities for energy, finance, interior, infrastructure, industry and investment. Moroccan Agency for Sustainable Energy (MASEN) acts as the main investor-facing focal point and coordinator, but it does not itself replace the wider permitting, land, infrastructure and territorial governance chain (Medias24, 2025). The result is a system that is highly visible and politically backed at the centre, yet operationally dispersed across overlapping agencies and multi-level territorial bodies. Note that none of Morocco's eight major hydrogen projects has yet moved into implementation; the analysis below concerns the planning and design phase.

Morocco has positioned itself at the forefront of green hydrogen development on the African continent,⁷¹ aiming to translate its exceptional renewable endowment into a cornerstone of a new energy economy (Zekeik et al., 2025). The country seeks to become a global supplier of green hydrogen and its derivatives while leveraging this transformation to strengthen domestic industries and reduce dependence on imported fossil fuels, with energy sovereignty as its overarching goal.⁷² In 2021, Morocco became the first country on the African continent to publish a dedicated national hydrogen roadmap, which was developed by the National Hydrogen Commission (*Commission Nationale de l'Hydrogène*) (Ersoy et al., 2024). The roadmap is structured across three stages – industrial use and early exports (2020–2030), integration into the national energy mix (2030–2040), and deep decarbonisation across heat, mobility and aviation (2040–2050) – and reflects a long-term, phased approach.

At the political level, hydrogen has become a cornerstone of Morocco's green growth narrative, embedded within a highly centralised and top-down policy framework that characterises the country's broader energy transition (Amouzai & Haddioui, 2023; Ersoy et al., 2024; Okpanachi et al., 2022).⁷³ The launch of the "Morocco Offer" in 2024 marked a decisive step toward the materialisation of this vision (Head of Government of Morocco, 2024). The initiative is designed as an integrated investment framework to attract international consortia, facilitate access to land, and channel capital into large-scale hydrogen and derivative production. With this, the country wants to act simultaneously as a reliable energy partner for Europe and as a regional innovation hub.⁷⁴ Behind Morocco's hydrogen strategy lies a complex institutional architecture involving ministries, public agencies and territorial authorities. Strategic direction originates at the royal level, while operational coordination is organised through the Head of Government. The architecture is structured around two central bodies. The Steering Committee (*Comité de pilotage*) is chaired by the Head of Government and comprises representatives of the Ministry of Energy Transition and Sustainable Development, and those of Economy and Finance, Interior, Equipment and Water, and Industry and Commerce; it oversees the implementation of the *Offre Maroc* and the strategic orientation of hydrogen development. A separate Green Hydrogen Investment Committee (*Comité d'investissement hydrogène vert*) evaluates investor applications and decides on the allocation of land parcels.

71 Interview with a government hydrogen programme official

72 Interviews with an academic expert on environmental governance, a policy advisor and hydrogen expert and an international development agency representative

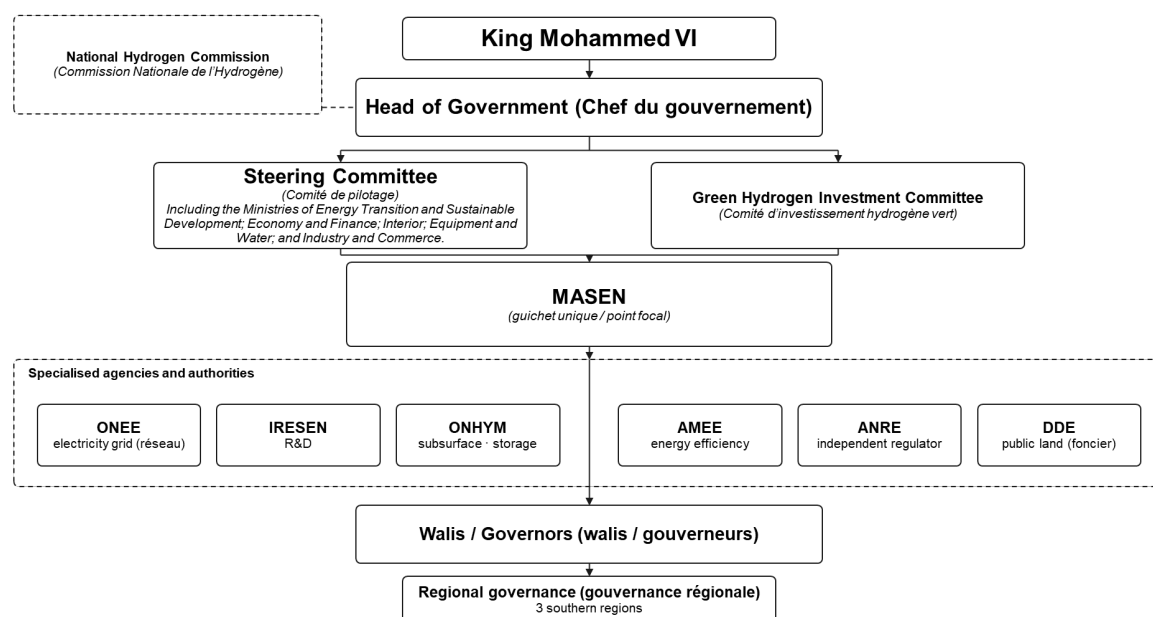
73 Interviews with a university-based energy and hydrogen scientist, an international development cooperation official and an advocate for civil society and environment

74 Interview with a policy advisor/hydrogen expert

At the operational level, MASEN serves as the central interface (*guichet unique*) for investors. Its role includes promoting the hydrogen offer, guiding investors through administrative processes, coordinating with ministries and regional authorities, verifying infrastructure requirements, and preparing allocation scenarios for consideration by the Investment Committee. Around this core sits a constellation of specialised agencies and authorities. The Institute for Research in Solar Energy and New Energies (*Institut de Recherche en Énergie Solaire et Énergies Nouvelles*, IRESEN), supports the national energy strategy by translating it into concrete research and development projects and by fostering collaboration with international partners. The *Office National de l'Électricité et de l'Eau Potable* (ONEE) focuses on conventional power generation, electricity transmission and distribution, and water supply and wastewater management, and remains central to grid connection for new projects. The *Office National des Hydrocarbures et des Mines* (ONHYM) contributes its subsurface expertise, leading on the geological storage of hydrogen and carbon dioxide, on the exploration of natural (“white”) hydrogen, and on related gas-transport infrastructure. The *Autorité Nationale de Régulation de l'Électricité* (ANRE) regulates the electricity sector. Complementing these, the Moroccan Agency for Energy Efficiency (*Agence Marocaine pour l'Efficacité Énergétique*, AMEE) is responsible for formulating national, regional and sectoral energy-efficiency plans, while the Directorate of State Property (*Direction des Domaines de l'État*, DDE), under the Ministry of Economy and Finance, mobilises the public land on which projects are sited.

Finally, implementation is territorially embedded in southern Morocco and Moroccan-controlled areas of Western Sahara, where Walis and governors coordinate regional interfaces, including land allocation processes, alongside local administrative structures. The following figure seeks to unpack the complex institutional architecture underpinning Morocco's emerging hydrogen initiative, highlighting the principal actors, their respective mandates, and the interactions that shape decision-making and project implementation. Overall, the governance model combines centralised strategic steering with a dispersed implementation structure. While this enables coordination across multiple sectors, responsibility for environmental and social safeguards remains dispersed across different institutions, with no single entity holding an overarching mandate.

Figure 2: Overview of hydrogen decision-making & stakeholders in Morocco



Source: Author

Like Oman, Morocco does not yet have a dedicated hydrogen law. Green hydrogen is currently regulated under the broader renewable energy framework, which encompasses laws on renewable energies, electricity sector regulation and self-generation of electricity. Recent reforms in 2023 streamlined authorisation procedures for renewable projects and introduced the possibility for operators to obtain certificates of origin confirming the renewable nature of electricity production. While these measures enhance procedural transparency, a specific regulatory framework for hydrogen certification and guarantees of origin is still under development and is unlikely to be subject to public consultation.⁷⁵ According to one interviewee, a unified hydrogen regulation would be highly desirable but appears unlikely given the technological and sectoral complexities of the hydrogen value chain.⁷⁶ In the meantime, industrial regulations for fertiliser and chemical production continue to apply to ammonia facilities, thereby providing an additional (though indirect) layer of oversight (Okpanachi et al., 2022). However, the absence of standardised procedures has produced a fragmented regulatory landscape, in which investors and developers rely on their own, often divergent, practices.⁷⁷ Moreover, Morocco currently lacks hydrogen-specific production standards and safety regulations. Existing facilities are instead classified as “major hazard installations” due to their handling of hazardous materials, which subjects them to stringent but non-hydrogen-specific safety requirements (Taouil, 2024). Introducing dedicated standards would offer several advantages, such as providing clear, hydrogen-specific safety and operational guidance, enhancing risk management, reducing regulatory uncertainty for investors, aligning with international best practices, and supporting consistent compliance monitoring and workforce training.

At present, Morocco is advancing eight major projects that focus exclusively on green hydrogen and Power-to-X technologies (see Table 4). Projections conclude that Morocco could supply around 4 per cent of global hydrogen demand by 2030, corresponding to potential annual revenues of roughly €2 billion, with long-term estimates surpassing €30 billion by 2050. Under different modelling scenarios, including both reference and optimistic pathways, Morocco could further achieve additional reductions in annual CO₂-equivalent emissions of between 10 and 20 per cent (Lebrouhi et al., 2024). Yet, the end use and purpose of the produced hydrogen remain to be decided. There will be no interconnected national grid; rather, production is expected to take place in isolated hydrogen clusters. This raises questions about how to manage such configurations efficiently and whether surplus electricity could be extracted and made publicly available as a service, for instance to supply local populations with power.⁷⁸

The following table reflects publicly announced projects and their latest reported stage. The March 2025 selections were followed by preliminary land reservations and development steps in 2025–2026, but most projects remain in the planning or early-development phase rather than construction or operation.

75 Interview with a policy advisor/hydrogen expert

76 Interview with an independent environmental consultant

77 Interviews with two policy advisors/hydrogen experts

78 Interview with a representative of an international development agency

Table 4: Overview of hydrogen projects associated with Morocco's hydrogen strategy

#	Project Name	Consortium/ Partners	Location	Selection date	Description/ Notes
1	MELHY Project	HDF Energy, SOMAS	Mohammedia, near Casablanca	November 2023	Green hydrogen storage in salt caverns with fuel cells
2	White Dunes Project	HDF Energy, Falcon Capital	Dakhla, Western Sahara	November 2023	Large-scale green H ₂ project integrating wind, solar, and ammonia production
3	Chbika 1	TotalEnergies	Chbika, Guelmim-Oued Noun, Southern Morocco	October 2024	Morocco Offer, Early-stage green hydrogen development
4	Ornx	Ortus, Acciona, Nordex	El Aaiún (Laâyoune), with sites near Boujdour, and Dakhla, Western Sahara	March 2025	Morocco Offer, Large-scale green ammonia production
5	Taq & Cepsa	Taq, Cepsa	Dakhla, Western Sahara	March 2025	Morocco Offer, Green ammonia and synthetic fuels
6	Nareva	Nareva	Not officially disclosed	March 2025	Morocco Offer, Ammonia, synthetic fuel, green steel production
7	ACWA Power	ACWA Power	Not officially disclosed	March 2025	Morocco Offer, Green ammonia production
8	UEG & China Three Gorges	UEG, China Three Gorges	Not officially disclosed	March 2025	Morocco Offer, Green ammonia production

Notes: Regional designation follows Moroccan administrative usage; some of the regions lie largely within Western Sahara, whose status remains unresolved under international law.

Source: Author

Industrially, hydrogen development builds directly upon Morocco's longstanding expertise in the phosphate and fertiliser sectors (Tanchum, 2024).⁷⁹ The state-owned OCP (Office Cherifien des Phosphates) Group, one of the world's largest phosphate producers, plays a pivotal role in the hydrogen transition, and its approach has also been considered as a "blueprint"⁸⁰ and as "foundation" (Bouzekri, 2026) for Morocco's hydrogen ambitions by some. Historically focused on converting phosphate into fertilisers, OCP now aims to produce green ammonia domestically, reducing the need to import expensive ammonia and positioning the country to benefit from emerging policies such as the Carbon Border Adjustment Mechanism (CBAM).⁸¹ By substituting imported ammonia with domestically produced green ammonia, Morocco seeks to mitigate vulnerability to global market shocks and rising costs, while simultaneously decarbonising one

⁷⁹ Interview with a corporate hydrogen expert

⁸⁰ Interview with an academic expert on environmental governance, a policy advisor and hydrogen expert and an international development agency representative

⁸¹ Interviews with an academic expert on environmental governance, an international development cooperation official and a corporate hydrogen expert

of its most energy-intensive industries (Lebrouhi et al., 2024).⁸² Already, in December 2022, the Moroccan government and OCP Group had committed to a \$13 billion initiative aimed at fully decarbonising the company's energy use. Central to this plan is ramping up green ammonia production to 1 million tons by 2027, with ambitions to reach 3 million tons by 2032, reducing reliance on imports. If realised, this expansion could elevate Morocco into the world's top ten green ammonia producers (Bouzekri, 2026). OCP's approach could serve as a potential best-practice model for other industrial sectors (i.e. green steel, synthetic fuels, chemical processing) though it remains largely isolated.⁸³ If scaled and interconnected, such initiatives could help foster domestic value chains, stimulate technological learning, and generate high-quality employment opportunities across Morocco's emerging green economy.⁸⁴

Alongside their economic and industrial development potential, Morocco's hydrogen projects must also be analysed in light of the broader geo-economic dynamics in which they are embedded, namely: (i) international energy geopolitics; (ii) Morocco's regional leadership ambitions in Africa; and (iii) territorial sovereignty questions, particularly regarding land control and the Western Sahara conflict, which affect investment security, reputational risks and due-diligence requirements for companies.

With regard to the first round of the Morocco Offer, one international observer noted:

The process [i.e. the Moroccan Offer], which was primarily geopolitical and aimed at appeasing all key partners remained unclear even in the decree as to who actually controls the land (...). In general, the tendering process was very non-transparent (...). Furthermore, lessons had been learned from previous experience that no project should proceed without an offtake agreement, and the prime assets should not be allocated immediately, but only after initial negotiations.⁸⁵

This assessment highlights a tension between Morocco's geopolitical ambitions and domestic governance challenges. While the Moroccan offer seeks to attract investment, secure future offtake agreements, and accommodate key international partners, concerns remain regarding the transparency of land allocation and decision-making processes. These issues are particularly salient as several proposed hydrogen projects are planned in territories with contested political status. As a result, questions of legitimacy, local benefit-sharing, and territorial governance become closely intertwined with Morocco's broader international hydrogen strategy.

At the same time, Morocco's hydrogen ambitions are closely linked to European interests. Owing to its geographic proximity, abundant renewable-energy potential and existing energy connections, Morocco is increasingly viewed by European actors as a strategic partner for the import of renewable hydrogen and hydrogen-derived products. Accordingly, Morocco maintains strategic partnerships with several European countries and institutions, most notably through bilateral hydrogen alliances and international financing programs (Ersoy et al., 2024). These partnerships provide access to concessional finance and technology transfer, and aim to secure offtake agreements, but also increase debt and foreign dependencies (Amouzai & Haddioui, 2023).⁸⁶ European ports such as Rotterdam are already developing dedicated import terminals for Moroccan green ammonia, signalling a tightening integration between Morocco's hydrogen strategy and Europe's decarbonisation agenda. Germany has played an important role in this process through the German–Moroccan Energy Partnership (PAREMA), established in 2012,

82 Interviews with a policy advisor/hydrogen expert and a corporate hydrogen expert

83 Interview an official of the government hydrogen programme

84 Interview an official of the government hydrogen programme

85 Interview with an international observer

86 Interview with a policy advisor/hydrogen expert

although the partnership's effectiveness and perceived balance have been assessed differently by various stakeholders (Amouzai & Haddioui, 2023).⁸⁷ The country is also asserting a geo-economic and geopolitical role by leading international initiatives to accelerate renewable energy access in developing countries, participating in the Sustainable Electricity Trade Roadmap for cross-regional electricity integration, and providing capacity-building for about 20 African nations (Amouzai & Haddioui, 2023; Okpanachi et al., 2022).⁸⁸ Having established the broader context of Morocco's hydrogen strategy and its underlying objectives, mirroring the preceding discussion of Oman, the following section turns to the four analytical categories that structure the framework of this study.

Resource endowment

Owing to the favourable combination of solar and wind resources, Morocco aims to become one of the world's most cost-efficient producers of green hydrogen (Bouzekri, 2026; Ourya et al., 2023; Zekeik et al., 2025).⁸⁹ Recent techno-economic assessments suggest that hydrogen produced under optimal hybrid conditions could reach competitive cost levels well below European domestic production, even when transport is included (Ersoy et al., 2024; Ourya et al., 2023; Zekeik et al., 2025). The country benefits from some of the highest solar irradiance levels in North Africa, reaching more than 5 kWh/m²/day (Azeroual et al., 2018; Ourya et al., 2023). The Atlantic coastline, particularly from Essaouira down to the southern reaches of Western Sahara, has moderate to strong winds of 5–7 m/s (Azeroual et al., 2018; Ourya et al., 2023; Zekeik et al., 2025). Complementarity between coastal wind and inland solar enables a more stable renewable electricity mix and positions Morocco among the few countries capable of sustaining large-scale green hydrogen production throughout the year.⁹⁰

Geography constitutes another strategic advantage for Morocco. Its proximity to Europe, just a few kilometres from Spain, positions it as a natural bridge for North–South energy integration (Ersoy et al., 2024). Existing infrastructure, such as the Maghreb–Europe gas pipeline, could be adapted to transport hydrogen or hydrogen-derived products. Morocco's maritime network, including Casablanca, Jorf Lasfar, Agadir and Tanger-Med, and the new port infrastructure under development in Dakhla, Western Sahara, provides critical export capacity, with several ports already handling ammonia and related chemicals while also aiming for ambitious decarbonisation goals, as is the case with Tanger-Med (Zekeik et al., 2025). Harnessing the great potential for hydrogen, however, intersects with the country's acute ecological structural water constraints (Miftah et al. 2025; Tanchum, 2024) or, as one interviewee summarised: "Large H₂ projects are not a social flashpoint, although they could become one if water scarcity becomes increasingly apparent."⁹¹ Such concerns are informed by past experiences: for example, the rollout of large-scale solar power facilities has significantly increased the demand for cooling water lately. The Noor I CSP facility, for instance, requires approximately 1.66 million cubic metres of water each year for cooling (Lebrouhi et al., 2024). Against this backdrop, and in the context of growing water stress, localised water-quality challenges, and the substantial water requirements of planned hydrogen and green ammonia projects, the Moroccan government has emphasised from an early stage that additional water demand associated with green hydrogen

87 Interview with a representative of an international development agency

88 Interview with a policy advisor/hydrogen expert

89 Interview with a corporate hydrogen expert

90 Interviews with a renewable energy company representative, an international development cooperation official and a policy advisor/hydrogen expert

91 Interview with an international development cooperation official

production should not draw on potable or irrigation resources. Instead, dedicated desalination facilities are envisaged as the primary water source for all hydrogen projects.⁹²

Morocco has initiated one of the most ambitious desalination programmes on the African continent, with the goal of sourcing half of the nation's drinking water from seawater by 2030. New desalination facilities are planned or under construction in Agadir, Casablanca, El Jadida, Safi, and Dakhla, Western Sahara, many of them designed to be powered by renewable energy (Lebrouhi et al., 2024). Also similar to Oman, voices within Morocco emphasise the country's open-ocean setting, which is believed to mitigate some of the localised environmental impacts of desalination.⁹³

Others caution that the practice nonetheless poses a significant long-term sustainability concern, particularly in ecologically sensitive coastal zones (Amouzai & Haddioui, 2023).⁹⁴ In this context, a 2022 report by the Moroccan *Conseil Économique, Social et Environnemental* (CESE) already emphasised the potentially detrimental impacts of desalination, particularly on marine biodiversity and coastal ecosystems. The report called for the implementation of more stringent systems for monitoring, regulation, and continuous environmental oversight of desalination plants (CESE, 2022). Other interviewees emphasised that the expansion of desalination could create conflicts with the fishing industry, which is also slated for expansion, as well as with the tourism sector, particularly in coastal areas popular for windsurfing and other water sports.⁹⁵ In Guelmim-Oued Noun, where fishing remains one of the most important economic activities, large ammonia or hydrogen projects are designed in way that means they are not in direct competition with local communities and their livelihoods. This includes, for instance, TotalEnergies' plan for a separate port far from existing fishing zones.⁹⁶

Public discussions often emphasise that planned desalination plants will also irrigate agricultural land.⁹⁷ Critical voices counter that this primarily serves to sustain a heavily subsidised agri-food system geared toward export, involving water-intensive crops poorly suited to climatic conditions, such as avocados and tomatoes (Amouzai & Haddioui, 2023).⁹⁸ Benefits of desalinated water are likely to accrue mainly to agricultural areas in close proximity to desalination plants, rather than further away.⁹⁹ Since the desalination facilities for hydrogen production have not yet been constructed, this remains an aspect to watch closely as the projects develop.

Morocco is also facing a decline in water quality, in addition to longstanding water scarcity (the most acute scarcity easing in 2025 owing to higher rainfall, though structural pressure remains). Water-quality pressures are linked to a range of human activities, including intensive agriculture, livestock operations, sanitation deficits, and industrial discharges, while nitrate contamination has been documented in several groundwater basins, particularly in intensively used agricultural areas in the north and east (Miftah et al., 2025).¹⁰⁰ At the same time, the distribution of these

92 Interview with a government hydrogen programme official

93 Interviews with a university-based energy and hydrogen scientist, an energy and climate policy expert and a policy advisor/hydrogen expert

94 Interviews a policy advisor/hydrogen expert and a civil society and environmental advocate

95 Interview with a university-based energy and hydrogen scientist, an international development cooperation official

96 Interview with an international development agency representative

97 Interviews with a renewable energy company representative, an economic researcher, a policy advisor/hydrogen expert and an international development agency representative

98 Interview with a civil society and environmental advocate

99 Interview with a civil society and environmental advocate

100 Interview with a policy advisor/hydrogen expert

pressures is uneven, and the south is not necessarily affected in the same way as the northern basins. Planned hydrogen and green ammonia projects could add new water-demand and wastewater-management challenges in some locations, especially where desalination, brine disposal, and industrial effluents are involved, but their eventual effects on water quality will depend on site-specific design, treatment standards and enforcement.¹⁰¹

Beyond water, land governance plays a decisive role in shaping Morocco's hydrogen trajectory. Under the national "Morocco Offer", the state has designated approximately 1 million hectares for renewable hydrogen development, with an initial 300,000 hectares already accessible to investors. International observers note that land allocation remains non-transparent¹⁰² and is determined only at a later point, which makes it difficult for external partners and investments. Essentially, everyone wants land 'north of the dashed line' (i.e. outside Western Sahara, which the UN lists as a Non-Self-Governing Territory), but at least three of the eight projects (see Table 4) are planned south of it, in Western Sahara; the locations of three further projects have not been officially disclosed.¹⁰³

Land allocation for hydrogen production is centrally managed by MASEN through a publicly not disclosed procedure that prioritises large-scale integrated projects capable of combining solar, wind, desalination and electrolysis within defined industrial clusters.¹⁰⁴ These clusters are primarily located in sparsely populated areas in southern Morocco (e.g. Guelmim-Oued Noun) and in Western Sahara (around Laâyoune and Dakhla), where renewable potential, coastal access and available land converge. Some of these areas, particularly in Western Sahara, are politically sensitive. Official statements emphasise that hydrogen projects will use scientific methods to ensure preservation and proper use of public land (LesEco, 2026). While the state's centralised management approach seeks to ensure strategic coherence in project development, it simultaneously raises critical concerns about inclusiveness, land rights and the equitable distribution of economic gains across regions, as discussed further below (Amouzai & Haddioui, 2023; Hamouchene, 2023).

Environmental risks

Environmental governance in Morocco is formally led by the Ministry of Energy Transition and Sustainable Development (MTEDD), but responsibilities are dispersed across a dense network of agencies and state-linked actors (see Figure 2). In fact, it is sometimes described as a "black box".¹⁰⁵ While Morocco has developed a comprehensive sustainability and environmental governance framework over recent decades, this architecture has not yet been fully adapted to the emerging hydrogen sector. As analysed here below, oversight remains fragmented, cumulative ecological impacts are insufficiently monitored, and no dedicated body is responsible for environmental and social assessment of hydrogen projects. MASEN, as the central investor interface under the *Offre Maroc*, coordinates project development but has no explicit mandate for environmental or social assessment.

Morocco's environmental assessment framework is based on law 12-03 on environmental impact studies and two implementing decrees. However, law 49-17 on environmental assessment, adopted in 2020, significantly improved the previous framework. The reform substantially modernises the assessment regime by introducing strategic environmental assessment,

101 Interview with a policy advisor/hydrogen expert

102 Interviews with a university-based energy and hydrogen scientist and a policy advisor/hydrogen expert

103 Interview with an international development cooperation official

104 Interviews with a university-based energy and hydrogen scientist, an international development cooperation official and a policy advisor/hydrogen expert

105 Interview with a policy advisor/hydrogen expert

environmental audits, accredited assessment consultancies, strengthened public participation, and binding environmental authorisations. These reforms respond to longstanding issues, including limited transparency, weak public participation, and insufficient accountability (Tih & Ait Boubkr, 2026; World Bank, 2023; Hatim, 2020). Yet, none of the existing assessment frameworks include hydrogen-specific environmental and social requirements, leaving important questions regarding large-scale electrolysis, desalination, ammonia production, storage and transport insufficiently addressed.

This gap is particularly relevant given that many planned hydrogen projects are concentrated in southern Morocco and Moroccan-controlled areas of Western Sahara, where development will take place within environmentally sensitive and resource-constrained landscapes. These regions are characterised by arid steppe ecosystems with limited endemic biodiversity, notably argan forests and endangered species such as Cuvier's gazelle, and pronounced water scarcity. Climate-change projections suggest that, unlike the northern regions, the south could experience increased offshore wind speeds, potentially enhancing hydrogen production suitability (Zekeik et al., 2025). Planned industrial clusters spanning hundreds of square kilometres pose substantial ecological risks, land-use changes, habitat fragmentation and pressures on coastal and marine ecosystems (Amouzai & Haddioui, 2023). Coastal operations and port facilities for green ammonia storage and shipping are of particular concern.¹⁰⁶ The chemical's volatility and toxicity create environmental hazards in the event of leaks or accidental releases, especially given that the existing port infrastructure is largely not equipped to safely handle such materials.¹⁰⁷

One interviewee sought to put this into perspective by emphasising that the country has been handling millions of tons of ammonia for years. Despite ammonia's toxicity, this has not previously attracted significant public interest; only with the emergence of the hydrogen debate is the issue receiving greater attention.¹⁰⁸ Nonetheless, as one academic interviewee put it, "the state of mind in Morocco is that biodiversity is marginalised in discussions and does not receive the same importance as economic revenues."¹⁰⁹

Decision-making and governance arrangements

Morocco's hydrogen governance concentrates strategic authority in a small circle of state agencies, royal-court allies, and large industrial groups (notably OCP), while routine permits are issued through MASEN and regional governors (*Walīs*). Formally, regional and local institutions, including the regions and municipalities, remain part of the institutional framework, but in practice their room for autonomous influence appears limited. The configuration therefore accelerates implementation and tends to restrict local input by design. Decision-making authority is concentrated within a technocratic core, Moroccan government, MASEN, key ministries, in close cooperation with private energy companies and international financial institutions (Okpanachi et al., 2022).¹¹⁰ In the words of several interview partners, Morocco's hydrogen rollout is "the king's project", highlighting the strong political commitment from the palace and the central role of *al-Makhzan* (i.e. the royal establishment and its network of power) in shaping and steering the country's energy transition agenda.¹¹¹

106 Interviews with a policy advisor/hydrogen expert and a civil society and environmental advocate

107 Interview with an independent environmental consultant

108 Interview with a policy advisor/hydrogen expert

109 Interview with an academic expert on environmental governance

110 Interview with an international development cooperation official

111 Interviews with a university-based energy and hydrogen scientist, an international development cooperation official and a policy advisor/hydrogen expert

Critical scholarship describes Morocco's energy sector as "governed largely by autocratic instruments" (Moustakbal, 2023, p. 224), with MASEN functioning as a highly centralised institution closely aligned with the king and his inner circle. In practice, authority is exercised through a network of close allies, which ensures coordination but limits broader participation.¹¹² This arrangement may marginalise not only local communities and citizens, but even parliamentarians, who remain largely excluded from substantive decision-making processes (for hydrogen, see: Amouzai & Haddioui, 2023; as a general overview, see: Bogaert, 2018).¹¹³ Because of the close alignment between large industrial actors and state authorities, as well as the structural reliance on financially robust external investors, small and medium-sized enterprises (SMEs) appear to be marginalised in Morocco's national hydrogen development plans, despite their potential to make significant contributions to ancillary manufacturing, service provision, and component supply chains. The 2021 National Hydrogen Strategy and the "Morocco Offer" focus on large-scale industrial projects and international consortia, with no explicit provisions for SME participation identified in the publicly available policy documents (Kingdom of Morocco, 2021; Head of Government of Morocco, 2024). According to expert interviews, this regulatory gap, combined with high minimum investment thresholds and large land parcel requirements, creates structural barriers that effectively exclude smaller domestic actors from direct participation in hydrogen production, though their role in ancillary supply chains remains an underexplored area for policy intervention.¹¹⁴

While such centralised structures may streamline project approvals and accelerate implementation, they have also alienated much of the population from meaningful participation, despite formal commitments to inclusiveness in policy documents. Several interviewees described the system as at times dysfunctional, noting that the small group of 10 to 15 key decision-makers often pursue their own, sometimes competing, agendas, which undermines coordination and consistent communication.¹¹⁵ As one observer put it, the problem lies "less in conflicting mandates than [in] the lack of effective information-sharing and transparency."¹¹⁶

This imbalance is also reflected in the composition of stakeholder meetings, where representatives of state agencies and international companies typically dominate discussions, while "the voices of those most directly impacted by these projects, including local communities, small-scale farmers, pastoralists and agricultural workers, remain largely absent" (Amouzai & Haddioui, 2023, p. 18). Morocco's energy landscape illustrates how these power asymmetries are embedded institutionally: for instance, *Energie Eolienne du Maroc (EEM)*, a subsidiary of Nareva Holding, whose majority shareholder is the Moroccan royal family, holds a near-monopoly in the wind energy sector (Amouzai & Haddioui, 2023).¹¹⁷

Nevertheless, occasional openings for participation and public influence do occur, albeit under exceptional circumstances. One example mentioned concerns the 2018 Agadir wind project involving a Spanish company, which initially sparked protests by environmental NGOs and fishers concerned about coastal access and marine ecosystems. The case suggests that public concerns can ultimately be taken into account, but only after mobilisation had escalated and the issue reached the royal palace. The project was then relocated, but the process also led to a

112 Interview with an international development cooperation official

113 Interview with an international development cooperation official and two policy advisors/hydrogen experts.

114 Interviews with a university-based energy and hydrogen scientist and an academic expert on environmental governance

115 Interviews with a civil society and environmental advocate and an international development agency representative

116 Interview with an independent environmental consultant

117 Interview with an international development agency official

three-year delay in implementation.¹¹⁸ Such rare instances of responsiveness highlight that participatory mechanisms remain ad hoc and reactive rather than institutionalised, depending largely on political visibility and royal intervention rather than procedural transparency. In general, it should also be noted that hydrogen has not emerged as a top priority for civil society, partly because of its technical complexity, partly because attention remains focused on long-standing concerns about pollution, water availability and quality, and land grabbing, and partly because nothing has yet been implemented at scale.¹¹⁹

As in Oman, environmental assessment is formally required for major projects, whereas neither country's legal framework mandates a separate social impact assessment. Where ESIA's are conducted, they are typically driven by a combination of international lender requirements and domestic legislation (Tih & Ait Boubkr, 2026). As mentioned above, in Morocco two laws in particular (12-03 of 2003 and 49-17 of 2020) engage with requirements that projects in designated categories, including power plants and industrial facilities, have to undergo an environmental impact assessment (*étude d'impact sur l'environnement*, EIE). Assessments are reviewed by dedicated national (*Comité National des Études d'Impact sur l'Environnement*, CNEIE) or regional (*Comités Régionaux des Études d'Impact sur l'Environnement*, CREIE) committees, depending on project scale, and environmental authorisation is granted only after a positive decision of environmental acceptability. The framework also requires a public inquiry, allowing affected communities to review project documentation and submit comments. On paper, the system therefore incorporates formal mechanisms for public participation (Tih & Ait Boubkr, 2026; Medias24, 2025; World Bank, 2023).¹²⁰

In practice, however, several factors constrain their effectiveness. Public inquiries are administered through the deconcentrated structures of the Ministry of the Interior, with no formal role for elected municipal councils. Moreover, several interviewees remarked shortcomings regarding transparency, access to environmental information, accountability and meaningful public participation.¹²¹ Although Law 49-17 (2020) substantially modernises the assessment framework, introducing strategic environmental assessment, environmental audits, accredited assessors and binding environmental authorisations (Hatim, 2020; Tih & Ait Boubkr, 2026), for hydrogen projects additional governance challenge arises from the sequencing of decision-making. Environmental and social considerations inform investor selection, but detailed impact assessments are conducted only after investors have been selected and preliminary land allocation has taken place. Consequently, environmental assessment occurs after key strategic decisions regarding project location have already been made, limiting its influence on project design.¹²² Consequently, environmental and social assessment in Morocco continues to follow a predominantly technical-administrative model. While this approach establishes formal procedural safeguards, scholars have noted that such frameworks do not necessarily translate into meaningful stakeholder participation or substantive consideration of social impacts in project design (Terrapon-Pfaff et al., 2015; Okpanachi et al., 2022; Amouzai & Haddioui, 2023).

Studies are prepared by project proponents and reviewed by appointed committees, while monitoring, transparency and long-term follow-up remain limited.¹²³

118 Interviews with an energy and climate policy expert and an international development cooperation official

119 Interviews with a policy advisor/hydrogen expert and an international development cooperation official

120 Interviews with an international development cooperation official, an international development cooperation official and a civil society and environmental advocate

121 Interviews with two policy advisors/hydrogen experts as well as a policy advisor/hydrogen expert

122 Interview with a civil society and environmental advocate.

123 Interview with a policy advisor/hydrogen expert; Interview with an academic expert on environmental governance

As several interviewees noted, social and environmental assessments often appear robust on paper but lack effective implementation in practice.¹²⁴ For this study, this could not be independently confirmed, nor were institutionalised procedures for participation or transparent grievance mechanisms identified.

Consequently, as one interviewee noted, “EIAs are a black box, unclear, who does it, and review it and follow up on processes.”¹²⁵ Insights from two interviews suggest that environmental assessments are often passed through expedited permitting procedures or prepared primarily to comply with international standards, while substantive follow-up after approval seems limited.¹²⁶ This dynamic is particularly evident in Morocco’s “hydrogen priority zones”, such as Guelmim-Oued Noun, where the government seeks to attract foreign investment and showcase pilot projects (Amouzai & Haddioui, 2023). The delegation of responsibilities creates tensions between environmental oversight and investment promotion: MASEN operates simultaneously as the primary contact point for investors and as a coordinator of project approvals, while high-level governmental committees (in essence the Steering Committee and the Green Hydrogen Investment Committee) focus on accelerating project timelines in response to international competition (A&O Shearman, 2024). The institutional configuration, in which a one-stop-shop approach designed to facilitate investment may place pressure on balancing a thorough environmental review with expediting the permitting procedure, can potentially blur the distinction between independent oversight and the promotion of investment.¹²⁷

Consultants involved in these processes further criticised the absence of systematic follow-up mechanisms, particularly regarding whether identified risks, mitigation measures and stakeholder concerns raised during the ESIA process were subsequently addressed or monitored. This gap contributed to perceptions of ESIA as largely symbolic or as a form of “green window dressing”.¹²⁸ Moreover, discrepancies were frequently reported between internal technical assessments and the final published ESIA reports (e.g. project-level ESIA disclosure reports submitted to or published by relevant authorities), with key risks or recommended actions significantly downplayed or omitted in the publicly available versions.¹²⁹ As one interviewee summarised:

Developers don’t really need to enforce ESIA. Sometimes they have it on paper, but there is no follow-up or monitoring to see whether the proposed measures have actually been implemented.¹³⁰

In this regard, it might not be surprising that public participation tends to be nominal, reinforcing existing socio-political hierarchies and leaving affected communities excluded from decision-making (Amouzai & Haddioui, 2023; Hamouchene, 2023; Okpanachi et al., 2022). As one interviewee summarises:

There are standards for environmental and social impact assessments, and it is evident that every major project in Morocco adheres to them. However, when it comes to the broader aspects surrounding hydrogen production, such frameworks and guidelines are largely absent. For instance, while there are standards for ammonia production,

124 Interviews with an energy and climate policy expert and two civil society and environmental advocates

125 Interview with a policy advisor/hydrogen expert

126 Interviews with two policy advisors/hydrogen experts

127 Interviews with an academic expert on environmental governance and a civil society and environmental advocate

128 Interview with a university-based energy and hydrogen scientist

129 Interview with a policy advisor/hydrogen expert

130 Interview with an academic expert on environmental governance

because of the country's extensive experience in this sector, these standards focus primarily on safety and security rather than on social or environmental considerations. In short, for the time being, there is a lot to do.¹³¹

Officials directly engaged in Morocco's hydrogen development emphasise that they regularly conduct workshops within local communities, deliberately travelling to communities rather than expecting them to come to Rabat, to acknowledge local perspectives early, undertake participatory studies, and foster genuine dialogue.¹³²

Social equity dynamics

As explained below, Morocco's hydrogen rollout is unlikely, on its current trajectory, to generate the broad-based direct employment that its political framing promises. At first glance, the sector appears highly advantageous, reducing energy dependence, attracting foreign investment, generating revenue, modernising infrastructure, advancing decarbonisation, creating employment in a context of high youth unemployment. The International Renewable Energy Agency (IRENA) projected in 2022 that Morocco's hydrogen sector could generate more than 15,000 direct and indirect jobs by 2030, with further expansion anticipated through 2050 (IRENA, 2022, p. 48). At the same time, policy discussions also emphasise that green hydrogen could stimulate indirect and induced employment across the wider value chain, including logistics, construction, training, industrial services and downstream applications such as green ammonia and related industrial inputs (World Bank, 2022).

However, the distributional impact of these employment opportunities raises fundamental concerns about inclusivity and equity. The hydrogen sector is inherently specialised, demanding highly technical skills concentrated in engineering, industrial processing and research domains rather than creating broad-based employment accessible to diverse segments of the population (Tanchum, 2024).¹³³ As one interviewee pinpointed:

I think social aspects represent one of the greatest challenges for hydrogen development so far, especially when measured in terms of job creation (...) we should talk about conditions and empowerment; for instance, I have witnessed someone digging a hole for two hours, and that was counted as a job (...) this was overseen by a big consultancy firm plus its consortium.¹³⁴

The Noor Ouarzazate analogue is informative: a large solar complex, marketed as a job engine, generating few lasting local jobs beyond the construction phase (Terrapon-Pfaff et al., 2019).¹³⁵ OCP takes the lead, operating its own university and actively building specialised expertise,¹³⁶ but Morocco needs a comprehensive, large-scale training programme to implement its plans.¹³⁷

131 Interview with a policy advisor/hydrogen expert

132 Interview with a government hydrogen programme official

133 Interviews with an international development cooperation official, a policy advisor/hydrogen expert and a civil society and environmental advocate

134 Interview with a policy advisor/hydrogen expert

135 Interviews with an international development cooperation official and a civil society and environmental advocate

136 Interviews with an international development agency representative and a corporate hydrogen expert

137 Interview with a corporate hydrogen expert

The government aims to “provide training, establish platforms, and create master’s programmes”¹³⁸ structured around three parallel approaches: the Green H2A Platform developed by IRESEN and OCP Group for research, demonstration, training and technology transfer; the GreenH2 Cluster, established in 2020 to coordinate public–private collaboration; and a significant expansion of universities and degree programmes in hydrogen and Power-to-X.¹³⁹ As one interviewee said: “we need to train thousands upon thousands of people (...) and this is the top priority, above technology and even economics.”¹⁴⁰

However, the outlook remains uncertain. Morocco’s current clean hydrogen programmes do not mandate local sourcing, and investors face few incentives to engage domestic suppliers or develop a local supply chain (Bouzekri, 2026). Even if future policies move beyond an investor-centric approach toward regional development strategies emphasising job creation through capacity-building, workforce development is likely to remain uneven across regions and social groups (Bouzekri, 2026). Temporary employment during construction phases often fails to translate into sustained livelihoods, and operational roles typically require technical expertise unavailable locally. In this regard, one interviewee recalled the Noor solar complex project, where the promises of job creation were never fulfilled.

Beyond employment, another deeper structural inequality concerns the uneven distribution of costs and benefits associated with hydrogen projects and initiatives. Historical precedents from the Noor Ouarzazate and Midelt solar complexes reveal that state-led development often places significant burdens on local communities, including land dispossession, water scarcity and disruption of traditional livelihoods, while tangible benefits disproportionately accrue to elites, investors and urban centres (Amouzai & Haddioui, 2023; Hamouchene & Sandwell, 2023; Rignall, 2016).¹⁴¹

Some interviewees expressed critical views on the distribution of the financial benefits from recent investments, raising concerns that the financial returns may be unevenly distributed.¹⁴² Another commented, “like with the solar projects, it’s [i.e. hydrogen] not economically sound, it costs a lot, and the population ends up paying for it.”¹⁴³ However, these remarks reflect critical, anonymised perspectives, and whether they materialise in practice remains uncertain, as many projects are still at the planning stage. Since the specific project locations remain undisclosed so far, accurately assessing opinions about their impacts proves challenging. One interviewee noted that once sites become known, local resistance may arise, especially where land tenure is customary or past projects caused disputes over access.¹⁴⁴

Fears persist that Morocco’s hydrogen rollout could reproduce earlier patterns of land dispossession witnessed in the Ouarzazate and Noor Midelt solar complexes (Okpanachi et al., 2022; Rignall, 2016). In both cases, project sites were officially classified as collective lands (*terres collectives*), traditionally governed under customary law. By invoking colonial-era legislation from the French protectorate period, the state redefined these territories as property of “public interest”, enabling their transfer to MASEN. Consequently, local herders and farmers from communities such as Ait Oufella, Ait Rahou Ouali and Ait Massoud Ouali lost access to

138 Interview with a government hydrogen programme official

139 Interview with a government hydrogen programme official and a civil society and environmental advocate

140 Interview with a government hydrogen programme official

141 Interviews with an international development cooperation official and a civil society and environmental advocate

142 Interview with an international development cooperation official

143 Interview with a civil society and environmental advocate

144 Interview with a policy advisor/hydrogen expert

ancestral grazing and agricultural lands (Hamouchene, 2023). Although local populations received compensation, the execution and operational processes lacked full transparency.¹⁴⁵

Several interviewees mentioned a 1981 law that allows the state to expropriate land for public necessity or temporary use. Compensation is generally determined through negotiation with the landowner; if an agreement cannot be reached, a committee of local officials sets the amount based on market value. While this law has been applied to urban development, some interviewees criticised it, noting that the state often sets a “ridiculously low” amount.¹⁴⁶ At the same time, a reform of Morocco’s expropriation framework is currently under discussion, suggesting that the procedural rules and compensation mechanisms may change in the near future (Khatla, 2026; Médias24, 2025). Disputes over compensation are generally resolved through judicial procedures, which may be difficult to navigate for affected communities due to high costs, lengthy proceedings, and limited access to specialised legal expertise (Advisian, 2023).

These potential injustices pose a particular risk in the Western Sahara, where numerous hydrogen projects are planned for the future. While one interviewee pointed out that such developments could bring wealth and prosperity to the region,¹⁴⁷ several others expressed concern that local land and resources could be developed without adequate consultation of the local population or mechanisms of accountability.¹⁴⁸ Given the low levels of public awareness and acceptance, these risks are considered especially acute in these peripheral areas.¹⁴⁹ One interviewee suggested that the Moroccan government may also see hydrogen and the targeted allocation of land in Western Sahara as a means of reinforcing its de facto control over the territory and its resource base. In doing so, the government may also benefit from the global race to secure a role in the future hydrogen economy, creating conditions in which investors may be more willing to overlook reputational and regulatory risks.¹⁵⁰ This assessment could not be independently verified.

A related but separate example is provided by ongoing initiatives in Guelmim-Oued Noun, where the German Agency for International Cooperation (GIZ) is implementing the project “Green recovery through green energy and hydrogen in Morocco” on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ). The project uses the Guelmim-Oued Noun region as a pilot area to strengthen the institutional, legal and technical frameworks for renewable energy expansion and green hydrogen production. It supports public institutions in Rabat and local decision-makers in Guelmim-Oued Noun in developing participatory planning processes, investment approval procedures, and gender-sensitive value chains, with the aim of attracting private investment and ensuring the socio-economic and long-term ecological sustainability of energy projects (Jumelages & Partenariats, 2025; GIZ n.d.).¹⁵¹

145 Interview with an academic expert on environmental governance

146 Interview with an international development cooperation official

147 Interview with a renewable energy company representative

148 Interview with a university-based energy and hydrogen scientist and a civil society and environmental advocate

149 Interviews with a university-based energy and hydrogen scientist and two civil society and environmental advocates

150 Interview with an international development cooperation official

151 Interview with an international development cooperation official.

7 Sustainability trade-offs and safeguards in emerging hydrogen economies: lessons from Oman and Morocco

The comparison between Oman and Morocco suggests that governance arrangements shape how hydrogen-related sustainability risks are identified and addressed. The two countries differ in project allocation, environmental review and opportunities for participation. These differences warrant comparison, but the projects' early stage and the absence of accessible project-level impact assessments do not yet permit conclusions about their relative sustainability outcomes.

Read together, the cases reveal different pathways to a similar procedural risk: affected communities may have limited influence over siting, water allocation and benefit-sharing. In Oman, Hydrom coordinates land allocation through a comparatively clear central process, while public participation and independent oversight remain less well documented. In Morocco, central strategic steering coexists with more dispersed implementation responsibilities. This does not establish that participation is equally weak in both countries; the available evidence supports a concern about when and how communities can influence decisions. Oman has conducted pre-auction scoping, while full project-specific assessment generally follows allocation. For Morocco, the timing and influence of assessment cannot be established consistently across projects from the material available. In both cases, the key test is whether environmental and social evidence can still change project location, scale or resource use before these choices become difficult to reverse.

Each case therefore offers a narrower institutional lesson: Oman's coordinated allocation process may help clarify responsibilities in Morocco, while Morocco's longer experience with statutory assessment may inform Omani practice. Neither feature is a safeguard in itself. Its value depends on early disclosure, independent review and the ability to alter project decisions.

Overall, Oman appears to offer more procedural coherence and centralised coordination, while Morocco shows stronger pre-existing technical capacity, a more mature ecosystem of education, vocational training and research institutions, and more developed renewable-energy institutions in selected areas, partly due to the established OCP ecosystem and longer experience with renewable-energy deployment. Yet potential social and environmental tradeoffs become apparent.

Similar tensions emerge around land governance. In Oman, concession blocks in Duqm and Dhofar are largely located on sparsely populated state land, reducing tensions around customary tenure and enabling comparatively streamlined project development. Morocco faces more complex territorial dynamics: some of the announced projects within the Morocco Offer framework are situated south of the dashed line, in Western Sahara, where sovereignty disputes, customary land claims and biodiversity concerns overlap. This comparison illustrates that project siting itself constitutes a governance challenge. Comparable governance challenges also arise in the field of water management. Both countries plan to use coastal desalination for hydrogen production; the electricity source and water supply remain project-dependent. Whereas desalination can ease reliance on scarce fresh water, it creates new dependencies on electricity, coastal infrastructure, and technical equipment. The governance question is how the resulting water and infrastructure are allocated and regulated. Hydrogen projects may put export-oriented industry in competition with drinking-water supply, agriculture and local businesses. Large-scale desalination also requires oversight of marine impacts, particularly brine discharge, and coordination among water, energy, industrial, environmental and local authorities. In water-stressed countries, it may thus reshape resource dependencies without resolving scarcity.

Both countries face a gap between project-level assessments and the monitoring of impacts across several projects sharing land, coastal waters or infrastructure. The study could not assess the quality of undisclosed project-level documents or verify how safeguards operate in practice. Hydrogen certification can verify attributes such as renewable origin and greenhouse-gas intensity, but it cannot be a substitute for site-specific review of brine discharge, ammonia handling, habitat effects or public participation. Closing this gap requires clear responsibilities for independent assessment, cumulative-impact monitoring and public access to environmental and social information.

Questions of governance also extend to labour markets and social equity. Both Oman and Morocco present hydrogen production as a vehicle for economic diversification, green employment and regional development, accompanied by investments in workforce-development programmes. However, the distribution of anticipated benefits remains uneven. In Oman, tensions surrounding migrant labour and Omanisation reflect patterns long established within the hydrocarbon economy. In Morocco, policy discussions also suggest possible indirect and induced employment across supply chains, logistics and downstream industrial uses, but the direct employment effects are likely to remain limited and concentrated in highly skilled technical positions. More equitable outcomes will depend on transparent compensation mechanisms, fair hiring practices, and deliberate integration of local suppliers and labour into emerging value chains.

Against this backdrop, the comparison highlights a broader lesson: hydrogen development poses not only technical challenges but also institutional and political ones. Land allocation, water scarcity, environmental monitoring, labour inclusion and domestic value creation all depend on governance arrangements capable of balancing investment objectives with social and ecological safeguards.¹⁵²

¹⁵² This assessment is based on the information gathered to date and is intended to provide a structured overview of emerging trends and trade-offs; it should not be interpreted as exhaustive, and some gaps or uncertainties may remain.

Table 5: Overview of prospective social and environmental risks, evidence limits and safeguards in Oman and Morocco

Dimension	Key Driver/Trade-off	Explanation/Examples	Potential Mitigation
Land Use & Habitat	Large-scale solar/wind/ammonia siting may fragment habitat or affect other land use	Oman: Hydrom identified large development zones, but early auction blocks were about 300–320 km ² each.	Pre-siting sensitivity mapping; biodiversity offsets; phased construction to minimise disruption
		Morocco: Project locations and footprints are not specified clearly enough to quantify effects on customary land, biodiversity or disputed territory.	
Water & Desalination	Desalination reduces freshwater withdrawals but creates power, coastal and pipeline demands.	Oman: Marine effects depend on intake, outfall, local ecology and cumulative discharges; an open coast does not necessarily establish low risk.	Set water-allocation rules; assess intake and brine conditions; foster R&D in terms of seawater electrolysis research and monitor marine impact
		Morocco: Impacts on water allocation, fisheries or agriculture depend on project design and location.	
Pollution & Lifecycle Emissions	Brine discharge, ammonia spills create site-specific hazards; blue hydrogen pathways also raise methane concerns	Oman: Product carbon certification does not verify brine or spill controls. Actual impacts remain unmeasured.	Require site-specific permits, discharge limits, safety plans and incident reporting.
		Morocco: No blue-hydrogen project is identified here; marine and safety evidence is limited.	
Regulatory & Governance	Allocation and permitting can speed investment while limiting scrutiny or leaving responsibilities unclear.	Oman: The effects of the proposed single-permit process cannot yet be assessed.	Institutionalise participatory processes, cumulative environmental monitoring, public access to permits/data
		Morocco: Agency responsibilities are dispersed; participation and implementation may differ across projects.	
Labour & Social Equity	Demand for high-skill jobs and uneven access may limit local gains.	Oman: Training programmes exist, but durable outcomes for local and migrant workers remain unverified.	Expand vocational training for women/youth, ensure transparent benefit-sharing, third-party verification, phased local hiring. Introduce local content requirements, incentivise domestic supplier integration
		Morocco: High-skill jobs but scope unclear; OCP as enabler for training, research and education	

Source: Author

Ultimately, Oman and Morocco illustrate both the opportunities and risks of hydrogen-led development and the difficulty of governing its prospective social and ecological effects. The evidence here identifies risks and gaps in safeguards rather than measured project impacts. Whether hydrogen contributes to genuinely sustainable and equitable transitions will presumably depend less on technological feasibility than on the extent to which environmental safeguards, participatory governance and distributive justice become embedded within the institutions governing the emerging hydrogen economy.

8 Conclusion and ways to move forward

The emerging hydrogen sectors in Oman and Morocco show how resource endowment and political commitment can attract investment without guaranteeing sustainable outcomes. Both nations have set ambitious export-oriented strategies and are trying to align project development with international market expectations, especially from Europe. At the same time, project viability remains uncertain because of cost pressures, uncertainties about evolving demand, and technology bottlenecks, while environmental and social safeguards are still being developed and have only recently become a more prominent focus of research, and due-diligence practice is unevenly developed and unevenly implemented.¹⁵³ Because in both countries hydrogen projects remain pre-operational, this study has analysed governance in the making rather than realised impacts. No hydrogen project in either country has reached final investment decision, and no project-level ESIA document could be obtained. The conclusions below are accordingly anticipatory, and are offered in the spirit of learning from the interim results of an ongoing process.

Despite these uncertainties, the comparison yields three main lessons:

1. First, institutional design shapes the conditions under which sustainability risks can be addressed. Both Oman and Morocco formally project relatively centralised governance models, but differ in how project allocation, environmental review and implementation are organised. The relevant test is whether responsibilities are clear, oversight is independent and evidence can alter decisions before concessions and permits become difficult to revise. The present evidence establishes differences in procedure, not a ranking of realised sustainability outcomes.
2. Second, recent work on the global green hydrogen ambition and implementation gap shows that announced hydrogen project pipelines and associated socio-ecological risks have grown much faster than actual deployment and the regulatory frameworks needed to govern them. This finding points to a structural lag between ambition and safeguards (Odenweller & Ueckerdt, 2025). Issues such as water stress, land-use conflicts, biodiversity pressure, and industrial hazards are likely to become more salient as projects move from planning into implementation. In Oman and Morocco, land-use, water, biodiversity and industrial-safety risks could become more consequential as projects progress, while the promised jobs and broader economic benefits remain uncertain. The immediate governance task is to assess these risks before siting and resource-allocation decisions are fixed, and to assign responsibility for monitoring them during operation. Where projects share water sources, coastal receiving waters, land corridors or grid infrastructure, assessment must also address their combined effects. The scale of announced zones makes such clustering plausible, but its impacts cannot be inferred before project locations and designs are known.

153 Interview with an international hydrogen financing expert and with an independent hydrogen expert

3. Third, centralised permitting and technocratic decision-making can accelerate project rollout, but they also create pressure on transparency, accountability and participation. The one-stop-shop logic can simplify approval processes, yet it may also blur the line between investment promotion and independent oversight if environmental and social review is not clearly separated and made public.¹⁵⁴ This is why the design of grievance mechanisms, disclosure rules and monitoring responsibilities matters significantly.

Taken together, the evidence identifies gaps in safeguards rather than a measured sustainability trajectory. The coming years, when several projects may move from pre-FEED to FID, will be decisive for whether land use, water allocation, ecological safeguards and social inclusion are managed in ways that support a just transition. Building on these findings and addressing research question three (RQ3: What safeguards can realistically be achieved?), the five recommendations below specify the responsible actor, the project stage and the evidence needed to check compliance. Public authorities must address siting and shared resources before allocating land; tendering bodies can set supplier and employment conditions at award; developers and financiers must maintain grievance and compliance mechanisms throughout implementation.

1. Require early environmental review and public disclosure: Before tendering land, competent authorities should publish zone-level screening of sensitive habitats, water sources and affected land uses, together with areas excluded from development. Before a construction permit is issued, the competent environmental authority should publish and independently review each project's ESIA and an accessible non-technical summary, allowing changes to siting or design. In Oman, Hydrom should disclose screening and concession conditions, while the environmental authority retains review powers. In Morocco, the responsible authority should apply the same disclosure and review milestones across the different project-award routes. The regional effects of clustered projects are addressed separately in recommendation four.

- Development partners across Germany and the EU can support this division of responsibilities in specific ways. GIZ and KfW could finance reviewer training and registry infrastructure where national authorities commit to disclosure rules; the European Investment Bank (EIB) can require publication of assessments for projects it finances. These measures depend on the competent national authorities retaining the power to review, publish and enforce decisions.

2. Promote local supplier development and job promises: Tendering authorities should require each bidder to submit a regional supplier map and a phased procurement and training plan before award. Contracts should distinguish temporary construction jobs from lasting operational jobs and require annual reporting on local and migrant employment, job quality, supplier contracts and training outcomes. Targets should follow an assessment of domestic capacity, with a corrective plan if agreed milestones are missed. This makes claims about employment and economic diversification testable without imposing uniform quotas that early-stage suppliers cannot meet.

- In Oman, Hydrom could ask bidders for phased supplier-development and training plans, tied to demonstrated domestic capacity and reviewed against their costs. Whether public support for local equipment or service suppliers is warranted would require a separate assessment of fiscal costs and likely domestic value creation.
- In Morocco, the relevant tendering authority could pilot this approach in an affected region such as Guelmim-Oued Noun by mapping existing SMEs and training providers

¹⁵⁴ Interviews with an academic expert on environmental governance and a civil society and environmental advocate

before procurement, setting project-specific supplier and apprenticeship milestones, then publishing contract awards and sustained employment by region. National quotas should follow evidence of capacity rather than precede it.

- German development cooperation could fund supplier mapping and vocational curricula with local training institutions, then help establish annual reporting on supplier contracts and durable jobs. These tasks require agreement with the responsible Moroccan or Omani authority and should be assessed against actual procurement, not training participation alone.

3. Establish an accessible grievance mechanism before construction begins: Developers should publish local-language channels, response deadlines, procedures for escalation to the competent authority and anonymised records of complaints and outcomes. The mechanism should cover environmental and social risks, including water impacts, pollution, employment and land and livelihood effects. Authorities should check that unresolved complaints can still inform siting or permit conditions. This mechanism complements consultation and independent review.

- In Oman, Hydrom could require the mechanism in bid and concession documents, with a local contact point and a published route to the competent land or environmental authority. Quarterly anonymised reports should show the type of concern raised, response time and whether a remedy was implemented.
- In Morocco, the authorities awarding hydrogen projects should use a common contractual clause that requires the same local-language access, response deadlines and escalation route across project regimes. The competent authority should review unresolved cases before issuing permits or approving the next project phase.
- Financiers (including KfW, EIB, and private banks) could require evidence that the grievance channel is operating before the first construction disbursement. Later disbursements should depend on anonymised reporting and a corrective-action plan for unresolved material complaints, consistent with IFC Performance Standard 1 and the OECD Guidelines for Multinational Enterprises.

4. Assess cumulative impacts before allocating clustered projects, then monitor them during development and operation: Where facilities may share water sources, coastal receiving waters, ecosystems or infrastructure, the competent regional environmental and water authorities should establish a common baseline and assess the combined effects before fixing site and resource allocations. Permits should assign monitoring indicators, reporting duties and corrective-action triggers. Public reports should then show whether combined effects remain within the agreed limits; further expansion should be reconsidered if those limits are exceeded. This regional assessment complements project-level ESIA (IFC, 2013).

- A regional assessment should first be commissioned where multiple projects are confirmed to share a water source, coastal receiving area or infrastructure corridor. Guelmim-Oued Noun, Laâyoune-Sakia El Hamra and Oman's hydrogen zones are candidates for this screening, but the authority should define the assessment boundary from verified project locations and resource links rather than announcements alone.
- The GIZ pilot project "Relance verte" in Guelmim-Oued Noun (2025–2027) could be examined as one possible setting for regional monitoring, subject to confirmation of its mandate, funding and agreement with the responsible Moroccan authorities. This could serve as a model for other regions.

- 5. Embed international safeguard principles in hydrogen concession contracts:** Contracts can require early and public ESIA, stakeholder engagement, land and livelihood protections, site-specific water and brine controls, ammonia-safety measures, **monitoring** and remedies. The competent public authorities must retain oversight. Certification of renewable origin or greenhouse-gas intensity can support product claims, but not verify these site-specific safeguards. Any broader certification requirement should name the exact scheme, version and criteria, and be checked against the risk it is meant to address (e.g. TÜV SÜD CMS 70; CertifHy; IFC; UNIDO).
- EU offtakers and financiers can require evidence of these safeguards through procurement and financing contracts. Safeguards can also be aligned to the supply-chain due diligence regulations such as the EU Corporate Sustainability Due Diligence Directive (CSDDD).

References

- A&O Shearman. (2024). Morocco green hydrogen offer: Key takeaways. <https://www.aoshearman.com/en/insights/morocco-green-hydrogen-offer-key-takeaways>
- Abdelshafy, A., Lambert, M., & Walther, G. (2024). *MENA region as a potential hydrogen supplier for the European market: Analysing a prospective route between Kingdom of Saudi Arabia and Germany*. The Oxford Institute for Energy Studies.
- Advisian. (2023). Low carbon hydrogen economy in Morocco: Executive summary. Supported by the European Bank for Reconstruction and Development (EBRD) Shareholder Special Fund. https://www.ebrd.com/content/dam/ebd_dxp/assets/pdfs/green-economy-transition/EBRD_Policy_Academy.Low_Carbon_Hydrogen_Economy_in_Morocco.pdf
- Ahshan, R. (2021). Potential and economic analysis of solar-to-hydrogen production in the Sultanate of Oman. *Sustainability* 13, 9516. <https://doi.org/10.3390/su13179516>
- Al Bulushi, L., Thangavel, S., & Chitt, M. (2024). Analyzing the hydrogen economy and sustainable development in Oman through Social Life Cycle Assessment (SLCA). *Proceedings of the International Conference on Industrial Engineering and Operations Management*. <https://doi.org/10.46254/GC02.20240101>
- Al-Hamzah, A. A., & Fellows, C. M. (2024). Drinking water quality in the Kingdom of Saudi Arabia. *Water*, 16(13), 1810. <https://doi.org/10.3390/w16131810>
- Aljamal, A., Speece, M., & Bagnied, M. (2022). Understanding resistance to reductions in water subsidies in Kuwait. *Local Environment*, 27(1), 97-111. <https://doi.org/10.1080/13549839.2021.2002287>
- Al Kalbnai, A. S. A., Othman, M. B., & Ajmal, H. N. M. (2025). Public-private partnerships in Oman: Legal framework and comparative perspectives. *International Journal of Research and Innovation in Social Science*, 9. <https://doi.org/10.47772/IJRISS.2025.915EC002>
- Al Maimani, R. (2025, May). Oman Green Hydrogen Strategy, Hydrom, Muscat. https://erranet.org/wp-content/uploads/2025/05/S5P3_AI_Miamani_Green-Hydrogen-in-Oman_Oman2025.pdf
- Al-Mamari, I., Ruhaili, S. A., Al Naamani, E., & Heidari, M. (2024, 1 December). Insight into future directions for the utilization of green hydrogen in Oman. Proceedings of the International Conference on Industrial Engineering and Operations Management. <https://doi.org/10.46254/GC02.20240045>
- Alshawaf, M., Van Haute, M., Alsayegh, O., Constantinou, A., Dewil, R., Bellotti, D., Barberis, S., Rivarolo, M., Magistri, L., Massardo, F., Al-Qassimi, M., & Al-Salem, S. M. (2025). Hydrogen energy prospects in Gulf Cooperation Council states: Opportunities and challenges. *Renewable and Sustainable Energy Reviews*, 212, 115421. <https://doi.org/10.1016/j.rser.2025.115421>
- Amoatey, P., Al-Nadabi, A., Chen, M., Nikoo, M. R., Al-Maktoumi, A., Al-Hinai, A., & Izady, A. (2024). Transition to sustainable hydrogen energy in Oman: Implication for future socio-economic transformation and environmental well-being. *Environment, Development and Sustainability*, 27(7), 15213-15234. <https://doi.org/10.1007/s10668-024-04657-8>
- Amouzai, A., & Haddioui, O. (2023). *Green hydrogen in Morocco: Just transition or greenwashing neocolonialism? The case of Guelmim-Oued Noun*. Transnational Institute, Committee for the Abolition of Third World Debt (CADTM), Siyada Network. <https://www.tni.org/en/publication/green-hydrogen-in-morocco>
- Ansari, D. (2022). *The hydrogen ambitions of the Gulf States: Achieving economic diversification while maintaining power* (SWP Comment 2022/C 44). <https://doi.org/10.18449/2022C44>
- Ansari, D. (2023). *Omani hydrogen for Germany and the EU: Not just a matter of energy policy* (SWP Comment 2023/C 18). <https://doi.org/10.18449/2023C18>
- Ansari, D., & Holz, F. (2020). Between stranded assets and green transformation: Fossil-fuel-producing developing countries towards 2055. *World Development*, 130, 104947. <https://doi.org/10.1016/j.worlddev.2020.104947>
- Ascari, G., Colciago, A., Haber, T., & Wöhrmüller, S. (2026). Inequality along the European Green Transition. *The Economic Journal* 136(677), 1729–60. <https://doi.org/10.1093/ej/ueaf130>

- Azeroual, M., El Makrini, A., El Moussaoui, H., & El Markhi, H. (2018). Renewable energy potential and available capacity for wind and solar power in Morocco towards 2030. *Journal of Engineering Science and Technology Review*, 11(1), 189-198. <https://doi.org/10.25103/jestr.111.23>
- Bade, S. O., & Tomomewo, O. S. (2024). A review of governance strategies, policy measures, and regulatory framework for hydrogen energy in the United States. *International Journal of Hydrogen Energy*, 78, 1363-1381. <https://doi.org/10.1016/j.ijhydene.2024.06.338>
- Bauer, C., Treyer, K., Antonini, C., Bergerson, J., Gazzani, M., Gencer, E., Gibbins, J., Mazzotti, M., McCoy, S. T., McKenna, R., Pietzcker, R., Ravikumar, A. P., Romano, M. C., Ueckerdt, F., Vente, J., & Van Der Spek, M. (2022). On the climate impacts of blue hydrogen production. *Sustainable Energy & Fuels*, 6(1), 66-75. <https://doi.org/10.1039/D1SE01508G>
- Bengezi, K. (2022). *New constructions of environmental orientalism: Climate change mitigation solar power projects in the Sahara Desert*. POMEPS. <https://pomeps.org/new-constructions-of-environmental-orientalism-climate-change-mitigation-solar-power-projects-in-the-sahara-desert>
- Ben-Hasan, A., & Christensen, V. (2019). Vulnerability of the marine ecosystem to climate change impacts in the Arabian Gulf: An urgent need for more research. *Global Ecology and Conservation*, 17, e00556. <https://doi.org/10.1016/j.gecco.2019.e00556>
- Bogaert, K. (2018). *Globalized authoritarianism: Megaprojects, slums, and class relations in urban Morocco*. University of Minnesota Press.
- Bouzekri, H. (2026). *Morocco green hydrogen push: Catalyst for industrial transformation or export-led growth?* Carboun Institute. <https://www.carboun.com/morocco-green-hydrogen-push>
- Calabrese, J. (2025). *Oman's hydrogen horizon: Linking local industry to global decarbonization*. Arab Gulf States Institute in Washington. <https://agsi.org/analysis/omans-hydrogen-horizon-linking-local-industry-to-global-decarbonization/>
- Carley, S., & Konisky, D. M. (2020). The justice and equity implications of the clean energy transition. *Nature Energy*, 5(8), 569-577. <https://doi.org/10.1038/s41560-020-0641-6>
- Cezne, E., & Otsuki, K. (2025). The making of H₂-scapes in the Global South: Political geography perspectives on an emergent field of research. *Political Geography*, 118, 103294. <https://doi.org/10.1016/j.polgeo.2025.103294>
- Chew, Y. E., Cheng, X. H., Loy, A. C. M., How, B. S., & Andiappan, V. (2023). Beyond the colours of hydrogen: Opportunities for process systems engineering in hydrogen economy. *Process Integration and Optimization for Sustainability*, 7(4), 941-950. <https://doi.org/10.1007/s41660-023-00324-z>
- Chigbu, U. E., & Nweke-Eze, C. (2023). Green hydrogen production and its land tenure consequences in Africa: An interpretive review. *Land*, 12(9), 1709. <https://doi.org/10.3390/land12091709>
- Cooper, J., Dubey, L., Bakkaloglu, S., & Hawkes, A. (2022). Hydrogen emissions from the hydrogen value chain: Emissions profile and impact to global warming. *Science of the Total Environment*, 830, 154624. <https://doi.org/10.1016/j.scitotenv.2022.154624>
- DeBoom, M. J. (2025). *Displaced decarbonization: Climate necropolitics and the contested spatialities of green hydrogen in Namibia*. Environment and Planning C: Politics and Space. <https://doi.org/10.1177/23996544251332856>
- Dillman, K. J., & Heinonen, J. (2022). A "just" hydrogen economy: A normative energy justice assessment of the hydrogen economy. *Renewable and Sustainable Energy Reviews*, 167, 112648. <https://doi.org/10.1016/j.rser.2022.112648>
- Ersoy, S. R., Terrapon-Pfaff, J., Pregger, T., Braun, J., Jamea, E. M., Al-Salaymeh, A., Braunschweig, P., Bereschi, Z., Ciobotaru, O. T., & Viebahn, P. (2024). Industrial and infrastructural conditions for production and export of green hydrogen and synthetic fuels in the MENA region: Insights from Jordan, Morocco, and Oman. *Sustainability Science*, 19(1), 207-222. <https://doi.org/10.1007/s11625-023-01382-5>
- Falcone, P. M., Hiete, M., & Sapio, A. (2021). Hydrogen economy and sustainable development goals: Review and policy insights. *Current Opinion in Green and Sustainable Chemistry*, 31, 100506. <https://doi.org/10.1016/j.cogsc.2021.100506>

- Fladvad, B. (2023). Infrastructuring environmental (in)justice: Green hydrogen, Indigenous sovereignty and the political geographies of energy technologies. *Geographica Helvetica*, 78(4), 493-505. <https://doi.org/10.5194/gh-78-493-2023>
- Forget, M., & Bos, V. (2022). Harvesting lithium and sun in the Andes: Exploring energy justice and the new materialities of energy transitions. *Energy Research & Social Science*, 87, 102477. <https://doi.org/10.1016/j.erss.2021.102477>
- Gabor, D., & Sylla, N. S. (2023). Derisking developmentalism: A tale of green hydrogen. *Development and Change*, 54(5), 1169-1196. <https://doi.org/10.1111/dech.12779>
- Gasparatos, A., Doll, C. N. H., Esteban, M., Ahmed, A., & Olang, T. A. (2017). Renewable energy and biodiversity: Implications for transitioning to a green economy. *Renewable and Sustainable Energy Reviews*, 70, 161-184. <https://doi.org/10.1016/j.rser.2016.08.030>
- Gazze, K., & Abubakar, I. R. (2018). Regional disparity in access to basic public services in Saudi Arabia: A sustainability challenge. *Utilities Policy*, 52, 70-80. <https://doi.org/10.1016/j.jup.2018.04.008>
- Geißler, G., Rehhausen, A., Fischer, T. & Hanusch, M. (2019). Effectiveness of strategic environmental assessment in Germany? – Meta-review of SEA research in the light of effectiveness dimensions. *Impact Assessment and Project Appraisal* 37(3-4), 219–32. <https://doi.org/10.1080/14615517.2019.1587944>
- GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit). (n.d.). *Promoting renewable energy and green hydrogen: Relance verte through green energy and hydrogen in Morocco*. <https://www.giz.de/en/projects/relance-verte-through-green-energy-and-hydrogen-morocco>
- Goita, E. G., Beagle, E. A., Nasta, A. N., Wissmiller, D. L., Ravikumar, A., & Webber, M. E. (2025). Effect of hydrogen leakage on the life cycle climate impacts of hydrogen supply chains. *Communications Earth & Environment* 6(1), 160. <https://doi.org/10.1038/s43247-025-02141-3>
- Griffiths, S., Sovacool, B. K., Kim, J., Bazilian, M., & Uratani, J. M. (2021). Industrial decarbonization via hydrogen: A critical and systematic review of developments, socio-technical systems and policy options. *Energy Research & Social Science*, 80, 102208. <https://doi.org/10.1016/j.erss.2021.102208>
- Günel, G. (2016). The infinity of water: Climate change adaptation in the Arabian Peninsula. *Public Culture*, 28(2), 291-315. <https://doi.org/10.1215/08992363-3427463>
- Hafner, M., Raimondi, P. P., & Bonometti, B. (2023). *The energy sector and energy geopolitics in the MENA region at a crossroad: Towards a great transformation?* Springer International Publishing. <https://doi.org/10.1007/978-3-031-30705-8>
- Hamblin, J. (2019). An American miracle in the desert: Environmental crisis and nuclear-powered desalination in the Middle East. In A. M. Kirchhoff & J. F. McNeill (Eds.), *Nature and the Iron Curtain: Environmental policy and social movements in communist and capitalist countries, 1945–1990* (pp. 205–219). University of Pittsburgh Press.
- Hamouchene, H. (2023). The energy transition in North Africa: Neocolonialism again! In H. Hamouchene & K. Sandwell (Eds.), *Dismantling green colonialism. Energy and climate justice in the Arab region* (pp. 29-48). Pluto Press.
- Hamouchene, H., & Sandwell, K. (Eds.) (2023). *Dismantling green colonialism: Energy and climate justice in the Arab region*. Pluto Press.
- Hancher, L., & Suci, S. (2024). Hydrogen regulation in Europe: The EU’s “hydrogen and decarbonised gas market” – Best practice or missed opportunity? In R. Fleming (Ed.), *The Cambridge handbook of hydrogen and the law* (1st ed., pp. 13-29). Cambridge University Press. <https://doi.org/10.1017/9781009459259.003>
- Hanieh, A. (2018). *Money, markets, and monarchies: The Gulf Cooperation Council and the political economy of the contemporary Middle East*. Cambridge University Press.
- Hatim, Y. (2020, 8 July). House of Councillors adopts law to protect Morocco’s natural environment. *Morocco World News*. <https://www.moroccoworldnews.com/2020/07/68214/house-of-councillors-adopts-law-to-protect-moroccos-natural-environment>

- Head of Government of Morocco (2024). *Circular No. 03/2024 on the implementation of the “Morocco Offer” for the development of the green hydrogen sector*. 11 March 2024. URL: <https://micepp.gov.ma/en/le-ministere/actualites/application-royal-high-directives-head-government-issues-circular>
- Helerea, E., Calin, M. D., & Musuroi, C. (2023). Water energy nexus and energy transition—A review. *Energies*, 16, 1879. <https://doi.org/10.3390/en16041879>
- Henderson, C. (2023). Unjust transitions: The Gulf States’ role in the ‘sustainability shift’ in the Middle East and North Africa. In H. Hamouchene & K. Sandwell (Eds.), *Dismantling green colonialism: Energy and climate justice in the Arab region* (pp. 275–289). Pluto Press.
- Heymann, M., & Wengenroth, U. (2009). *Forscher, Pioniere und Visionaere: Wasserstoff als Energietraeger*. Piper.
- Hine, A., Gibson, C., & Carr, C. (2024). Green hydrogen regions: Emergent spatial imaginaries and material politics of energy transition. *Regional Studies*, 58(8), 1618-1635. <https://doi.org/10.1080/00343404.2024.2314553>
- Houdret, A., Kadiri, Z., & Bossenbroek, L. (2017). A new rural social contract for the Maghreb? The political economy of access to water, land and rural development. *Middle East Law and Governance*, 9(1), 20-42. <https://doi.org/10.1163/18763375-00901003>
- Howarth, R. W., & Jacobson, M. Z. (2021). How green is blue hydrogen? *Energy Science & Engineering*, 9(10), 1676-1687. <https://doi.org/10.1002/ese3.956>
- Hussein, H., & Schuetze, B. (2024). Risks of Morocco's green hydrogen plans. *Science*, 386(6721), 501-502. <https://doi.org/10.1126/science.adr4421>
- Hydrom (Hydrogen Development Oman). (2024). *Oman green hydrogen strategy*. <https://hydrom.om/Media/Pdf/Oman-Green-Hydrogen-Strategy-2024.pdf>
- IFC (International Finance Corporation). (2013). *Good practice handbook: Cumulative impact assessment and management: Guidance for the private sector in emerging markets*. Author. <https://www.ifc.org/content/dam/ifc/doc/mgrt/ifc-goodpracticehandbook-cumulativeimpactassessment.pdf>
- Irrarazaval, F., Albornoz, C., & Bogolasky, F. (2026). The troubled geography of green jobs: Examining the estimations and expectations of green hydrogen development in regional labor markets in Chile. *Applied Geography*, 186, 103828. <https://doi.org/10.1016/j.apgeog.2025.103828>
- Jumelages & Partenariats. (2025). Morocco/Guelmim-Oued Noun: Workshop on the “Green Revival” project. *Jumelages & Partenariats*. <https://jumelages-partenariats.com/en/actualites.php?n=23018>
- Kalt, T., & Cezne, E. (2026). *Geographies of hydrogen: A review of trends, themes and concepts*. Human Geography.
- Kalt, T., Simon, J., Tunn, J., & Hennig, J. (2023). Between green extractivism and energy justice: Competing strategies in South Africa’s hydrogen transition in the context of climate crisis. *Review of African Political Economy*, 50(177-178). <https://doi.org/10.1080/03056244.2023.2260206>
- Kingdom of Morocco (2021). *Stratégie Nationale de l’Hydrogène Vert*. Ministry of Energy, Mines and Environment. https://www.mem.gov.ma/Lists/Lst_rapports/Attachments/28/Strategie%20nationale%20de%20l%20Hydrogene%20vert.pdf
- Khan, M. A., & Al-Ghamdi, S. G. (2023). Hydrogen economy for sustainable development in GCC countries: A SWOT analysis considering current situation, challenges, and prospects. *International Journal of Hydrogen Energy*, 48(28), 10315-10344. <https://doi.org/10.1016/j.ijhydene.2022.12.033>
- Khan, M. A., Al-Attas, T., Roy, S., Rahman, M. M., Ghaffour, N., Thangadurai, V., Larter, S., Hu, J., Ajayan, P. M., & Kibria, M. G. (2021). Seawater electrolysis for hydrogen production: A solution looking for a problem? *Energy & Environmental Science*, 14(9), 4831-4839. <https://doi.org/10.1039/D1EE00870F>

- Khanzada, N. K., Al-Juboori, R. A., Ibrahim, Y., Khatri, M., Ahmed, F. E., An, A. K., & Hilal, N. (2026). Desalination and the Middle East: Research, practices, implications, and prospects. *NPJ Clean Water*, 9(1), 21. <https://doi.org/10.1038/s41545-026-00554-x>
- Khatla, K. (2026, 23 February). Expropriation pour utilité publique: Délais réduits, nouvelles règles... ce que prévoit une nouvelle réforme. *Médias24*. <https://medias24.com/2026/02/23/expropriation-pour-utilite-publique-delaiss-reduits-nouvelles-regles-ce-que-prevoit-une-nouvelle-reforme-1632459/>
- Klerke, A., Christensen, C. H., Norskov, J. K., & Vegge, T. (2008). Ammonia for hydrogen storage: Challenges and opportunities. *Journal of Materials Chemistry*, 18(20), 2304. <https://doi.org/10.1039/b720020j>
- Koch, N. (2019). *AgTech in Arabia: "spectacular forgetting" and the technopolitics of greening the desert*. *Journal of Political Ecology*, 26(1). <https://doi.org/10.2458/v26i1.23507>
- Koch, N. (2022). *Gulf hydrogen horizons: Why are Gulf oil and gas producers so keen on hydrogen?* IASS. https://publications.iass-potsdam.de/rest/items/item_6002525_1/component/file_6002526/content
- Kojima, Y. (2024). Safety of ammonia as a hydrogen energy carrier. *International Journal of Hydrogen Energy*, 50, 732-739. <https://doi.org/10.1016/j.ijhydene.2023.06.213>
- Lachkar, Z., Levy, M., & Smith, K. S. (2019). Strong intensification of the Arabian Sea oxygen minimum zone in response to Arabian Gulf warming. *Geophysical Research Letters*, 46(10), 5420-5429. <https://doi.org/10.1029/2018GL081631>
- Lebrouhi, B. E., Lamrani, B., Zeraouli, Y. & Kousksou, T. (2024). Key challenges to ensure Morocco's sustainable transition to a green hydrogen economy. *International Journal of Hydrogen Energy*, 49, 488–508. <https://doi.org/10.1016/j.ijhydene.2023.09.178>.
- Lehmann, R., & Wiertz, T. (2025). "Green tech" geographies: The role of technology in contemporary frontier-making processes. *Environment and Planning C: Politics and Space*. <https://doi.org/10.1177/23996544251384103>
- LesEco. (2026). Hydrogène vert: Les premiers contrats de réservation foncière signés. *LesEco.ma*. <https://leseco.ma/maroc/hydrogene-vert-les-premiers-contrats-de-reservation-fonciere-signes.html>
- Lindner, R. (2023). Green hydrogen partnerships with the Global South: Advancing an energy justice perspective on "tomorrow's oil". *Sustainable Development*, 31(2), 1038-1053. <https://doi.org/10.1002/sd.2439>
- Longden, T., Beck, F. J., Jotzo, F., Andrews, R., & Prasad, M. (2022). "Clean" hydrogen? Comparing the emissions and costs of fossil fuel versus renewable electricity based hydrogen. *Applied Energy*, 306, 118145. <https://doi.org/10.1016/j.apenergy.2021.118145>
- Low, M. C. (2020). Desert dreams of drinking the sea, consumed by the Cold War: Transnational flows of desalination and energy from the Pacific to the Persian Gulf. *Environment and History*, 26(2), 145-174. <https://doi.org/10.3197/096734018X15254461646549>
- Marin, A., & Goya, D. (2021). Mining: The dark side of the energy transition. *Environmental Innovation and Societal Transitions*, 41, 86-88. <https://doi.org/10.1016/j.eist.2021.09.011>
- Marzouk, O. A. (2024). Portrait of the decarbonization and renewables penetration in Oman's energy mix, motivated by Oman's national green hydrogen plan. *Energies*, 17(19), 4769. <https://doi.org/10.3390/en17194769>
- Médias24. (2025, 7 March). Offre Maroc hydrogène vert: Les premières explications de Masen [Interview with T. Moufaddal]. *Médias24*. <https://medias24.com/2025/03/07/offre-maroc-hydrogene-vert-les-premieres-explications-de-masen/>
- Melber, H., Camfield, L. & Kothari, U. (2025). Development as (in)justice: The case of Namibia. *Progress in Development Studies*, 14649934251388766. <https://doi.org/10.1177/14649934251388766>.
- Miftah, M., Ait Brahim, Y., Hssaisoune, M., Ayaou, A., Berrouch, H., & Bouchaou, L. (2025). Moroccan water resources under pressure: Challenges of groundwater quality and nitrate contamination. *Journal of Hydrology: Regional Studies*, 61, 102724. <https://doi.org/10.1016/j.ejrh.2025.102724>

- Monciardini, D. (2025). *Regulating EU sustainability reporting: Learning from failure and success*. Cambridge University Press.
- Moustakbal, J. (2023). The Moroccan energy sector: A permanent dependence. In H. Hamouchene & K. Sandwell (Eds.), *Dismantling green colonialism. Energy and climate justice in the Arab region* (pp. 220-232). Pluto Press.
- Müller, F. (2024). Energy colonialism. *Journal of Political Ecology*, 31(1). <https://doi.org/10.2458/jpe.5659>
- Müller, F., Tunn, J., & Kalt, T. (2022). Hydrogen justice. *Environmental Research Letters*, 17(11), 115006. <https://doi.org/10.1088/1748-9326/ac991a>
- Naderi Beni, A., Marriner, N., Sharifi, A., Azizpour, J., Kabiri, K., Djamali, M., & Kirman, A. (2021). Climate change: A driver of future conflicts in the Persian Gulf region? *Heliyon*, 7(2), e06288. <https://doi.org/10.1016/j.heliyon.2021.e06288>
- Namaganda, E. (2023). Contradictions to decent African jobs under energy transition-related extractivism: The case of graphite mining in Mozambique. *Review of African Political Economy*, 50(177-178). <https://doi.org/10.1080/03056244.2023.2288485>
- Nilsson, M., Griggs, D., & Visbeck, M. (2016). Policy: Map the interactions between Sustainable Development Goals. *Nature*, 534(7607), 320-322. <https://doi.org/10.1038/534320a>
- Ocko, I. B., & Hamburg, S. P. (2022). Climate consequences of hydrogen emissions. *Atmospheric Chemistry and Physics*, 22(14), 9349-9368. <https://doi.org/10.5194/acp-22-9349-2022>
- OCP (Office Chérifien des Phosphates). (2024). *Plan d'engagement des parties prenantes: Projet de la station modulaire de dessalement des eaux de mer à Jorf Lasfar* [Stakeholder engagement plan]. European Bank for Reconstruction and Development, Project 54662. https://www.ebrd.com/content/dam/ebd_dxp/documents/project/54662/stakeholder-engagement-plan--jorf-lasfar.pdf
- Okpanachi, E., Ambe-Uva, T., & Fassih, A. (2022). Energy regime reconfiguration and just transitions in the Global South: Lessons for West Africa from Morocco's comparative experience. *Futures*, 139, 102934. <https://doi.org/10.1016/j.futures.2022.102934>
- Odenweller, A. & Ueckerdt, F. (2025). The green hydrogen ambition and implementation gap. *Nature Energy* 10(1), 110–23. <https://doi.org/10.1038/s41560-024-01684-7>.
- Olawuyi, D. S., & Aryanpour, M. (2024). Hydrogen regulation in the Middle East and North Africa region: Trends, limitations, and ways forward. In R. Fleming (Ed.), *The Cambridge handbook of hydrogen and the law* (1st ed., pp. 84-97). Cambridge University Press. <https://doi.org/10.1017/9781009459259.007>
- Omerspahic, M., Al-Jabri, H., Siddiqui, S. A., & Saadaoui, I. (2022). Characteristics of desalination brine and its impacts on marine chemistry and health, with emphasis on the Persian/Arabian Gulf: A review. *Frontiers in Marine Science*, 9, 845113. <https://doi.org/10.3389/fmars.2022.845113>
- Ourya, I., Nabil, N., Abderafi, S., Boutammachte, N., & Rachidi, S. (2023). Assessment of green hydrogen production in Morocco, using hybrid renewable sources (PV and wind). *International Journal of Hydrogen Energy*, 48(96), 37428-37442. <https://doi.org/10.1016/j.ijhydene.2022.12.362>
- Pinto, M. C., Gaeta, M., Arco, E., Boccardo, P., & Corgnati, S. P. (2025). Mapping the suitability of North Africa for green hydrogen production: An application of a multi-criteria spatial decision support system combining GIS and AHP for Tunisia. *Energy, Sustainability and Society*, 15(1), 20. <https://doi.org/10.1186/s13705-025-00512-4>
- Piotrowski, P., Blaney, J., & Hanvey, S. (2021). *Middle East: The H₂ handbook. Legal, regulatory, policy, and commercial issues impacting the future of hydrogen*. K&L Gates. https://marketingstorageragrs.blob.core.windows.net/webfiles/Hydrogen-Handbook_MiddleEast.pdf
- Plank, F., Daum, B., Muntschick, J., Knodt, M., Hasse, C., Ott, I., & Niemann, A. (2023). Hydrogen: Fueling EU-Morocco energy cooperation? *Middle East Policy*, 30(3), 37-52. <https://doi.org/10.1111/mepo.12699>

- Pouran, H. (2022). *The Middle East's worsening dust storms are making it harder to deploy solar energy*. Middle East Institute. <https://www.mei.edu/publications/middle-easts-worsening-dust-storms-are-making-it-harder-deploy-solar-energy>
- ProPublica. (2026). *Why carbon capture cannot solve climate change*. <https://projects.propublica.org/why-carbon-capture-cant-solve-climate-change/>
- Rehbein, J. A., Watson, J. E. M., Lane, J. L., Sonter, L. J., Venter, O., Atkinson, S. C., & Allan, J. R. (2020). Renewable energy development threatens many globally important biodiversity areas. *Global Change Biology*, 26(5), 3040-3051. <https://doi.org/10.1111/gcb.15067>
- Richards, A., & Waterbury, J. (1996). *A political economy of the Middle East (2nd ed.)*. Westview Press.
- Rignall, K. (2016). Solar power, state power, and the politics of energy transition in pre-Saharan Morocco. *Environment and Planning A: Economy and Space*, 48, 540–57. <https://doi.org/10.1177/0308518X15619176>.
- Roefs, P., Moretti, M., Welkenhuysen, K., Piessens, K., & Compernelle, T. (2019). CO₂-enhanced oil recovery and CO₂ capture and storage: An environmental economic trade-off analysis. *Journal of Environmental Management*, 239, 167-177. <https://doi.org/10.1016/j.jenvman.2019.03.007>
- Sadiq, M., Mayyas, A., Mezher, T., & El Fadel, M. (2023). Policy and economic challenges towards scalable green-H₂ transition in the Middle East and North Africa region. *International Journal of Hydrogen Energy*, 48(85), 32995-33016. <https://doi.org/10.1016/j.ijhydene.2023.05.083>
- Scholten, D., Bazilian, M., Overland, I., & Westphal, K. (2020). The geopolitics of renewables: New board, new game. *Energy Policy*, 138, 111059. <https://doi.org/10.1016/j.enpol.2019.111059>
- Schuetze, B., & Hussein, H. (2023). The geopolitical economy of an undermined energy transition: The case of Jordan. *Energy Policy*, 180, 113655. <https://doi.org/10.1016/j.enpol.2023.113655>
- Schulkes, P. (2025, 17 November). Hy hopes: The goals and challenges of Oman's hydrogen strategy. *Noria Research*. <https://noria-research.com/mena/hy-hopes-the-goals-and-challenges-of-omans-hydrogen-strategy/>
- Schumm, L., Abdel-Khalek, H. & Brown, T., Ueckerdt, F., Sterner, M., Parzen, M., & Fioriti, D. (2025). The impact of temporal hydrogen regulation on hydrogen exporters and their domestic energy transition. *Nature Communications* 16(1), 7486. <https://doi.org/10.1038/s41467-025-62873-w>
- Shabaneh, R., Roychoudhury, J., Braun, J. F., & Saxena, S. (2024). *The clean hydrogen economy and Saudi Arabia: Domestic developments and international opportunities*. (1st ed.). Routledge. <https://doi.org/10.4324/9781003294290>
- Sharifinia, M., Afshari Bahmanbeigloo, Z., Smith, W. O., Yap, C. K., & Keshavarzifard, M. (2019). Prevention is better than cure: Persian Gulf biodiversity vulnerability to the impacts of desalination plants. *Global Change Biology*, 25(12), 4022-4033. <https://doi.org/10.1111/gcb.14808>
- Shehabi, M. (2024). *Just energy transitions? Lessons from Oman and Morocco*. Carnegie Endowment for International Peace. <https://carnegieendowment.org/research/2024/05/morocco-oman-energy-transition-oil-exporting-renewable>
- Sola, A., Rosa, R., & Ferrari, A. M. (2024). *Green hydrogen and its supply chain: A critical assessment of the environmental impacts*. Advanced Sustainable Systems. <https://doi.org/10.1002/adsu.202400708>
- Sovacool, B. K. (2021). Who are the victims of low-carbon transitions? Towards a political ecology of climate change mitigation. *Energy Research & Social Science*, 73, 101916. <https://doi.org/10.1016/j.erss.2021.101916>
- Sovacool, B. K., Hook, A., Martiskainen, M., Brock, A., & Turnheim, B. (2020). The decarbonisation divide: Contextualizing landscapes of low-carbon exploitation and toxicity in Africa. *Global Environmental Change*, 60, 102028. <https://doi.org/10.1016/j.gloenvcha.2019.102028>
- Sovacool, B. K., Martiskainen, M., Hook, A., & Baker, L. (2019). Decarbonization and its discontents: A critical energy justice perspective on four low-carbon transitions. *Climatic Change*, 155(4), 581-619. <https://doi.org/10.1007/s10584-019-02521-7>

- Special Economic Zone Authority at Duqm (SEZAD). (n.d.). Environmental impact assessment guideline. Government of Oman. <https://duqm.gov.om/upload/files/environment/environmental-impact-assessment-guideline.pdf>
- Staffell, I., Scamman, D., Velazquez Abad, A., Balcombe, P., Dodds, P. E., Ekins, P., Shah, N., & Ward, K. R. (2019). The role of hydrogen and fuel cells in the global energy system. *Energy & Environmental Science*, 12(2), 463-491. <https://doi.org/10.1039/C8EE01157E>
- Suleman, F., Dincer, I., & Agelin-Chaab, M. (2015). Environmental impact assessment and comparison of some hydrogen production options. *International Journal of Hydrogen Energy*, 40(21), 6976-6987. <https://doi.org/10.1016/j.ijhydene.2015.03.123>
- Sultanate of Oman. (2001). Royal Decree 114/2001 promulgating the Law on Conservation of the Environment and Prevention of Pollution. *Official Gazette*. <https://decree.om/2001/rd20010114/>
- Sultanate of Oman. (2017). Ministerial Decision no. 48/2017. Regulations for organizing environmental permitting. Ministry of Environment and Climate Affairs. *Official Gazette* 1195. <https://faolex.fao.org/docs/pdf/oma130995E.pdf>
- Sultanate of Oman. (2019, July 1). Royal Decree 52/2019. Promulgating the public-private partnership law. *Official Gazette* 1300. <https://decree.om/2019/rd20190052/>
- Sultanate of Oman. (2021). Decision 17/2021. Issuing the controls regulating the environmental permits in special economic zones and free zones. Public Authority for Special Economic Zones and Free Zones. *Official Gazette*. <https://opaz.gov.om/upload/files/en-regulations-for-the-regulation-of-issuance-of-environmental-permits.pdf>
- Sultanate of Oman. (2023, February 16). Royal Decree 10/2023. Allocating some lands for the purposes of renewable energy and clean hydrogen projects. *Official Gazette*. <https://decree.om/2023/rd20230010/>
- Suškevičs, M., Ehrlich, T., Peterson, K., Hiiemäe, O. & Sepp, K. (2023). Public participation in environmental assessments in the EU: A systematic search and qualitative synthesis of empirical scientific literature. *Environmental Impact Assessment Review*, 98, 106944. <https://doi.org/10.1016/j.eiar.2022.106944>.
- Szabo, J. (2021). Fossil capitalism's lock-ins: The natural gas-hydrogen nexus. *Capitalism Nature Socialism*, 32(4), 91-110. <https://doi.org/10.1080/10455752.2020.1843186>
- Tanchum, M. (2024). Green hydrogen production in North Africa: Challenges and opportunities. In *Energy transition in the Middle East: Opportunities and challenges* (pp. 183-205). I.B. Tauris.
- Taouil, A. (2024). Green hydrogen market in Morocco: Needs and barriers. *Atalayar*. <https://www.atalayar.com/en/articulo/economy-and-business/h2-market-in-morocco-needs-and-barriers/20240103121329195350.html>
- Terrapon-Pfaff, J., Ersoy, S. R., Prantner, M., & Viebahn, P. (2024). Country risks analysis for the development of green hydrogen and synthetic fuel sectors in the MENA region. *Frontiers in Energy Research*, 12, 1466381. <https://doi.org/10.3389/fenrg.2024.1466381>
- Terrapon-Pfaff, J., Fink, T., Viebahn, P., & Jamea, E. M. (2019). Social impacts of large-scale solar thermal power plants: Assessment results for the NOORO I power plant in Morocco. *Renewable and Sustainable Energy Reviews*, 113, 109259. <https://doi.org/10.1016/j.rser.2019.109259>
- Terrapon-Pfaff, J., Schinke, B., Viebahn, P., Fink, T., & Brand, B. (2015). *Energy and development: Exploring the local livelihood dimension of the Nooro I CSP project in Southern Morocco*. Wuppertal Institute for Climate, Environment and Energy; Germanwatch. https://wupperinst.org/uploads/tx_wupperinst/SocialCSP_summary_en.pdf
- Tian, M., Zhong, S., Al Ghassani, M., Johanning, L., & Ion Sucala, V. (2024). Simulation and feasibility assessment of a green hydrogen supply chain: A case study in Oman. *Environmental Science and Pollution Research*, 32. <https://doi.org/10.1007/s11356-024-32563-z>.
- Tih, Z., & Ait Boubkr, A. (2026). Comparative evaluation of environmental impact assessment frameworks in Morocco and the World Bank using structured performance criteria. *Environmental Economics*, 17(1), 94-108. [https://doi.org/10.21511/ee.17\(1\).2026.08](https://doi.org/10.21511/ee.17(1).2026.08)

- Thaler, P. & Hofmann, B. (2022). The impossible energy trinity: Energy security, sustainability, and sovereignty in cross-border electricity systems. *Political Geography*, 94, 102579. <https://doi.org/10.1016/j.polgeo.2021.102579>
- TÜV Rheinland. (2022). TÜV Rheinland paves the way for green hydrogen and green ammonia certification. <https://insights.tuv.com/blog/t%C3%BCv-rheinland-paves-the-way-for-green-hydrogen-and-green-ammonia-certification>
- Tunn, J., Kalt, T., Muller, F., Simon, J., Hennig, J., Ituen, I., & Glatzer, N. (2024). Green hydrogen transitions deepen socioecological risks and extractivist patterns: Evidence from 28 prospective exporting countries in the Global South. *Energy Research & Social Science*, 117, 103731. <https://doi.org/10.1016/j.erss.2024.103731>
- UNIDO (United Nations Industrial Development Organization). (2025). *Guidelines for sustainable hydrogen projects in developing countries*. UNIDO/UNEP/UNECE/AfDB/JET Green Hydrogen Portfolio/IDOS/MENA Hydrogen Alliance.
- Unruh, G. C. (2000). Understanding carbon lock-in. *Energy Policy*, 28(12), 817-830. [https://doi.org/10.1016/S0301-4215\(00\)00070-7](https://doi.org/10.1016/S0301-4215(00)00070-7)
- Valeri, M. (2017). *Oman: Politics and society in the Qaboos state*. Hurst & Company.
- Van de Graaf, T., Overland, I., Scholten, D. & Westphal, K. (2020). The new oil? The geopolitics and international governance of hydrogen. *Energy Research & Social Science*, 70, 101667. <https://doi.org/10.1016/j.erss.2020.101667>
- Vermeulen, W. N. (2018). Scarcity drives economic development: The effect of energy subsidies on export diversification in the Middle East. In H. Verhoeven (Ed.), *Environmental politics in the Middle East* (pp. 193-222). Oxford University Press.
- Vidican, G. (2014). Reforming fossil-fuel subsidy regimes in the Middle East and North African countries. In A. Pegels (Ed.), *Green industrial policy in emerging countries* (pp. 148-178). Routledge.
- Virens, A. (2024). Green hydrogen futures: Tensions of energy and justice within sociotechnical imaginaries. *Energy Research & Social Science*, 114, 103587. <https://doi.org/10.1016/j.erss.2024.103587>
- Weidner, T., Tulus, V., & Guillen-Gosalbez, G. (2023). Environmental sustainability assessment of large-scale hydrogen production using prospective life cycle analysis. *International Journal of Hydrogen Energy*, 48(22), 8310-8327. <https://doi.org/10.1016/j.ijhydene.2022.11.044>
- Weipert-Fenner, I. (2025). *Green hydrogen production in Tunisia: The interplay of old and new lines of conflict* (PRIF Report). Peace Research Institute Frankfurt (PRIF).
- Wolff, K., & Young, K. E. (2024). *Energy transitions in the Middle East: Challenges and opportunities*. Bloomsbury Publishing.
- World Bank. (2022). *The employment benefits of an energy transition in Morocco*. <https://documents1.worldbank.org/curated/en/099045112072229005/pdf/P17054605f2e8209208fa80241ca43a9fa7.pdf>
- World Bank. (2023). *Morocco climate change development report*. <https://thedocs.worldbank.org/en/doc/114ddeee175075258d629a28271c8de4-0280012023/original/TK-Note-Morocco-CIAA-CCDR-may23.pdf>
- Yahya Engineering & 5 Capitals Environmental and Management Consulting. (2020, February). Ibri II Solar Independent Power Project (IPP), Sultanate of Oman: Stakeholder engagement plan (version 4). Prepared for ACWA Power. Asian Infrastructure Investment Bank. https://www.aiib.org/en/projects/details/2020/approved/download/Oman/Ibri-2-IPP_SEP_v4.pdf
- Yu, Q., et al. (2024). A probe into the acid deposition mitigation path in China over the last four decades and beyond. *National Science Review*, 11(4), nwae007. <https://doi.org/10.1093/nsr/nwae007>
- Zekeik, Y., Haddi, A., El Mourabit, Y., Alvarez-Garcia, F. J., & Ortiz-Bevia, M. J. (2025). Modelling green hydrogen scenarios in coastal Morocco based on offshore wind energy potential. *International Journal of Hydrogen Energy*, 158, 150513. <https://doi.org/10.1016/j.ijhydene.2025.150513>
- Zumbraegel, T. (2022). *Political power and environmental sustainability in Gulf monarchies*. Springer Nature Singapore. <https://doi.org/10.1007/978-981-19-4431-4>

- Zumbraegel, T. (2025a). From grey to green? Navigating the geopolitics of the energy transition in the Middle East and North Africa. In A. Al-Sarihi & M. Mason (Eds.), *Climate policy and politics in the Middle East: Environmental, economic and political challenges*. I.B. Tauris.
- Zumbraegel, T. (2025b). The technopolitics of hydrogen: Arab Gulf States' pursuit of significance in a climate-constrained world. *Geoforum*, 158, 104168. <https://doi.org/10.1016/j.geoforum.2024.104168>
- Zumbraegel, T. (2026). Redefining the hydro-social contract in Saudi Arabia: Between vision and structural inertia. *Society & Natural Resources*, 1-20. <https://doi.org/10.1080/08941920.2026.2677128>
- Zumbraegel, T., & Sons, S. (2024). Gulf aid goes green: Reflecting on the geopolitics of environmental sustainability assistance in Arab monarchies. *Journal of Gulf Studies*, 1(2), 145-167. https://doi.org/10.1386/jgs_00013_1

Annex

Table A1: Interviews

Interview 1	International hydrogen financing expert	Virtual, 26.05
Interview 2	Senior official, national hydrogen authority	Muscat, 29.05
Interview 3	Port and special economic zone official	Muscat 29.05
Interview 4	Representative of national oil company/hydrogen project developer	Muscat, 01.06
Interview 5	Hydrogen expert and economic development official	Muscat, 01.06
Interview 6	Independent hydrogen expert	Muscat, 01.06
Interview 7	Senior official, national hydrogen think tank	Muscat, 02.06
Interview 8	University-based hydrogen scientist	Muscat, 02.06
Interview 9	Policy advisor and hydrogen expert	Muscat, 02.06
Interview 10	Senior official, national hydrogen authority	Muscat, 03.06
Interview 11	Independent environmental consultant	Muscat, 03.06
Interview 12	State-owned energy company representative	Muscat, 04.06
Interview 13	Energy ministry official	Muscat, 04.06
Interview 14	Representative of logistic company	Muscat, 04.06
Interview 15	Port authority and free zone official	Muscat, 04.06
Interview 16	Academic researcher and hydrogen expert	Muscat, 04.06
Interview 17	Government policy advisor	Muscat, 05.06
Interview 18	University-based energy and hydrogen scientist	Virtual, 27.08
Interview 19	University-based energy and hydrogen scientist	Rabat, 28.08
Interview 20	Academic expert on environmental governance	Rabat, 28.08
Interview 21	Renewable energy company representative	Rabat, 29.08
Interview 22	Energy and climate policy expert	Tanger, 30.08
Interview 23	International development cooperation official	Rabat, 31.08
Interview 24	Economic researcher	Rabat, 01.09
Interview 25	Policy advisor and hydrogen expert	Rabat 01.09
Interview 26	Independent environmental consultant	Rabat 01.09
Interview 27	International development agency representative	Rabat, 02.09
Interview 28	Civil society and environmental advocate	Rabat 02.09
Interview 29	Civil society and environmental advocate	Casablanca, 03.09
Interview 30	International development agency representative	Virtual, 12.09
Interview 31	Policy advisor and hydrogen expert	Virtual, 16.09
Interview 32	Corporate hydrogen expert	Virtual 16.09
Interview 33	Government hydrogen programme official	Virtual, 18.09