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Governance of novel "green" desalination processes in the Kingdom of Bahrain

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This paper examines the forms of governance that will impact the implementation of new "green" desalination process to identify areas which may support or challenge urban infrastructure adaptation. The chosen context is the Kingdom of Bahrain. Bahrain is chosen as it has been successful in achieving high standards of living for its populace, but the upheaval of water and energy system change is urgent and essential due to its extreme climate, resource availability, and wider economic context. Bahrain faces challenges common to many jurisdictions in having high standards of living, but where social practices need to drastically change if those standards are to be maintained into the future. The forms of governance are considered as a system and defined and applied to the Bahraini context through a documentary analysis, qualitative interviews and focus groups with experts and communities within Bahrain. The results find prima facie, policy, and regulatory support for system change, although progress is slow. A deeper analysis identifies opportunities for policy re-direction but beyond policy, it identifies norms, values, and Constitutional expectations that require respect and care in how they are managed if change is to be accepted at pace. The results offer opportunities for governance comparisons across jurisdictions and have implications for innovators in how new systems are designed and framed and for policymakers in identifying and dismantling barriers to change.

KEYWORDS
governance, infrastructure, innovation, socio-technical systems, water-energy nexus

1 Introduction

This paper explores how governance systems respond to novel energy-water infrastructure technologies at their early stages of development. The context for the study is the Kingdom of Bahrain (Bahrain), a country within the Gulf Co-operation Council (GCC), whose recent economy has been built on fossil fuels, with a nascent renewable energy sector, and where water stress is very high (Government of Bahrain, 2024).

Energy and water infrastructure systems have been at the core of human development for millennia. The current configurations of global energy and water systems, however, exceed planetary boundaries in resource extraction and greenhouse gas emissions (GHGs). If society is to flourish into the future, then a rapid transition to more sustainable practices is urgently required (UNEP, 2025). Governance systems have had to look beyond national boundaries to manage the global impacts of the climate crisis. The Paris Agreement is a legally binding international treaty where signatory countries commit to

reduce their GHG emissions and work to adapt to the impacts of climate change (United Nations, 2015). Bahrain has committed to reduce its GHGs by 30% by 2025 (Government of Bahrain, 2008). As the smallest country within the GCC, the Bahraini context is under-explored but offers a microcosm to explore tensions and opportunities of major infrastructure transitions in countries which have been successful in terms of average standards of living, but are highly fossil fuel dependent, with extreme temperatures and increasing drought, and where sustainable issues urgently need to be addressed. Bahrain has the highest water dependency in the GCC with water resourcing dependent on energy intensive desalination or depleting groundwater reserves (Sherif et al., 2023). It is progressing with diversifying its economy away from fossil fuels but movement toward renewable energy is slow and cautious (Ali and Abdalla, 2025). How its governance systems respond to new greener technologies, particularly in energy-intensive water processing, becomes a critical area of research.

Innovating and adapting our energy and water infrastructure is essential but infrastructure is more than physical, hard engineering. Adapting engineered systems in a changing environment requires cognisance of wider social systems and, as a socio-technical system, requires supportive governance. In countries with high standards of living, such as Bahrain, the governance goals involve deconstructing current "successful" systems and rebuilding newer more sustainable systems all whilst maintaining societal support. Governance and technology are interconnected with the success of a proposed technological solution heavily influenced by the governance regime (van Vliet et al., 2011); it is not always the lack of technology that holds back a desired transition but whether there is a governance regime in place to support it (Goodwin et al., 2019). In framing infrastructure in this way, the complexity involved in governing these systems is exposed (Marchant, 2020).

The research seeks to identify the governance challenges and opportunities that arise with new, novel integrated water and energy infrastructure systems using experiences of experts and communities. The work forms part of the Horizon Europe funded DeSOLination project (DeSOL) (EU, 2021). The Bahraini focus allows for that exploration to take place in a context where standards of living are currently high but unsustainable and where substantial change to infrastructure services are urgently required that may impact social practices and expectations. Data is gathered through five semi-structured expert interviews and two community focus groups. The results highlight what at first appears to be a positive policy landscape but behind the policies are significant governance challenges, potentially hindering new and novel innovations. Learning of these challenges, even with positive policy drivers, adds nuance to the literature on energy transitions and stresses the urgency in bottom-up initiatives to meet top-down policy with supportive legal systems. The results also offer insights into how a project team might approach the implementation of their technology.

The paper is separated into the following sections. Section 2 provides the Bahraini context and the energy-water project under discussion in more detail (the DeSOL, project) (EU, 2021). Section 3 provides a literature review relevant to energy-water systems in Bahrain and the forms of governance that expand beyond a traditional policy focus. Section 4 sets out the methodology and section 5 present the data. The conclusion at section 6 sets out the limitations and suggested next steps. The research aligns with priorities under Sustainable Development Goals 6, 7, 9, and 11.

TABLE 1 Selected water and energy infrastructure statistics for Bahrain.

Data category	Bahrain data
Solar radiation (DNI)	High (Solargis, 2021)
Concentrated Solar Power (CSP)	No targets (solely PV) (Ministry of Sustainable Development, 2017)
Renewable energy target	20%* renewables by 2035 (Ministry of Sustainable Development, 2017; Supreme Council for Environment, 2026) (*doubled since the NREAP was published).
Desalination	c.100% of domestic and industrial supply (Supreme Council for Environment, 2026)
Land area	0.00079 Mkm^2 (Government of Bahrain, 2008; Ministry of Sustainable Development, 2017)
Population	1.59 M (densely populated) (Supreme Council for Environment, 2026)

2 Context

Bahrain is a country in the Arabian Gulf made up of around 30 islands with the capital, Manama situated on the largest island. Bahrain is mostly flat and desert with no rivers or perennial lakes but has a strong cultural connection to water with "Bahrain" meaning "two seas." Participants engaging in the research often referenced this advising the researchers that the two seas referred to the seawater that surrounds it and the freshwater springs and aquifers under and around the islands.

Table 1 provides statistics relevant to water and energy infrastructure by way of an overview. Bahrain has a small land mass of 0.00079 Mkm^2 contrasted, for example, with Kingdom of Saudi Arabia (KSA) with 2.15 Mkm^2. Bahrain is one of the most densely populated countries in the world, ranked seventh globally (World Population Review, 2026), with most of the population resident in two of its cities on the main island. Its rapid population growth is in part due to a high expatriate community making up about 50% of the population (Government of Bahrain, 2024).

Bahrain is a constitutional monarchy. Bahrain's Constitution was ratified in 2002 (Kingdom of Bahrain, 2002). Launched by King Hamad bin Isa Al Khalifa, Bahrain's Economic Vision 2030 document aligns with the United Nations 2030 Agenda for Sustainable Development (Government of Bahrain, 2008). It is the core document for sustainable development often behind and driving other policies in the country's water and energy sectors. Key Government bodies and core policy documents[1] also identified are included in Table 2.

The Economic Vision is premised on the need to diversify from a fossil fuel economy for future sustainability, in the context of depleting oil and gas reserves (Ministry of Sustainable Development, 2017), with

1 Policy documents were not always readily available. Where that is the case, documents which summarize or outline the text are included.

TABLE 2 Core government agencies and policy documents.

Sector	Key government bodies	Associated government bodies	Core policy documents
Vision (plus economy)	Crown Prince; Prime Minister; Ministry of Sustainable Development.	Ministry of Finance and National Economy; Economic Development Board (EDB).	Economic Vision 2030 (Government of Bahrain, 2008; Legislation and Legal Opinion Commission, 2013); National Action Charter (Legislation and Legal Opinion Commission, 2013); Economic Recovery Plan (Ministry of Finance and National Economy, 2021).
Energy	Ministry of Oil and Environment; Ministry of Electricity and Water Affairs (incorporates Sustainable Energy Authority).	Electricity and Water Authority (EWA); BAPCO.	National Energy Strategy National Renewable Energy Action Plan (Ministry of Sustainable Development, 2017; Electricity and Water Authority, 2023); Energy Transition Plan (Electricity and Water Authority, 2023).
Water	Ministry of Electricity and Water Affairs	Electricity and Water Authority (EWA)	National Water Strategy 2030 (Bahrain News Agency, 2018)
Agriculture	Ministry of Works; Ministry of Municipalities Affairs and Agriculture.	National Centers (various)	National Food Security Strategy (Government of Bahrain, 2025). National Initiative for the Development of the Agricultural Sector (NIAD, 2010).
Environment	Supreme Council for the Environment.	National Centers (various)	Voluntary National Review 2023 (Crown Prince and Prime Minister, and Ministry of Sustainable Development, 2023)

shocks in oil prices also causing concern. The stated aim of the Economic Vision is not to exclude oil and gas but to use those reserves in areas where carbon emissions are hard to abate (Government of Bahrain, 2008). Most energy production remains fossil fuel based. On an institutional level fossil fuels are managed separately to electricity and water supply, with the Ministry of Oil and Environment and the Ministry of Electricity and Water Affairs, respectively. In 2021, during the 26th Conference of Parties (COP26), Bahrain increased its renewable energy target from 10% (or 710 MW installed capacity) to 20% (Ministry of Sustainable Development, 2026; Supreme Council for Environment, 2026), although as of 2025 was behind target (International Renewable Energy Agency, 2025). The National Renewable Energy Action Plan in 2017 (NREAP) policy notes that renewable energy was negligible in the energy mix (Ministry of Sustainable Development, 2017), and renewable energy penetration remains low. This contrasts with KSA for example which aims to achieve 50% by 2030 (or 130GW) capacity (Government Saudi Arabia, 2016; NREP, 2017). Most of the renewable energy in Bahrain comes from solar PV. There are no concentrated solar plants (CSP) in Bahrain, linked to its low land availability. To contrast KSA, with its larger land mass, has a target of 2.7GW of CSP by 2030 (Government Saudi Arabia, 2016; NREP, 2017).

Domestic water is governed by the Electricity and Water Authority (EWA). Almost 100% of the domestic water supply in Bahrain is from desalinated water mostly piped directly into homes. Bahrain has virtually no freshwater resources making it reliant on desalination and depleting natural groundwater sources. Its water use is unsustainable with Bahrain ranked as the world's most water stressed country in terms of its withdrawals against renewable supply (Mahmoud, 2024). Desalination is energy intensive and mostly powered in the region by fossil fuels, highlighting the interconnectivity of water and energy systems, with desalination accounting for 8% of Bahrain's electricity supply (Siddiqi and Anadon, 2011). Alongside GHGs, there are issues in terms of air and water pollution with the latter from brine, chemicals used in processing, and thermal discharge. Water policy and conservation have been described as fragmented (UN Global Compact: Water Action Hub, 2025).

Groundwater for agriculture is dealt with separately through the Ministry of Municipalities, Affairs and Agriculture. Most of Bahrain's water is directed to domestic supply with a relatively modest 33% directed to agriculture, in comparison with 70–90% in agricultural economies (UN Global Compact: Water Action Hub, 2025; World Population Review, 2025). As with other GCC countries, some 85% of Bahrain's food supplies are sourced overseas but despite water scarcity, low food production, and land limitations the GCC is said to have relatively high food security (Al Mubarak, 2025). Revenues from fossil fuel exports are used to help fund policies, including securing supply chains by buying land overseas for food production, and from advances in agricultural practices (Siderius et al., 2020; Al Mubarak, 2025; Government of Bahrain, 2025). As well as water processing, new technologies and advances in food production can also be energy intensive (Siderius et al., 2020). Despite the headline achievements, there remain threats to food security in the region due to high levels of imports and risks to disruption in supply chains (Moussa et al., 2025).

Land is at a premium in Bahrain which is an issue for agriculture and an issue for renewable energy such as CSP and solar and their associated land requirements. Legislative protections and land controls are noted in the policy documents. Relevant to renewable energy

for example are restrictions on the percentage of land used for solar PV systems within industrial zones (Ministry of Industry and Commerce, 2025). Water-energy and food issues (WEF) are deeply interconnected. Stress within the WEF system in the GCC region has been referred to as a "polycrisis," with governance described as one of the key issues in tackling these complex issues (Bouckaert et al., 2025). There are high resource inputs in terms of energy, water, food, and investment to maintain current living standards, leading to vulnerabilities. It is therefore a prosperous country with a rich cultural history which finds itself at a crossroads where radical change is needed if current standards are to be sustainably maintained (Government of Bahrain, 2008).

Against this background, the DeSOL project is introduced. DeSOL is funded by Horizon Europe and brings together 21 universities and organization across 13 countries. It is not proposed to discuss the technical specifications in detail here although data is available on the DeSOL website (EU, 2021). In short, the DeSOL project seeks to produce desalinated water more efficiently and using green, renewable energy rather than fossil fuel sources. In the current configuration it is powered by waste heat from existing CSP plants. Also, in terms of circularity its aims are to re-purpose the brine produced in the desalination process as a resource rather than a waste product to be disposed of. The technology is still in development and is reaching prototype stage in the Kingdom of Saudi Arabia (KSA). It appears to address some of the resilience issues and needs facing Bahrain with benefits in terms of energy use within water production and reducing the discharge of pollutants. How the governance system might respond is to be explored.

3 Literature review

3.1 Governance

There is no single definition of governance and indeed there are different philosophical underpinnings and approaches to governance (Korhonen-Kurki et al., 2025). It has been noted that government is not the same as governance. Governance references the shift from top-down government structures to multi-sector and multiscalar systems often with a mix of public, private and community stakeholders (Walker, 2014). On a global scale, Biermann's articulation of earth systems governance includes principles of credibility (namely the commitment of resources and accountability), stability (avoiding short-termism and political change), adaptiveness (to complexity and uncertainty) and inclusiveness (including frequently under-represented groups; Biermann, 2007). It is possible to see some alignment with the intentions of the Paris Agreement which created structures of reporting against targets and a focus on sustainable development designed to promote a long-term, legally enforceable and funded commitment to address climate change (United Nations, 2015).

The approach to governance adopted in this paper aligns with socio-technical and transitions research (Loorbach et al., 2017) in keeping with the conceptualization of infrastructure as a socio-technical system and with a focus on new technology. It considers that governance is a complex system which can be adapted to provide an operating space for societal change or to allow space for new technologies to develop (Korhonen-Kurki et al., 2025).

Transitions research helps articulate how society can move from an unsustainable state to a sustainable system. Understanding governance when transitioning our systems toward sustainability can help unpick the structures that support or hinder change. Governance can initiate change and alternatively, during a transition there is likely to be disruption to the social sphere that governance can help soften or manage. When developing new technologies, the multi-level perspective (MLP) is a useful model to visualize the progress of a new technology from its formative niche to its launch into the surrounding regime beyond the laboratory and finally embedded into the landscape (Geels, 2002). Far from a straightforward or linear, the movement between stages can be a complex process. New systems align or misalign with incumbent technologies and vie for a dominant position with existing systems. The role of governance viewed here is to influence the rules, stimulate learning and protect niches to nurture innovation (Rip and Kemp, 1998). Governance creates the space and defines the boundaries for that innovation which in turn will determine whether it will thrive or not. Governance should also have mechanisms for the active phasing out of the incumbent system (Geels et al., 2017). Different forms of governance might be applied, for example, the need for innovation in the niche stage might be stimulated and funded through policy interventions and incentives. Its release into the market might need regulatory reform and subsidies to give it a fighting chance against the incumbent systems. Similarly, forms of governance interplay and influence one another, for example through policy incentives and subsidies influencing norms and behaviors (Korhonen-Kurki et al., 2025).

In another example, Loorbach's governance framework (Loorbach, 2009) draws upon systems thinking and complexity to endorse adaptive forms of governance making space for innovation, trials and social learning across different actors and scales. Important for the water-energy nexus, for example, is governance that moves away from sector silos to ensure that governance structures are also affective horizontally across systems including water and energy (Pahl-Wostl, 2019). Although this study focusses on the socio-technical systems literature, the complexity of governing natural resources is an inherent issue with infrastructure systems across the water-energy nexus in the context of diminishing resources. Ostrom's Institutional Analysis and Development (IAD) framework for example engages with social mechanisms and formal and informal rules around natural resource management (Ostrom, 1990, 2011; Dietz et al., 2003). The complex interaction to governing human systems and natural resources embeds the need for an understanding of context, place and resources said to be sometimes lacking from socio-technical literature (Markolf et al., 2018; Ahlborg et al., 2019). In accepting complexity, governance needs to be able to adapt to inherent uncertainty in governing natural resources. Concepts of adaptive governance encourage reflexivity, learning and capacity building within communities and stakeholders including bottom-up forms of social engagement (Folke et al., 2005).

What is not always stressed in governance frameworks is that transitioning to different infrastructure systems is disruptive and bringing about transformational change is hard, as evidenced by the persistent failures to meet climate targets (IPCC, 2023). There are human, behavioral components. For example, a challenge to the need for "stability," are short-term political cycles; the cost of transformational disruptions may occur in the short term, in one political cycle, whilst the benefits might not be felt until the far future leading to short termism and institutional inertia (Biermann, 2007; Askari et al., 2026). Further examples of behavioral barriers include loss aversion and

status quo bias (Askari et al., 2026). Status quo bias explores the preference for maintaining the status quo even though alternatives exist. Loss aversion is the propensity when weighing up options, to give greater weight to a loss than the weight given to gain leading to excessive caution (Askari et al., 2026). These phenomena highlight the political difficulties in taking something away from a population even if it is replaced with something that could have greater benefit. With a proposed new, innovative infrastructure intervention, there may not be a precedent system to experience making it difficult for stakeholders to envision a different future. This underscores the importance of social learning and capacity building using tools such as back-casting and scenario building to help society vision change and its potential benefits (Loorbach, 2009). A governance system needs to be cognizant of these human features when deciding how the system of interest is driven toward its goals.

3.2 Forms of governance

Governance of infrastructure, for the purposes of the paper, draws upon earth systems governance and encapsulates the formal and informal rules, networks and processes that drive a system toward agreed societal goals (Biermann, 2014; Rhodes, 2017)In driving the system forward there are different forms of governance, or means of governing that can be exercised. Many studies focus upon policy and overlook, for example, legal and constitutional systems (Garmestani et al., 2019), or informal rules (Ostrom, 1990; Dietz et al., 2003). This misses an opportunity to examine governance through the methods deployed. Forms of governance are discussed below and highlighted in Figure 1, acknowledging that the forms interrelate and influence each other.

The overarching form of governance considered is the Constitution. A country's Constitution underpins the role and behavior of the State to its people and maps how power is exercised and accountability maintained. It can embed rights and set out the structures for justice to be exercised. As noted in Section 2, Bahrain is a constitutional monarchy. Its Constitution was ratified in 2002 and sets out the primary functions and, in effect, its social license to operate (Kingdom of Bahrain, 2002) and the principles upon which Bahraini society is based. The Constitution is part of the legal structure but is separated out here, to acknowledge its high-level importance and influence.

As noted, regulation and legal structures are often overlooked as forms of governance (Garmestani et al., 2019; Cosens et al., 2020) but carry weight in terms of enforceability of desired behaviors and practices and in confirming longer-term commitment (Korhonen-Kurki et al., 2025). Legal structures such as pollution controls can inhibit undesirable behavior, if properly enforced. Government backed financial breaks, such as favorable tax treatment or incentives, can encourage desired activities. From the perspective of new technologies already in development, legal structures may not be an obvious inhibitor when technology is in its early stages, but difficulties or lack of support might be more obvious as it is released into existing systems (Murphy et al., 2025).

As highlighted in Table 2, Bahrain has a network of policies relevant to energy and water systems stemming from its Economic Vision and has a set of institutions to support those policies. The issue then turns to the effectiveness of those policies. For example, whilst policy documents that set out a clear vision are important, recent research also highlights that policies need to adapt and change as the transition progresses; governance is not static and will respond differently at different stages (Murphy et al., 2025). Key policies to initiate ideas will be different to policies enabling favorable market conditions when the technology is developed (Murphy et al., 2025). They also do not operate in isolation from the rest of the governance process including legal and social support where necessary.

Within the governance system of institutions, stakeholders, and communities there are processes and networks to be understood and navigated (Rhodes, 2017). Top down and bottom-up connections between institutions and stakeholders help link policy to practice and innovators to resources. Horizontal institutional connections can also help with cross sector projects, notably energy and water projects such as the project in issue here, to counter disciplinary silos (Pahl-Wostl, 2019). Norms, values, and behaviors within those networks can help understand the informal societal rules that will encourage the acceptance and embedding of new infrastructure systems. The body of work around socio-ecological systems, for example, helps us understand how pivotal social rules can be when managing natural resources (Ostrom, 1990).

4 Methodology and governance themes

Data was collected through five semi-structured expert interviews and two community focus groups. The interviews took place with participants selected as policymakers and/or industry experts in desalination, innovation and/or water and energy systems in Bahrain. The interviews were online and took between 1 and 1.5 h each.

Table 3 provides information on the interview participants, whilst respecting confidentiality. Four were resident in Bahrain. One was resident outside Bahrain but with extensive experience of innovating in green desalination processes in the GCC and Bahrain. All were male and had over 20 years' experience in water and/or energy systems. The five interviewees were selected through expert sampling, based on their direct relevance to the study and their general prospective to the current and future development in the Water-Energy sector. The sample included academic and research expertise and a consultant in water and energy policy, a national-level energy advisor and hands-on industrial experience with on-site desalination operations.

There were two focus groups that took place in person in Bahrain with 15 participants in total. The focus groups took around 2.5 h each. Detailed demographic information was not obtained but selection criteria were used to ensure local residency, gender representation, and location to existing infrastructure. All were resident in Bahrain and Bahraini nationals, save for one that lived and worked in Bahrain but was a Kuwaiti national. Focus group participants were selected from diverse occupational backgrounds, including industry, academia, public sector, and students, ensuring a geographical representation across Bahrain's three main regions North, South, and Middle. Since Bahrain is a small country with a population heavily concentrated in the northern and middle regions, where the majority of residential and urban areas are located, the south remains comparatively low density in term of population distribution. The national desalination and electricity stations are situated in the north and south of the country, with the capital region in the middle having no stations. However, given the compact geography, the average distance between any participant's residence and the nearest desalination station is less



FIGURE 1
Features of a governance system explored in the study.

than 11 km. Table 4 provides sector and regional information. The Human Development Index for Bahrain is "Very High" with around 40% educated beyond mainstream secondary education (UNDP, 2023; World Bank Group, 2023). There is a complicated picture with a significant migrant workforce, predominantly in lower paid jobs with lower levels of educational attainment (De Bel-Air, 2019). As mostly Bahraini nationals, the participants were educated to bachelor's degree level or equivalent in a wide range of different disciplines. Engagement with the migrant workforce is raised in the limitations. A spread of participants living in different regions of Bahrain were selected with those living close to existing infrastructure and some more remote. Eleven participants were female and four were male. All were of working age, circa 20–55 years old; older participants could not be engaged.

The research team consisted of members of the DeSOL team from UK and Bahrain. During the visit, the opportunity was taken to tour the industrial region of Bahrain and see the main community centers. The planning and zoning practices in Bahrain were therefore seen as well as how infrastructure systems were visually present to communities. The University of Bahrain acted as the local gatekeeper for ethical access to community participants. The steps in the methodology are shown in Figure 2. For all data gathering and processing, University approved ethical processes were followed in full including ensuring informed consent was obtained.

The focus groups and interviews were audio recorded. Thematic analysis was used to interrogate and present the data (Braun and Clarke, 2008). The audio recordings were transcribed manually to ensure full engagement with the text and coded. Codes were arranged into themes. The codes were challenged and verified via discussions between two members of the research team. Themes were generated deductively and inductively. Themes were initially deductively drawn from the forms of governance in Figure 1. The forms of governance were found to be a useful device to organize the data. Themes were additionally inductively drawn using an interpretivist approach to capture themes emerging from the texts and also to add nuance to the themes that had been drawn deductively from the forms of governance. The extracted data within each theme was analyzed and narratives created. These narratives are presented in section 5. It was planned to report on interviews and focus groups separately but on analyzing the texts there were no significant contradictions between insights from experts and from communities. On presenting the data, the illustrative quotes from the texts were easier to digest and more coherent for a reader when presented together. Any nuances between the groups are expressly flagged in the narrative and discussion.

TABLE 3 Interview participants.

Participant number	Institutional experience	Sectors
Interview 1 (P1)	Government, Industry	Water, oil and gas, desalination
Interview 2 (P2)	Government, Academia, Industry	Engineering, renewable energy, desalination, water-energy-food nexus
Interview 3 (P3)	Academia	Water resource management, water-energy-food nexus
Interview 4 (P4)	United Nations, Government, Industry	Renewable energy, water systems, desalination
Interview 5 (P5)	Industry, Entrepreneur	Green desalination processes

The texts were thematically analyzed using forms of governance (Figure 1) as a starting point. These were adapted and added to as the texts were analyzed. The Themes are shown in Table 5. In addition to core themes, sub-themes were identified for each theme. The illustrative quotes from interviews and focus groups in support of sub-themes are set out in Supplementary Tables 1–5. For transparency, the illustrative quotes are clearly marked as (FG) for quotes from the focus groups and (IP) for quotes from the interviews.

Drawing a theme together around "policy" was considered but rejected for two reasons. Firstly, lack of policy was not considered a major issue by the participants. On the contrary, general policy support for new systems was noted. Secondly, there were disparate aspects of policy which could be better explored under other themes.

5 Data: themes

5.1 Constitution and water

Although water and electricity are governed by the same Government entity, the Ministry of Electricity and Water Affairs (MEWA), and both are highly subsidized, water systems and energy systems were articulated differently. The theme of Constitution and Water acknowledges this and looks at the responsibilities between the State and its people relating to water provision as viewed through the perspective of the participants. Constitution and Water had 5 sub-themes. These were Disruption to the Status Quo: Government as a Trusted Resource Manager; Security and Stability; Quality of Life; Subsidy, Awareness and True Cost of Water. Illustrative quotes from participants are set out in Supplementary Table 1.

Water as a human right is not expressly enshrined in the formal Constitution in Bahrain but the responsibilities of the State to its people in terms of natural resources are articulated in Article 11.

> *All natural wealth and resources are State property. The State shall safeguard them and exploit them properly, while observing the requirements of the security of the State and of the national economy.*

This includes water, oil and gas reserves with the State as carer on behalf of the people. The obligations of the State to the people appeared to be well known and understood with Government viewed as a trusted manager of their water, a highly precious resource. Water was viewed seriously as life-giving, with religious connotations and was associated with the standard of living they had come to enjoy. There were themes of security and stability both in terms of water providing security but appositely, the need to avoid disrupting the status quo if community acceptance was going to be gained. Security was expressed in a range of contexts encompassing a personal sense of security through to national security and stability. That the standard of living was high appeared recognized with it being described by one focus group as "luxurious," highlighting how much it was felt could be lost. This has clear alignment with behavioral studies notably around preserving the status quo and loss aversion.

A repeat topic of discussion was the subsidy regime. The high status of water and the role of Government as caretaker and provider, was said to have resulted in the current subsidy regime, where Bahraini nationals receive heavily subsidized electricity and water by the Government. Most participants noted the consequences of the subsidy regime. The expert interviewees noted the subsidy regime as unhelpful in terms of demand management and in failing to curb water use with one interviewee advising that it was both unjust and economically unsustainable. Although change was required it was acknowledged that change would be extremely difficult to address and even seriously destabilizing at a national level.

There were tensions and inconsistencies in the articulation of water, particularly within the focus groups. On the one hand, respect for water was observed. On the other hand, it was accepted that water use was excessive, which was linked to its low cost. Even with tiered charging, it was explained that the levels were so generous they did not need to consider how much water they were using; water infrastructure and provision was not something communities thought about as it was so easy and cheap to obtain. Further, when the conversations turned to changing the systems in some way, either that might be "greener" but may increase costs or where demand might be managed, there were negative comments, and it was seen as important to maintain the status quo.

Overarching this was a view that although the participants themselves felt aware of the need for sustainability, they articulated a general lack of awareness of climate risks and vulnerabilities and the true cost of water provision within their communities. There is a note of caution to express here. In the focus groups, pro-environment views were expressed on a personal level but when speaking of concerns or inactions these were often expressed as "community" issues. The extent that these concerns more accurately reflect the concerns of the individuals, and participants were instead expressing what they felt the organizers wanted to hear, could not be ruled out.

Water had a very high status akin to a perceived right and entitlement from Government. Overall, there needed to be greater awareness of the true cost of water provision to enable it to be more fully valued. An awareness of water infrastructure and its true cost both economically and environmentally needed far greater visibility if a project like DeSOL is going to be welcomed.

TABLE 4 Focus group participants.

#	Region	Sector/background
1	North	Industry
2	North	Industry
3	North	Industry
4	North	Public sector
5	North	Public sector
6	North	Academia
7	Middle	Industry
8	Middle	Public sector
9	Middle	Public sector
10	Middle	Public sector
11	Middle	Student (undergraduate)
12	Middle	Academia
13	South	Public sector
14	South	Student (undergraduate)
15	South	Student (undergraduate)

5.2 Legal structures

This theme gathers perceptions on the extent that legal structures create a functioning operating space for new infrastructure technologies or inhibit their development. Legal Structures had 4 sub-themes. These were Incentives; Regulatory Alignment; Pollution, Ecosystem Impacts; Regional Co-operation. Quotes from participants are set out



FIGURE 2
Methodology.

TABLE 5 Themes.

Theme	Description
Constitution and water	The fundamental sets of rules and principles relative to the State and its people. The focus is on those fundamental rules and principles relative to water.
Legal structures	The laws, regulations and formal rules that provide the operating space for new water-energy and infrastructures.
Networks	The networks of people and institutions operating in the WEF system.
Renewable energy and innovation	The policies and views relevant to renewable energy and innovation.
Norms, values and behaviors	Informal rules, values, and behaviors influence outcomes.

in Supplementary Table 2. Mostly it was felt that there were no formal legal structures that would inhibit new systems per se. If legal inhibitors arose, it was felt that the legal systems were nimble enough for them to be addressed.

There were, however, conflicting views over regulatory controls and pollution. There was a direct contradiction between participants about the extent brine discharge was an issue and regulatory controls therefore sufficient, reflected in the sub theme marked "pollution and ecosystem impacts." Projects like DeSOL are premised on the basis that by addressing brine discharge they are following the science and addressing a major polluting concern of the desalination process. It was expected that brine discharge from desalination processes would be recognized as a serious and pressing issue and processes that deal with brine would be highly valued. However, this was not universally recognized as an issue even within expert interviews. An explanation for why some experts did not think it an issue, and some did, could not be identified. This is an issue if the concerns within the wider scientific community are not well known within policy-makers making infrastructure decisions. Whilst not overtly against the technology, it also means strong legal drivers for change that support projects like DeSOL might be absent.

The importance of the sea and aquifer as a joint resource within the GCC were noted with some lack of transparency over the rules and the need for international controls considered. As the only major source of water, contamination to the sea was noted as a core requirement of a disaster management plan although this was expressed in terms of pollution from oil spills from the international tanker fleet rather than from the desalination processes. Indeed, when pollution was raised it was predominantly about localized concerns of air and water systems. There was less direct discussion about climate change and global systems. It does suggest that in aligning with values a project such as DeSOL should clearly have clear environmental goals in relation to improvements to local air and water quality. In terms of other existing legal structures, it was flagged that there was more scope to incentivize markets to promote greener technologies including through existing purchase agreements and contracts.

The lack of regulatory barriers might suggest that new potentially disruptive technologies have not been implemented yet so have not come to light. Recent studies acknowledge that regulatory barriers might not be evident until new technologies reach implementation stage (Murphy et al., 2025). This would be in keeping with the acknowledged nascent development of green energy technologies in Bahrain and the low penetration of renewable energy systems. This means a conclusion that there will be no regulatory hurdles for DeSOL would be premature.

Conversely, there are further potential regulatory incentives that could be put into play, for example around reductions in GHG emissions or pollutants, which favor green technologies over fossil fuels which are not currently utilized to their full effect. The current underpinning of the transition as discussed in the Economic Vision document (Government of Bahrain, 2008) is for green technologies to increase diversity within their infrastructure and economic systems, not replace fossil fuels. "Green" incentives are likely to create tension with incumbent technologies.

5.3 Networks

This theme explores the networks of people discussed by participants that govern water and energy systems and the extent they would engage with a project such as DeSOL. Networks had 5 sub-themes: Voice, Leadership; GCC, Regional Relationships; Markets; Government Agency and Power; Social Structures and Cultural Identity. Quotations are shown in Supplementary Table 3.

The importance of the GCC as a key part of the network was a common theme particularly in terms of ensuring that the technology introduced was compatible within those borders. Bahrain is clearly a much smaller country than KSA with less resources particularly around land. The sharing of resources and even decisions on where technology is developed for the greater good of the GCC was an issue for the region. GCC integration was not just expressed in technological terms but also social and economically, although at the same time respecting their cultural differences and identity.

One participant felt that there were gaps in the network at the very top, with issues over the slow pace of accepting new technologies and of weak global leadership and lack of direction giving confidence and voice to greener technologies. This was mirrored in comments by another participant about the general lack of voice and the need for a strong champion to promote the cause.

Internally to Bahrain, changes to the structure and hierarchy of public bodies in relation to energy were noted in the past, namely with changes to the Sustainable Energy Unit. There remained some fluidity within Government institutions suggesting a settled structure has not yet been attained. This was noted by the changing focus on energy systems from "oil and gas" to "energy" more widely. The changes were not just institutional but with policies also driving a move to a more market-based structure; Government agencies were adapting from infrastructure provider to incentivizing and mobilizing industry. Initiatives to stimulate the integration of new technologies and start-ups through entities such as BAPCO and the Economic Development Board were noted.

Participants recommended engagement with a range of stakeholders across Government, industry, academia, and society.

Of note was the insight that engagement within Bahrain was often with the Bahraini nationals. There was a very significant migrant workforce who were not as engaged. It was felt that those individuals, often taking on roles in the home, needed to be brought into the conversation. It was those individuals that were managing water and energy within households and their engagement was missing. This suggests that there are significant gaps in inclusivity as suggested by earth systems governance and the principles behind bottom-up and participatory governance.

5.4 Renewable energy and innovation

This theme looks at experiences and perceptions around innovation and renewable energy. Renewable Energy and Innovation had 4 sub-themes. These were Fossil Fuel Dependency, Incumbency; Independence, Sovereignty; Caution, Hesitancy; Renewable Strategy. Quotations are shown in Supplementary Table 4.

There were very low levels of personal experience of renewable energy systems in keeping with the low (but growing) penetration of renewable energy in Bahrain. Most of the discussions explored the prospect of changing from a fossil fuel economy.

The Economic Vision does not reject fossil fuels but rather suggests a road map to gradually reduce dependence upon them, diversify the economy, and meet environmental net zero obligations. The reason for a move to renewables is expressed as an economic need (Government of Bahrain, 2008). The climate and weather change impacts were not absent from policy but were not expressed as the dominant driver for changing the economy. This framing of the need for renewable energy was similar in the participant responses with fossil fuels not being irradicated, but their use gradually reduced.

The comments from participants illuminate the internal struggle inherent in a move away from a highly embedded fossil fuel system that has given them independence, security, and a high standard of living toward a radical change in new renewable technologies. Significant caution and concern over moving away from a system that had brought so much prosperity is evident. The nascent nature of renewable penetration was evident. There were concerns over how to tell whether they would be selecting the right technology, leading to hesitancy and inertia. Most experiences were limited and focused on solar. The challenges of solar energy systems in Bahrain were commonly commented upon noting dust as well as concerns over intermittency and grid integration. Climate risks as a trigger for change were acknowledged but with a variability in its perceived importance across the participants. There were some positive comments toward renewable energy, although often directly conflicting views over their efficacy.

The nuances in those comments however were deeper and highlight concerns over not losing all that had been achieved and uncertainty about the future without fossil fuels. There were concerns over what they would lose in terms of energy sovereignty and autonomy and whether by buying in new technologies they would become dependent on others.

5.5 Norms, values and behaviors

Norms, values and behaviors, around renewable energy have been included in section 5.4 and water in section 5.1. This section arises from expert interviews addressing innovation, an issue within their direct experience. Norms, Values and Behaviors had 4 sub-themes. These were Challenging Processes; Challenging Silos; Challenging Business Models; Challenging Caution. Quotations are shown in Supplementary Table 5.

"Challenging processes" and "challenging silos," came from experiences of innovators and academics working across water and energy systems. The discussions explored how established thinking was inhibiting innovation and how difficult it was to bring in something new if it did not fall squarely between an institution's mandate. This also ties into the fluidity noted in terms of institutional structures in 5.3.

"Challenging business models" followed a discussion on an energy-water nexus innovation, which looked at enhancing home grown food production. The innovation jarred with an existing business model which imported the same product. This import model was established and optimized. The innovation brought greater food security and efficiencies in resource use as an integrated water-energy-food system but of course required time for the crop to grow and ran the risk of crop failure. This was not a system the import business model valued.

Challenging caution stemmed from experiences of innovators and academics dealing with industrial partners with strict external performance standards to be met. This injected caution in trying something new when performance could be jeopardized, albeit the longer-term rewards could be great. A blocker, in terms of the over-reliance on a global consultant (whose identity has been redacted) was noted by one of the experts. Falling back on consultancy reports had become an expensive default setting rather than spending the same money on innovation directly. This discussion could also be linked to two separate themes on champions in Networks in 5.3 and on leadership, championing, and direction. For these participants, it was not a lack

of policy but the leadership pushing it that was lacking together with a fear of pushing in the wrong direction. All the above challenges could be viewed as issues over who is shouldering the risk of change. Keeping to one's specialism and tried and tested business models is less risky for some enterprises but may not meet societal needs in the longer term.

Despite lack of purported issues over policy, the comments suggest some more detailed vision is needed on how new infrastructure should look and how innovators and industry might be supported to get there.

6 Discussion

Turning to Biermann (2007) governance principles, although there were some changes within government departments they were not of major significance. Issues suggested by Biermann (2007) around stability were not noted as clear themes, (although decision-making processes within government institutions is an expansive subject in its own right and warrants its own focused study). In terms of credibility, there was evidence of commitment and some funding in place and no major issues flagged by participants. There are clear policies on water and energy systems starting with the Bahraini Economic Vision document and institutions created to implement the Vision. However, there were some comments from participants on the need to address water policy holistically with the whole water cycle in mind rather than in the fragmented way it is managed at present; as seen in the United Nations discussions on SDG 6 for clean water and sanitation, this is issue is by no means limited to Bahrain (United Nations, 2023). Generally, however, there were remarkably few policy issues flagged. There were independent policy drivers for desalination and for increasing amounts of renewable energy, but these policies do not clearly intersect to drive green desalination. In addition, there were Government agencies that were aligned to stimulate new ideas and technologies. However, despite a range of policy documents for sustainable development aligned with public institutions identified by participants, Bahrain has not yet undergone rapid change toward more sustainable energy-water systems. Bahrain's electricity generation is almost entirely based upon fossil fuels, with less than 1% renewable energy, and behind the target it set for itself (International Renewable Energy Agency, 2025). This places it toward the bottom of the GCC countries (International Renewable Energy Agency, 2023). This was partly explained by participants in terms of dust affecting solar efficacy and limited available land. There was also considerable caution about moving from incumbent systems, not only from a practical, efficiency or even economic point of view but fundamentally as a small but prosperous country about their values of sovereignty and autonomy. This adds nuance around behavioral issues on cautiousness and status quo bias and says more about security and values.

It was anticipated in a small country ranked seventh in the world in terms of population density that there could be issues over new infrastructure located too close to communities. This was not the case. There was a sense that the coastline, of historical and cultural significance to Bahraini society, was more valuable than the interior, which was already heavily built-up, but further research would need to be undertaken for a clearer understanding. However, approaches that ensure that communities are engaged with projects and where communities can develop existing technologies and expertise for their own context should be encouraged to retain knowledge and expertise and may help alleviate concerns over autonomy. This supports an adaptive governance approach where social learning and engagement helps to articulate possible futures.

For a new technology trying to break into the existing systems, difficulties are envisaged. Whilst no significant legal hurdles were mentioned, legal support was not mentioned. It was not possible to unravel the conflict in participant data around the efficacy of pollution controls for example, but strong, enforceable environmental protections and supporting technology to drive behaviors were not evident either. On the contrary, there was evidence of some regulatory systems that were unsustainable and maintaining the status quo and those related to the subsidy regime for water and energy. This is despite longstanding calls for reform of a system which privileges high- and middle-income households more than poorer families, (e.g., IMF, 2014). From participants data, the regime appeared to do more to encourage than discourage resource use. Neither are there levers of governance helping to phase out the existing systems (Geels et al., 2017), on the contrary, it is anticipated that existing systems will remain.

Bahrain is in the early stages where ideas and innovation is required to be stimulated, leading to two alternative policy approaches. The first is to re-evaluate current policies and re-design them to focus on the niche stage of innovation development where ideas are stimulated (Murphy et al., 2025). The role of the State would be to guide innovators as to core values and requirements of those systems and provide a place for those innovations to be considered and tested. In line with thinking around strategic niche management, it would also offer a space for experimentation (Rip and Kemp, 1998) (and as a natural consequence of that, space for mistakes, learning and adaption). It would provide confidence and a road map for innovation and take steps to de-risk innovation in core identified areas (Murphy et al., 2025). Funding systems would also align with this goal. This aligns with comments from participants about the need for a champion or voice for the renewable cause driving the governance network with policies and incentives closely aligned with niche development.

The alternative option arises through the country's connection to the GCC and that is to miss out the innovation stage and instead adopt the technologies developed elsewhere in the GCC. This would maximize the use of resources that might be more accessible and prevalent within the region. The role of the State would be to help select the technologies trialed elsewhere that meet the needs and values of the country but adapt it for the specific Bahraini context. In that case, policies would be realigned for that adoption (Murphy et al., 2025). They would also work to make alternative business models more attractive to support change. Projects like DeSOL, should then focus on showing that prototypes work within the GCC and explore how the proven technology would be adapted to work in a Bahraini context. At present, it appears Bahrain is closer aligned to this option although has not clearly chosen one path over the other. It appears to align with the values expressed by participants where connectivity within the GCC was viewed positively. There are already energy infrastructure interconnections, notably with KSA with governance arrangements in place, which could be further explored. This also aligns with wider calls for increased regional co-ordination for energy system planning within the GCC (Ali and Abdalla, 2025). Instead of trying to cover all phases of innovation, the second alternative route offers a means of focusing attention and resources.

These suggestions seek to tackle the move to renewable energy but do not address a more fundamental question over water consumption. Bahrain's per capita water consumption is not as high as other GCC countries, although a partial explanation for this is water for agriculture is much lower in Bahrain than across the GCC with domestic food production being very low. Even with low water use for agriculture, Bahrain has been ranked as one of the most water-stressed countries in the world (Mahmoud, 2024), including within the GCC. Domestic water supply is now dependent upon desalination processes with most water drawn from the surrounding seas.

Norms and values around water suggest it is viewed as fundamental akin to a right compounded by a very generous subsidy regime. With rights comes responsibilities and there appears to be a lack of awareness of the true cost of water, economically and environmentally. Adjusting the subsidy regime to better reflect cost would undoubtedly prove complex. One participant suggested a more just system could be based upon income with the wealthiest paying more, this would align with distributional justice (Rawls, 1999). Modeling could be undertaken to explore these ideas further. Whatever approach is taken, the strong sentiments of water akin to a constitutional right should not be underestimated. A program for change would need to consider that the subsidy system is extremely sensitive, the complexity of that change respected, and communication managed accordingly. The need for an intensive awareness campaign is indicated across resource use, climate impacts, and renewable systems. This engagement campaign should specifically include the migrant workforce.

The precariousness of the water supply and potential vulnerabilities were also noted. As highlighted by a participant, there is a critical dependency on the quality of surrounding seawater in a relatively enclosed area which is used extensively by shipping and where pollutants are discharged. One expert participant also admitted being unable to unravel some of the governance issues in this area. Maritime governance, resilience planning with disaster risk assessments falls outside the scope of this study but could be explored in future studies. Appropriately handled it could also be a means of communicating risk and responsibilities in terms of water systems to communities and build on the network governance and resource sharing across the GCC.

7 Conclusion

This research casts a light on the interface of governance and new technologies such as DeSOL, which intersect energy and water systems and are designed to address the climate and environmental crises. It does this specifically with different forms of governance in mind, moving beyond the general prevalence of policy in governance research, and including regulations and values. This helps view governance as a system of formal and informal rules that shapes the space for innovation.

In terms of renewable energy, existing legal structures were not a major inhibitor, but conversely, were not driving support for new renewable technologies over existing technology. There were also embedded systems that were maintaining the status quo, including well-documented issues over subsidy regimes. A successful direction of travel to meet the renewable goals Bahrain has set for itself has not been achieved. The well-established principles within strategic niche management and the multi-level perspective have obvious applicability but recent studies add to this literature specifically on narrowing policy. Two alternative suggestions flow from this firstly to re-focus policy on innovation or alternatively, miss that step and focus on adapting the innovations of others (Murphy et al., 2025). Choosing a path would help innovators to either focus on presenting evidence of prototype performance overseas, with KSA being an obvious candidate, or alternatively seeking out innovation funding within Bahrain itself.

Water was articulated as fundamental, akin to a Constitutional right. The norms, values and behaviors stemming from this coupled with the governance regime of generous subsidies available to Bahraini nationals, encourages rather than manages water demand. This suggests a twofold mechanism of subsidy reform with engagement to address water behaviors and re-value water, rebalancing rights with responsibilities. Reading this as akin to Constitutional amendments means the depth and difficulty of these changes should not be under-estimated.

The Bahraini example tackles issues common to many countries confronting the need to change when current systems appear to not only work well but offer security and very high standards of living. Governing change in that context is a complex challenge. The results suggest that in designing governance systems efforts could be focused upon societal learning and capacity building addressing issues such as loss aversion and status quo bias. In mobility studies it has been noted that trigger events that make life less comfortable, such as high energy costs or unpleasant driving conditions, can initiate a shift to more sustainable mobility practices (Teran-Escobar et al., 2026). It is hoped that experiencing such trigger events in terms of energy and water systems can still be avoided. Instead, scenario building exercises and education around a climate changed future might trigger that shift.

There are limitations to our work as well as areas of potential further research highlighted. Focus group participants, through their interest in being involved in the project might be pre-disposed to support sustainability issues. The comments might therefore be taken as more supportive of climate adaptation than the general population. With its perspective on a response to a new project, the research does not unpick regional governance within the GCC. This could also offer fruitful lines of enquiry, from sharing resources, expanding energy systems through to resilience, pollution control and management of key water resources and seas. Whilst gender representation was achieved, our research identified issues over engagement with the migrant population with highly complicated power dynamics and engagement to be overcome. The gaps in engagement, participation and inclusivity need to be overcome, in line with principles of adaptive governance, to include under-represented and marginalized groups. It is suggested that further work targets this group to engage with their experiences of water and energy use and build capacity for meaningful future engagement. Further research could directly target this demographic to fill that shortcoming together with targeted research to reach older populations.

Overall, the participants help to articulate the struggles with the energy transition, and it is acknowledged that moving to a new regime is tough. However, there is cause to be positive. There are technologies that can support the energy transition. There are policies and Government agencies aligned to sustainable development with evidence of social will. By viewing technological change

with a governance focus through the forms of governance, the system might be adapted to unblock the route to more sustainable practices.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

ES: Methodology, Data curation, Project administration, Conceptualization, Writing – original draft, Validation, Investigation, Resources, Formal analysis, Writing – review & editing. NB-O: Conceptualization, Data curation, Funding acquisition, Methodology, Resources, Supervision, Writing – review & editing. HA: Data curation, Investigation, Methodology, Resources, Writing – review & editing.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frsc.2026.1803963/full#supplementary-material

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