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Architectures of Desalination: A Multilevel Comparative Analysis of Israel and Spain

Eleonora Sala
University of Bologna
Corresponding author: eleonorasala.96@outlook.com

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Abstract:

Water scarcity has become a serious problem for countries exposed to greater climate variability, for reasons related to the morphology of the territory, poor resource management, and climate change. Often, these three factors are linked, causing significant discomfort to the national and interregional balance. This paper proposes an integrated strategic analytical model inspired by the comparison of two profoundly different models: the Spanish and Israeli models of water management and production. While the Spanish model complies with high environmental safety standards, the Israeli model aims for a much faster, more centralized decision-making infrastructure, more oriented towards economies of scale and production performance. The comparison makes it possible to observe how governments share technological outcomes and determine how desalination can be a tool for long-term water stability. The findings point to important trade-offs between centralization, flexibility and sustainability that policymakers must consider when relying on desalination to strengthen water security.

Keywords: *Desalination, Water governance, Seawater reverse osmosis (SWRO), Israel, Spain, National Water Security, Environmental sustainability, Comparative policy analysis.*

1. Introduction

As the global water crisis grows, many countries are looking for new and sustainable ways to manage water, guided by their national policies. Unconventional water production methods are being used to help stabilize freshwater supplies, especially as shortages become more likely. Desalination has shifted from a minor option to a key part of national water systems. Today, the most common method is reverse osmosis, which removes salt from seawater by applying high pressure. This method has gradually replaced evaporation, which uses more energy and is less sustainable. After desalination, water often goes through additional treatments like remineralization before it is used by cities, farms, and industries. These steps help ensure good water quality. Without them, the whole system could face serious risks.

But desalination involves more than just technology. Choices about where, when, and how to use desalination depend on many factors, such as government structure, coordination between institutions, energy plans, environmental rules, and long-term goals. Comparing how different countries approach desalination helps us see how technical and policy issues work together to solve similar problems. This study looks at Israel and Spain, two leading countries in desalination that have taken very different approaches.

Israel has built a highly centralized desalination system, where large-scale reverse osmosis plants are managed as part of a single national water network. This approach helps Israel stay resilient and supports its role as a global leader in water technology. On the other hand, Spain has grown its desalination capacity through a decentralized system that includes regional governments, basin authorities, and the European Union. Spain's strategy reflects its diverse regions, legal requirements, and strict environmental standards, especially along the Mediterranean and on islands. Both countries use desalination to manage long-term water shortages, but their systems, policies, funding, and environmental approaches are very different. These differences are not just about administration—they also affect technology and politics. Together, they shape how fast desalination can grow, how it fits into wider water policies, and how sustainable it is over time. Learning from these differences can help other water-scarce countries as they plan their own strategies.

This comparison aims to find similarities, key differences, and lessons that can guide future policy choices in other regions facing water shortages.

2. Literature Survey

2.1 Historical Background of Desalination

Desalination has an extraordinarily long history: its oldest forms are documented in some of the world's oldest civilizations. Archaeological and historical evidence suggests that Minoan sailors in the Aegean may have used rudimentary desalination techniques between 3200 and 1100 BC, while the ancient Persian Empire reportedly integrated evaporative principles into its early water distribution systems. In general, these early practices foreshadowed some of the fundamental principles that underlie modern desalination processes.

The transition to modern desalination began during the Industrial Revolution. While in the second half of the 20th century, desalination expanded significantly in arid regions, initially dominated by thermal methods such as multi-effect distillation (MED) and vapor compression (VC). These technologies, however, have required high energy inputs, limiting their economic feasibility. A decisive change occurred with the development and refinement of SWRO, which became the dominant technology worldwide in the late 20th and early 21st centuries.

One of its most visible manifestations of water scarcity is the increasing irregularity of rainfall, combined with the growing demand for water from agriculture, industry, and domestic activities. In response, governments are increasingly turning to unconventional water sources to stabilize supplies and reduce vulnerability to climate fluctuations. Among these options, seawater desalination has become one of the most significant technologies worldwide. Over the past two decades, efficiency improvements and reduced operating costs have transformed desalination from a marginal solution into a central component of national water strategies.

Today, seawater desalination is dominated by reverse osmosis (SWRO), a membrane-based technology that removes dissolved salts by applying high pressure to seawater. This method has progressively replaced thermal evaporation technologies, which require much more energy. While SWRO remains energy-intensive, recent technological advances have reduced electricity consumption and enabled the continuous, large-scale production of drinking water. The resulting water is then post-treated and remineralized to meet quality standards before being distributed to municipal, agricultural, or industrial networks.

However, desalination is not simply a technical issue. Decisions about where, when, and how to implement it depend on governance structures, institutional coordination, energy strategies, environmental regulation, and long-term planning priorities. Comparing national models is essential to understanding how technical and policy factors interact in employing different methods to address similar challenges.

The logic of the comparison between Spain and Israel stands inside profound differences and significant similarities. Their trajectories offer both points of convergence and sources of divergence, serving as both reference material for research and drivers of innovation. Israel has developed a highly centralized, nationally coordinated desalination system, in which large-scale SWRO facilities operate as strategic infrastructure within an integrated water framework. Desalination enhances national resilience and supports Israel's role as a global exporter of water technology and expertise. Spain, by contrast, has expanded desalination within a decentralized, multilevel system of governance involving regional governments, river basin authorities, and the European Union (especially linked to environmental law regulations). Its approach reflects territorial diversity, regulatory obligations, and stringent environmental requirements, especially along the Mediterranean coast and in island regions. While both countries rely heavily on desalination to address long-term water stress, they differ significantly in institutional design, policy factors, financial models, and environmental strategies. These differences are not merely administrative: they determine how quickly desalination can be expanded, how it is integrated into broader water policy frameworks, and how sustainable it is in the long term.

2.2 Modern Desalination Technologies, Energy and Environmental Implications

Contemporary literature identifies SWRO as the most widespread and energy-efficient desalination method. RO systems work by forcing salt water through semipermeable membranes at pressures typically between 25 and 50 atm. Such a procedure allows the production of fresh water while retaining dissolved salts and other ions. Depending on salinity, membrane type, and system design, SWRO power consumption ranges from 1.5 to 4 kWh/m^3. This method remains significantly inferior to thermal distillation, which often exceeds 8 kWh/m^3. Reverse osmosis plants require extensive pretreatment to remove particulate matter, biological matter, and suspended solids, while post-treatment (including remineralization, pH correction, and chlorination) ensures chemical stability and water quality. High-purity RO permeate is often rebalanced with minerals such as calcium and magnesium especially to prevent corrosion in distribution networks and to maintain high water quality standard. One of the central themes of recent literature concerns the close link between desalination and the energy market. As desalination continues to require high energy consumption, fluctuations in electricity prices directly affect operating costs and, in some cases, the utilization rates of installed plants.

This vulnerability has been found in several Mediterranean and Middle Eastern contexts, where energy price spikes have led to underutilization of otherwise technologically advanced plants. Environmental impact remains a matter of primary importance. High-salinity brackish streams, often enriched with trace metals, can alter local marine ecosystems if not adequately diluted. As numerous studies have shown, the location of the systems must be carefully studied and analyzed. Ecological risks must be gradually reduced, if not eliminated. Advanced diffusion and hydrodynamic modelling systems must be developed with a view to reducing ecological risks to a minimum. Furthermore, the environmental impact of desalination remains significant when powered by fossil fuels, prompting a growing body of research into hybrid systems powered by solar, wind, or other renewable energy sources.

2.3 Desalination and Water Governance in Israel

Israel is widely studied as a global reference for desalination-based water security. Its transformation from chronic scarcity to near-structural water stability is attributed to an integrated national water system, centrally governed by the Israel Water Authority and operationally managed by Mekorot. Research highlights how this institutional configuration enabled coordinated planning, unified tariffs, and rapid construction of large-scale SWRO facilities along the Mediterranean coast. Comparing several characteristics, the main features of the Israeli model come out:

- Centralised governance;
- Technological;
- High operational performance;
- Exceptionally low non-revenue water;
- Extensive wastewater reuse (90–95% of treated effluent reused for agriculture.

In addition, water diplomacy, in which Israel supplies water to neighboring entities (Jordan, the Palestinian Authority) and exports desalination technologies internationally, strengthens its regional influence. Scholars also explore the environmental, social, and political implications of desalination in Israel. While the country has largely mitigated water scarcity, debates remain regarding energy dependence, marine impacts, and the strategic implications of relying heavily on centralised infrastructure.

2.4 Desalination and Water Governance in Spain

Spain offers a contrasting case, shaped by regional autonomy, river-basin governance, and European Union regulatory frameworks. Historically rooted in the hydraulic mission paradigm of dams and inter-basin transfers, Spain's water policy gradually shifted toward integrated water-resource management in the early 2000s. The Plan AGUA (2004–2011) marked a major turning point: conceived as an alternative to the politically contentious Ebro Water Transfer, it aimed to expand desalination capacity along the Mediterranean coast and in island territories.
Spain rapidly became one of the world leaders in installed desalination capacity. However, the literature documents mixed outcomes:

- Underutilisation of plants;
- Heterogeneous decision-making rules;
- Public resistance;
- Financial constraints (especially post-2008);
- Strong influence of EU directives (especially the Water Framework Directive).

Spain's experience illustrates the challenges of embedding technologically advanced infrastructure within a fragmented, polycentric governance landscape. The literature stresses that desalination in Spain is embedded in broader debates on territorial equity, energy vulnerability, and the institutional fragmentation of Spanish water governance.

2.5 Comparative Insights and Identified Gap

A. Existing research provides robust analyses of both countries, and emerging studies have begun to compare Israel and Spain. However, the literature remains predominantly divided between:

- technological assessments (efficiency, costs, energy performance);
- policy analyses (Plan AGUA, Israel's national water reforms);
- environmental studies (brine impacts, carbon footprint);
- political narratives (water diplomacy, inter-regional conflicts).

B. What is still lacking is a systematic comparison that integrates:

- technological configurations;
- governance structures (centralised vs decentralised);
- energy and environmental sustainability;
- strategic and long-term resilience implications.

The article's contribution is the creation of an analysis framework that emphasizes the differences between two models using two distinct criteria. The first basic criteria aim to understand the governance method, the technological configuration and level of innovation, energy and production costs, and finally the strategic role that the model itself assumes in the long term for the sustainability of resources. In addition to the four analytical dimensions, there are a number of cross-cutting factors, considered low, that influence the long-term performance and sustainability of national desalination architectures.

These include:

- *Emergency water-risk governance*, particularly the capacity of governments to activate extraordinary measures, commissarial management structures, and crisis-response protocols during hydrological stress.
- *Preventive planning*, such as drought-preparedness strategies, early-warning systems, maintenance regimes, and long-term infrastructure investment plans.
- *Technological innovation*, including advancements in membrane efficiency, energy-recovery systems, pretreatment processes, monitoring technologies, and digital optimisation.
- *Public investment strategies*, with attention to financing models, tariff structures, public–private partnerships, and long-term capital-cost recovery mechanisms.
- *International cooperation*, both bilateral and regional, in areas such as cross-border water agreements, technology transfer, and shared infrastructure development.
- *Engagement with international organisations*, including compliance with EU directives, alignment with OECD water-risk frameworks, and participation in global water-governance networks.
- *Pipeline and distribution-network architecture,* which determines the ability of desalinated water to be transported across regions, is integrated into existing infrastructure and absorbed into national or regional water grids.
- *Environmental-sustainability policies*, especially brine-management regulation, discharge-diffuser requirements, salinity-alteration monitoring, adoption of zero-liquid-discharge (ZLD) technologies, and national rules governing marine ecosystem protection.

These cross-cutting variables enrich the multilevel comparative framework, ensuring that the analysis captures not only the technological and institutional characteristics of each national model but also their adaptive capacity, environmental performance, and strategic long-term alignment.

3. Proposed Methodology

3.1 Comparative Logic

The strategy applied for this comparative analysis includes two case studies. In this specific case, these are two states with different approaches to using desalination as an alternative tool for freshwater production. These are two authentic architectures that manifest positive and negative aspects.

A. Governance

This dimension examines how responsibilities for planning, financing, regulating, and integrating desalination into water networks are shared among institutions. It considers indicators such as:

- level of centralisation/decentralisation;
- role of national vs regional authorities;
- regulatory frameworks and tariff-setting;
- coordination across agencies and basins;
- decision-making speed and policy coherence.

This dimension is crucial because governance structures determine not only infrastructure deployment but also long-term system resilience, especially under energy, climatic, or financial stress.

B. Technological Configuration and System Integration

This dimension analyses the technical architecture of each national desalination system, focusing on:

- dominant desalination technologies (SWRO, MED, hybrid systems);
- plant scale, capacity, and spatial distribution;
- energy requirements and optimisation strategies;
- integration with national water grids and storage systems;
- pretreatment, post-treatment, and quality controls.

The aim is to assess how technological choices align with national constraints (coastline characteristics, salinity levels, industrial capacity, energy mix) and how effectively desalinated water is incorporated into broader water-management systems.

C. Energy, Costs, and Environmental Sustainability

Given the energy-intensive nature of desalination, this dimension evaluates:

- primary energy sources used by desalination plants;
- exposure to electricity price volatility;
- operational costs and cost-recovery mechanisms;
- carbon footprint of the desalination sector;
- environmental impacts, particularly brine disposal and marine ecosystems;
- mitigation measures (diffusers, renewable integration, circular-resource approaches).

This dimension is essential for assessing the long-term viability of desalination as a climate-adaptation measure, especially amid global energy-market instability.

D. Strategic Role, Resilience, and Policy Outcomes

Finally, this dimension evaluates the role desalination plays within each country's broader water-security strategy, considering:

- contribution to the national water supply;
- interaction with other measures (wastewater reuse, transfers, demand-management policies);
- capacity to buffer droughts and multi-year shortages;
- geopolitical implications (e.g., Israel's water diplomacy; Spain's regional negotiation dynamics);

- social acceptance and public perceptions;
- long-term resilience under climate and financial uncertainty.

This dimension allows the study to move beyond purely technical comparisons and assess desalination as a *socio-technical system* embedded in national development strategies.

3.2 Data Sources and Analytical Procedure

The analysis utilizes a combination of:

- Academic literature with particular attention to desalination, governance, and sustainability technologies;
- Policy documents and official reports (including publications of the Israel National Water Authority), including Mekorot Reports, documentation of the Spanish AGUA Plan, basin authority plans, and EU directives;
- Secondary datasets on desalination capacity, energy consumption, environmental indicators, and infrastructure distribution;
- Technical studies on SWRO plant performance, brine impacts, energy requirements, and cost structures;
- Historical sources tracing the evolution of desalination technologies from early thermal methods to modern reverse osmosis.

The study recognizes several limitations. While data on technology and governance are generally accessible, detailed cost information is not available. For example, private sector contracts in Israel or region-specific tariffs in Spain are only partially available. An important factor to consider is the volatility of energy markets, which introduces uncertainty into the assessment of long-term economic sustainability. Despite these constraints, the comparative structure of the analysis still allows for solid cross-case perspectives. Insights that can be useful in structuring and inspiring solid alternatives for other countries with similar characteristics and problems. By placing technological, institutional, environmental, and strategic aspects on an equal footing within a single framework, this methodology goes beyond studies that focus exclusively on engineering performance or isolated governance outcomes. It offers an integrated understanding of desalination not only as a technical solution, but as a strategy shaped by governance choices, energy systems, and long-term adaptation needs.

Furthermore, the study takes into account factors such as emergency water disaster management, advance planning, technological innovation in desalination, public investment strategies, international cooperation, pipeline and distribution infrastructure, and environmental sustainability measures —particularly brine management, zero-liquid discharge technologies, and salinity impacts.

4. Comparative Analysis

a. Governance

Israel's water system is built around a highly centralized institutional structure designed to ensure coordination, uniform standards, and rapid decision-making in a context of often water stress. At the top is the Israel Water Authority (IWA), created in 2007 to bring together under one roof tasks previously divided among different ministries and technical bodies. This represents the vertex of the pyramidal structure. The IWA oversees national water planning, tariff-setting, allocation across the domestic, agricultural, and industrial sectors, and the establishment of operational and quality standards throughout the entire water cycle. Therefore, it represents both the technical-operational and economic-commercial decision-making hub. In addition to these skills, it also oversees major public investments, long-term planning frameworks, and regulatory aspects of contracts with private desalination operators.

Alongside the IWA is Mekorot, the national water company founded in 1937. As the operational skeleton of the system, Mekorot manages not only the national distribution network but also the infrastructure connecting desalination plants to the national water supply, large storage and transportation systems, groundwater resources, and the country's entire wastewater reuse program. In recent years, Me-korot has strengthened the system's resilience by reducing leakage rates (now less than 5%), improving pressure management, and building integrated networks that connect coastal desalination plants to the nation's innermost and most remote regions. These improvements have increased reliability, redundancy and continuity of service.

Overall, Israel essentially operates as a single national water unit, with a unified tariff system and a fully integrated network that allows water transfers across very different climate zones. Centralisation brings clear benefits: simplified procedures, consistent national rules, coordinated investment strategies, and reduced regional disparities. This contributes directly to social equity, ensuring uniform access to water services nationwide. Fundamentally, it also allows for quick and consistent decision-making. Thanks to this rapid decision-making, it was possible to build large coastal desalination plants, such as Sorek, Hadera, and Ashkelon, and to efficiently integrate them into the national network.

Spain, by contrast, manages water through a highly decentralized structure. Responsibilities are divided between the central government, the 17 autonomous communities, river basin authorities, regional services, and local administrations. This multilevel arrangement produces diverse, sometimes conflicting, approaches to water management. This reflects the country's diverse economies, agricultural needs, and geographical conditions. Spanish water policy is also heavily shaped by EU legislation. The Water Framework Directive sets environmental objectives and standards, while Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) regulate planning projects and tools. These mechanisms strengthen environmental safeguards but also lengthen approval processes and add procedural complexity.

The desalination plants built under the AGUA Plan (2004–2011) were designed and financed by the national government, but their management was entrusted to regional and local authorities in a fragmented institutional context. This has led to slow, sometimes contentious decision-making, political tensions between regions (particularly between the Levant and Castile-La Mancha), disputes with farmers over water prices, and limited alignment between water and energy policy—a significant weakness in a country where electricity prices fluctuate significantly.

b. Technological Configuration and System Integration

The technological setup of Israel's and Spain's desalination systems shows clear differences in plant scale, energy use, treatment processes, and the way each system is integrated into the national water networks. These factors - often even more than governance alone - help explain why the two countries achieve such different levels of reliability in desalination.

In Israel, desalination is almost entirely based on SWRO, with average energy consumption of 3.2-3.8 kWh/m³ - among the lowest in the world. The country has chosen to build a small number of huge plants, all located on the Mediterranean coast, with capacities typically between 90 and 150 million m³ per year, and up to 200 million m³ per year for the new Sorek II plant. This large-scale approach has enabled Israel to take full advantage of economies of scale: the five main plants (Ashkelon, Hadera, Sorek, Palmachim, and Ashdod) already produce more than 750 million m³ annually, and this figure is expected to exceed 900 million m³ once Sorek II and the Western Galilee come online. Their size has also encouraged the adoption of advanced technologies - high permeability membranes, energy recovery devices with efficiencies above 96%, multistage filtration, and ultrafiltration-based pretreatment designed to reduce fouling. As a result, these plants operate very reliably, typically using 85–95% of their installed capacity. Desalinated water is fully integrated into the Israeli national system. All major plants are directly connected to the National Water Carrier, which transports water from the coast to the inland and northern regions.

Today, approximately 70% of Israel's drinking water comes from SWRO plants, with the remainder provided by surface water, groundwater, and treated wastewater. Post-treatment is standardized throughout the country: remineralization with calcium and magnesium chemically stabilizes the water and prevents corrosion in the distribution network.

This uniformity greatly simplifies system management and strengthens long-term resilience.

Spain also has very advanced desalination technology, but it is much more dispersed. Although SWRO is the dominant method, Spain has more than 750 plants of all sizes, ranging from small units producing 5 –20 million m³/year to large facilities such as Torrevieja (about 80 –90 million m³/year) and Águi-las (55 million m³/year). Total installed capacity exceeds 1.2 billion m³/year, placing Spain among the world's leading countries in terms of the number of desalination plants. However, utilization rates differ widely and can only fall to 10–20% in some regions when electricity prices rise. Although average energy consumption (2.8–4.0 kWh/m³) is similar to that of Israel, decentralized operation makes it more difficult to distribute fixed costs over time. Spanish plants use advanced pretreatment systems (specifically multimedia filtration, ultrafiltration, and chemical oxidation) to manage coastal waters that tend to have higher turbidity and biological variability than the eastern Mediterranean. EU rules also impose sophisticated brine discharge systems that meet specific requirements. These requirements are generally stricter than in Israel, where deeper coastal waters and stronger circulation allow for faster dilution of brine, which thus does not remain concentrated in narrower water areas, thus causing the salinity index to increase. Furthermore, integration into Spain's water networks is much less uniform. In the Levante region — which includes Murcia and the Valencian Community—desalinated water can cover up to half of drinking demand during drought. In other areas, such as parts of Andalusia, it remains mostly a reserve resource. In the Balearic and Canary Islands, desalination is essential for tourism and domestic supply, but its integration into local systems is strongly shaped by infrastructure limitations and highly seasonal demand.

In short, the two countries represent very different models. Israel has built a centralized, large-scale, and highly efficient system fully integrated into the national water supply, ensuring a stable share of the country's water supply. Spain, despite having advanced technologies, operates a highly distributed system in which strong technical capacity is often offset by fragmentation, inconsistent demand, and exposure to energy price volatility.

c. Energy, Costs, and Environmental Sustainability

Energy and economic considerations are among the most decisive factors in determining whether desalination can serve as a reliable tool for water security. Although Israel and Spain use similar technologies, they differ significantly in terms of operational efficiency, production costs, and environmental impacts. These differences arise mainly from the structure of their energy markets, the scope of their plants, and the regulatory frameworks in which they operate.

In Israel, desalination plants draw electricity from a national grid characterized by relatively stable prices and long-term contracts negotiated between the government and plant operators. This feature is one of the consequences of the governance system. This stability allows operators to plan costs with confidence and maintain continuous and intensive production. Average energy consumption ranges from 3.2 to 3.8 kWh/m³, and the cost of desalinated water is typically between €0.50 and €0.65 per m³ - one of the lowest ranges in the world for large-scale plants. Energy recovery devices with efficiencies of 96–97% further reduce overall consumption. Environmentally, most plants benefit from favorable coastal conditions - deep water and strong currents - that help disperse brine and limit local impacts. The main disadvantage is that Israel's electricity system still relies heavily on fossil fuels, with a carbon footprint of about 1.1 –1.8 kg CO_2 per cubic meter of produced water.

Spain presents a different picture. While the specific energy consumption of Spanish SWRO plants is broadly comparable to that of Israel (around 2.8–4.0 kWh/m³), the final cost of desalinated water is significantly higher, generally ranging from €0.90 to €1.50 per m³.

The electricity market in Spain is highly volatile, with operators purchasing energy at spot prices that can fluctuate significantly, making it the main factor. During the energy crises of 2008–2012 and 2021–2022, production costs increased by up to 60–80%, forcing some plants to reduce operations or temporarily close. The cost predictability is further compromised by the lack of long-term energy contracts and limited negotiating influence.

From an environmental point of view, Spain is subject to much stricter requirements than Israel (Water Framework Directive). This regulatory package imposes stringent standards for brine disposal, habitat protection, and cumulative impact assessment. As a result, many Spanish plants use advanced multi-port diffusers, high-speed exhaust systems and detailed hydrodynamic models. These measures improve environmental performance but also increase both capital and operating costs. Local variations in salinity are more likely to occur in Spain, especially in semi-enclosed or low-circulation areas, such as parts of the southern Mediterranean or some Balearic bays.

Overall, Israel achieves excellent economic and energy performance thanks to three main factors: economies of scale, stable electricity prices, and seamless integration of desalination into its national water system. In Spain, production costs are higher and desalination capacity is being used irregularly due to price volatility, institutional fragmentation, and stricter environmental rules. From an environmental perspective, both countries must manage the impacts of brine dumping and energy dependence. Spain stands out for its increased regulatory compliance, while Israel achieves superior operational efficiency but also has a higher carbon footprint due to its energy mix. These contrasts influence not only the financial sustainability of desalination but also its ability to serve as a long-term pillar of national water security.

d. Strategic Role, Resilience and Policy Outcomes

The most significant differences between Israel and Spain are highlighted by the strategic dimension of desalination, which focuses on how it is integrated into a long-term vision for national water security, not just about the technology itself. In both countries, desalination has emerged as a response to structural water scarcity, but has been incorporated into policy architectures that differ radically. These differences shape not only desalination's contribution to national supply but also its resilience to future shocks in energy, climate, and geopolitical dynamics.

In Israel, desalination plays a clearly systemic role: it is not conceived as a complementary resource or an emergency solution, but rather as a structural pillar of national water security. The five major SWRO plants now form the backbone of the drinking water supply, covering 70–80% of domestic demand during drought years. This centrality allows Israel to drastically reduce interannual variability in natural water availability and decrease dependence on aquifers and the Jordan River basin, contributing to their ecological rehabilitation.

The system ensures significant operational resilience, supported by:

- High infrastructure redundancy (backup systems, flexible flow modulation);
- Rapid transfers across the country are enabled by full integration with the National Water Carrier.
- Continuous operation can be maintained even under moderate energy constraints thanks to stable, long-term energy contracts.

Geopolitically, desalination strengthens Israel's diplomatic influence, supports water agreements with Jordan and the Palestinian Authority, and positions the country as a major exporter of water technologies (e.g., IDE Technologies, Mekorot International). This water diplomacy is an increasingly relevant component of Israel's foreign policy.

Overall, Israel presents a high-resilience model in which desalination not only compensates for scarcity but also serves as a macrostrategic stabilization tool. This also represents an additional element that we can also define as business continuity.

In Spain, the strategic role of desalination is more heterogeneous and territorially differentiated. This, on the other hand, means that there is not the same stability and continuity. There is no national system centralising priorities, investment and water flows; instead, the contribution of desalination varies significantly between regions, from only 2–3% of total supply in parts of Andalusia up to 50% in areas of the Levant during severe droughts. Consequently, desalination is understood as a regional adaptation tool, often activated in response to specific crises rather than incorporated into national water planning as a stable component. It is considered more of an emergency plan than a continuity plan. Spain's resilience is shaped by its polycentric governance structure, which, on the one hand allows for flexibility and adaptation to local conditions, but on the other generates:

- Discontinuous use of plants due to volatile energy prices;
- Limited capacity for integrated national planning;
- Insufficient interconnections hindering interregional water transfers;
- Marked differences in financial and technical capacity between the Autonomous Communities.

Strict EU regulations (WFD, EIA, SEA) make Spain one of the most environmentally compliant desalination systems in the world, but they also introduce procedural complexity that slows expansion and modernization. Unlike Israel, desalination in Spain has no geopolitical function and remains limited to internal management and regional negotiation processes. The result is a form of "segmented resilience": some regions (e.g. Murcia) show strong adaptive capacity, while others remain highly dependent on natural hydrology or inter-basin transfers.

Table 1: *Summary of the multilevel comparative analysis between Israel and Spain. The table presents key indicators that capture governance structures, infrastructure scale, operational utilization, economic costs, energy market exposure, strategic function, and environmental regulation, showing how each country's desalination architecture reflects distinct institutional and policy logics.*

DIMENSION	ISRAEL	SPAIN
Governance	Centralised, Unified, Rapid decision-making	Polycentric, Multilevel, Territorial conflictuality
Plants	Few and very large	Many and medium-sized
Utilisation rate	85–95%	10–70% depending on the region
Cost per m³	€0.50–0.65	€0.90–1.50
Energy	Stable, long-term contracts	Volatile, spot market
Strategic role	National backbone	Regional instrument
Network integration	Full integration	Heterogeneous integration
Environmental sustainability	Medium	High (due to EU regulations)

5. Conclusion

This study demonstrates that desalination does not operate in isolation as a technical process; rather, it is embedded in broader national architectures that combine governance, technology, energy strategies, and long-term policy directions. Comparing Israel and Spain across multiple analytical levels, this study shows how similar technological foundations yield profoundly different outcomes when embedded in contrasting institutional and strategic contexts.

On the one hand, Israel has developed a coherent and vertically integrated desalination architecture, characterized by centralized governance, large-scale coastal facilities, stable energy arrangements, and full integration into a unified national network. This architecture ensures high systemic resilience, continuous operation, and strong planning consistency. It also supports geopolitical engagement and technological leadership, transforming desalination into a structural component of national water security.

Spain's desalination architecture, by contrast, is polycentric and territorially fragmented, shaped by regional autonomy, variable energy exposure, and stringent EU environmental regulations. Although technologically advanced and environmentally robust, the Spanish system shows uneven use, discontinuous operation, and limited integration into national planning frameworks. The resilience that emerges from this architecture is therefore heterogeneous: strong in some regions, weaker in others. The comparison confirms that desalination performance depends less on the technology itself than on the architecture in which the technology is embedded. Centralized structures improve coherence, stability, and scalability, while decentralized structures offer flexibility and environmental guarantees, but at the expense of strategic continuity and economic efficiency.

These findings suggest that water-stressed nations considering desalination must evaluate not only the technology's technical feasibility but also the institutional architecture needed to implement it effectively. Future research should explore hybrid models that combine governance integration with regional flexibility, as well as the role of renewable energy in reducing the environmental and economic constraints of desalination.

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