4 DS ANALYSIS AND AI SCENARIOS FOR DS2A IN GREECE

The Greek Demosite consists of two pilot plants located on the island of Tinos, both addressing the challenges of sustainable water management, tourism, and agriculture under the WEFE Nexus perspective:

- DS2A – Agios Fokas: a solar-powered desalination unit integrated with a mangrove-inspired system for brine management, aiming to provide freshwater while minimising environmental impacts (described in this section)
- DS2B – Potamia (Tinos Ecolodge): an off-grid eco-tourism facility that applies integrated solutions for water reuse, renewable energy production, and sustainable agricultural practices (described in the following section 5).

As before for Codorniu demosite, the following sections present a brief summary of the context and challenges for the demosite, the top 3 previously prioritized in the workshop using the MCA tool, the results of the AI-driven scenario simulations and a final evaluation of the WEFE Nexus trade-off.

4.1 Context and Challenges

The pilot site of Agios Fokas (DS2A) is located on Tinos Island (Cyclades, Greece) and addresses one of the island’s main challenges: the limited availability of freshwater resources. The site features a solar-powered desalination system, designed to provide a sustainable source of drinking water for local needs while minimising dependency on conventional energy-intensive desalination. A mangrove-inspired unit is used for brine treatment, reducing the environmental impact of saline discharges and restoring balance to coastal ecosystems.

The Greek demosites, coordinated by NTUA in collaboration with Italian company PLANET and Tinos Ecolodge, aimed at integrating **solar desalination** technologies with greenhouse cultivation and agro-ecotourism. Tinos DS2A tested a **Zero Liquid Discharge (ZLD) solar desalination system** triggered by sun irradiation, **producing freshwater for irrigating tropical crops in a greenhouse**. The process also generates edible salt as a by-product, thereby closing material cycles.

This pilot directly contributes to the WEFE Nexus by providing **water security for tourism and agriculture**, integrating renewable energy sources, and reducing environmental pressures on fragile island ecosystems. It also represents an innovative model for Mediterranean islands facing climate change impacts and growing demand for freshwater, supporting sustainable tourism and agriculture on small Mediterranean islands.

4.2 Top 3 prioritised solutions

On June 24, 2023, a workshop titled “A Sustainable Future for the Mediterranean – How could tourism, nature-based solutions, and agricultural production be combined on the island of Tinos in Greece, towards a sustainable future?” was held in Tinos. This workshop brought together stakeholders from local authorities, tourism operators, environmental non-governmental organizations (NGOs), and research institutions to collaboratively develop integrated solutions for sustainable island management. The attendees utilized the SureNexus MCA tool to assess a comprehensive range of nature-based solutions (NBS) and bioeconomy-based solutions (BES). The findings revealed that three solutions exceeded the prioritization threshold of 50, indicating local priorities for water security, ecosystem resilience, and climate adaptation:

- **Agroforestry** was identified as the top-ranked solution, contributing strongly to to ecosystem and climate dimensions. It supports soil stabilisation, biodiversity conservation, and improved water retention, all of which are critical to reducing the vulnerability of local ecosystems to drought and erosion.
- **Residential rainwater harvesting** collects and stores rainfall from rooftops to supply non-potable domestic uses such as toilet flushing, garden irrigation, or cleaning. It reduces dependence on municipal water systems and enhances household-level water resilience.
- **Subsurface rainwater harvesting** was selected as the third priority. By enabling the storage of seasonal rainfall underground, this solution mitigates evaporation losses and provides a supplementary freshwater source to address agricultural and domestic demands, thereby enhancing water security.

Considering the **strategic role of solar desalination, especially when coupled with a salt factory in a zero-liquid-discharge (ZLD)** configuration, this integrated approach can become a cornerstone for **enhancing sustainable tourism and water security** in small Mediterranean islands such as Tinos, Greece. Solar desalination minimizes energy demand and greenhouse gas emissions while ensuring stable freshwater supply—an essential prerequisite for tourism-dependent island economies facing seasonal water stress. When the brine produced by desalination is valorized through salt recovery, the system **transitions from a linear extraction-waste model to a circular production loop**, reducing environmental pressure on coastal ecosystems and creating added economic value.

Throughout the analysis, we examined in detail both the **benefits and trade-offs of deploying solar desalination under island conditions**. The MCDA and Δ-heatmap results consistently showed that solar desalination outperforms conventional systems in all environmental dimensions, making it the most viable option for long-term resilience. However, desalination—solar or otherwise—cannot address all water challenges alone. For this reason, complementary approaches are essential to build a diversified and climate-resilient water portfolio.

In the following section 5, we therefore explore additional nature-based and distributed solutions tested under the same environmental and operational conditions on Tinos Island, specifically at **Tinos Ecolodge**. These include agroforestry interventions, roof and surface rainwater harvesting systems, and subsurface infiltration water harvesting, each contributing unique synergies within the WEFE Nexus. While desalination provides reliability and independence from rainfall, agroforestry can enhance soil moisture retention and biodiversity, and rainwater harvesting can reduce pressure on centralized water systems and increase household self-sufficiency during peak tourist demand.

Together, these solutions illustrate a portfolio approach: solar desalination ensures baseline supply; salt recovery minimizes waste and creates circular value; agroforestry reinforces ecosystem services; and rainwater harvesting enhances local resilience. This integrated strategy aligns with EU climate adaptation goals and offers a replicable model for other Mediterranean islands facing similar sustainability challenges.

4.3 AI scenario results for Solar Desalination

Figure 16 and Figure 17 provide a comparison of different desalinations systems, offering a visual clear analysis of the resulting trade-offs. **Solar Desalination** (S1) is vastly superior in terms of environmental footprint, consuming minimal grid energy (approx 12 kWh/month) just for pumping and producing negligible GHGs (approx 4 kgCO2e/month). On the contrary, a **conventional reverse osmosis (RO) desalination (S2) used as baseline**, is resource-intensive, consuming approx 49 kWh/month and emitting approx 26 kgCO2e/month. Considering the ecosystem impact, the solar desalination system produces slightly more brine (grey bars, approx 9.8 m^3/month) than the conventional RO system (approx 7 m^3/month).

Figure 16 substantiates that **solar desalination presents a mutually (win-win) beneficial solution for the Water-Energy nexus**, as it utilizes the same water source while reducing energy and carbon emissions. However, it is crucial to address the potential impact on local ecosystems.

While solar desalination offers a solution to the energy intensity problem by significantly reducing greenhouse gas emissions and augmenting water supply, it also highlights a persistent trade-off with ecosystems. The **increased production of brine from solar desalination** necessitates sustainable brine management strategies to effectively close the loop and mitigate the adverse effects on local ecosystems, especially on marine or soil ecosystems if not managed or valorized effectively.

Figure 17 illustrates the complexity of the WEFE Nexus. To achieve a **zero liquid discharge solution**, a **salt factory** was added (salt crystallization for mineral recovery). In this case, maximizing resource recovery (extracting salts) imposes a severe energy penalty, turning a water solution into an energy burden. While simultaneous water and salt recovery is technically feasible, it increases energy intensity by an order of magnitude, highlighting the need for renewable energy integration if resource recovery is prioritized.

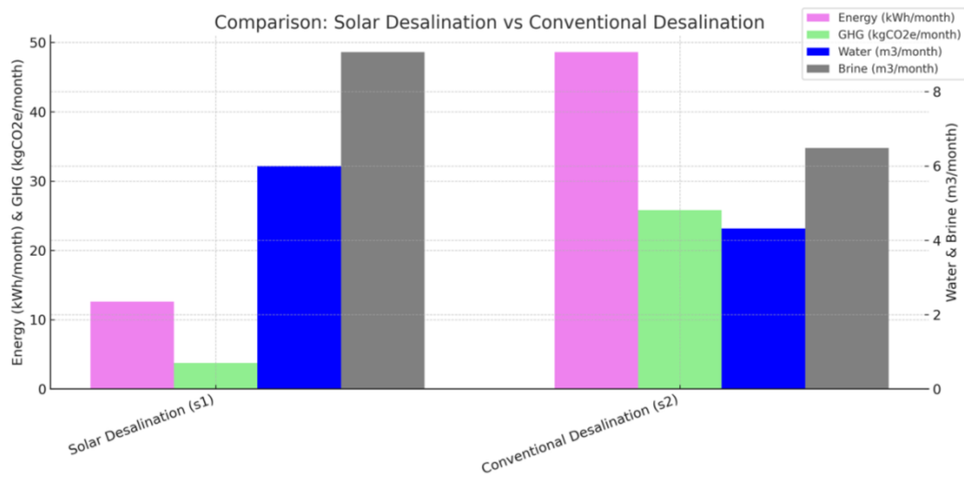


FIGURE 16. TRADE-OFFS BETWEEN WATER PRODUCTION, ENERGY USE, GHG EMISSIONS AND BRINE PRODUCTION IN DESALINATION DESIGNS (MONTHLY DATA)

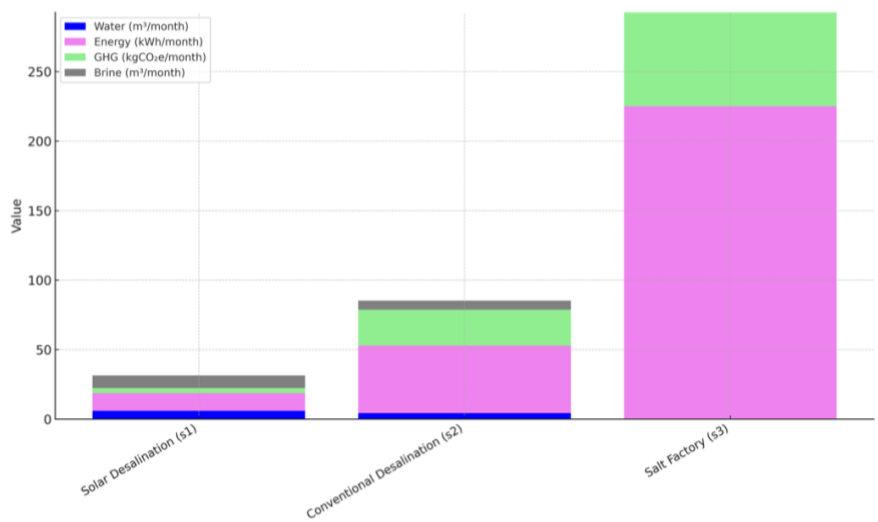


FIGURE 17. STACKED BAR COMPARISON BETWEEN THE DIFFERENT DESALINATION SYSTEMS.

The **multicriteria analysis (MCDA)** conducted for the three desalination-related scenarios in Tinos (Figure 18) provides a rigorous comparative assessment of their performance in terms of water production, energy consumption, greenhouse gas (GHG) emissions, brine discharge, and circular-economy potential (salt recovery). The results clearly show that **solar desalination (S1)** emerges as the most sustainable option across all weighting schemes, driven by its low energy demand, very low GHG emissions, and stable production output. Although its brine volume is slightly higher than that of the conventional system, this disadvantage is outweighed by its superior environmental performance.

The **conventional desalination system (S2),** while capable of producing the same amount of water or even more as the solar-powered alternative, performs significantly worse in the energy and GHG categories. Its reliance on grid electricity results in high operational emissions, making it a less favorable option under both balanced and environmentally weighted strategies. Even in a water-priority evaluation, S2 remains inferior to S1 because the environmental penalties are too large to offset its water contribution.

The **salt factory (S3)** plays a very different role in the system. It is not a water-generating technology, and therefore receives N/A in the water and brine categories. Its value lies in salt production, which provides a circular-economy co-benefit. However, the process is characterized by extremely high energy use and the highest GHG emissions among all scenarios.

Overall, the results indicate that **solar desalination should be prioritized in policy and investment decisions** for Tinos, particularly when the objectives include climate mitigation, cost stability, and renewable integration. Conventional desalination may serve as a complementary or emergency system, but its operational footprint makes it unsuitable as the primary long-term strategy. The **salt factory** should not be considered part of the water-supply portfolio but may be supported as a circular-economy industrial activity, provided that environmental mitigation measures are adequately put in place.

Figure 19 presents the **weighted Multicriteria Decision Analysis (MCDA)** results for the three desalination-related scenarios—solar desalination (S1), conventional desalination (S2), and the salt factory (S3) —under **three different prioritization strategies: Balanced, Environmental, and Water Priority**. The heatmap provides a synthetic but powerful visualization of how each scenario performs when weighting preferences change across the WEFE Nexus.

Across all weighting schemes, **solar desalination (S1) consistently achieves the highest overall performance**, with scores ranging from 0.58 (Balanced) to 0.78 (Water Priority). This confirms that **S1 is the most robust and resilient solution, benefiting from its low energy demand and very low greenhouse gas emissions**. Even when the criteria shift from environmental performance to water-focused priorities, the solar desalination system remains the top-ranking option, reflecting its strong adaptability within different policy contexts.

The **conventional desalination system** (S2) shows intermediate performance, with scores between 0.54 and 0.74. Although S2 performs nearly as well as S1 under the Water Priority strategy—due to both systems producing the same volume of water—its higher energy intensity and associated emissions limit its ranking in the Balanced and Environmental scenarios. This highlights that S2 is only competitive when water quantity is the dominant decision factor, but less suitable when sustainability considerations gain importance.

In a **zero liquid-discharge approach**, the **salt factory** (S3) contributes to circularity through salt recovery; however, the extreme energy requirements and highest GHG emissions make it an unfavorable option from both environmental and water management perspectives. The S3 heatmap illustrates how energy-intensive resource-recovery processes may significantly undermine sustainability unless supported by substantial renewable energy sources.

Overall, Figure 19 shows that **solar desalination demonstrates the best performance regardless of the chosen weighting approach**, making it the preferred option from a strategic planning standpoint. Meanwhile, conventional desalination may play a complementary role where higher water volumes are needed, and the salt factory should be considered primarily as an industrial by-product recovery solution rather than a water-supply technology.

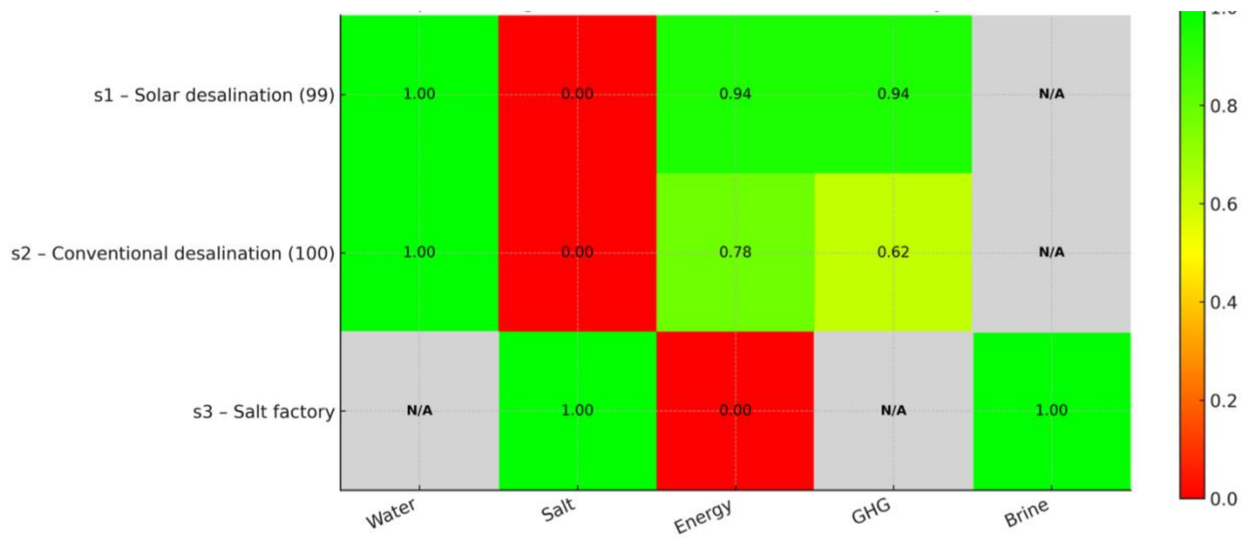


Figure 18. MCDA Heatmap (Unweighted) for the desalination systems.

Scenario	Water (m^3/month)	Energy (kWh/month)	GHG (kg CO_2e/month)	Brine (m^3/month)	Salt (kg/month)
s1 – Solar desalination (99)	6	12.6	3.77	9.06	N/A
s2 – Conventional desalination (100)	6	48.6	25.8	6.48	N/A
s3 – Salt factory	N/A	225	67.5	N/A	60

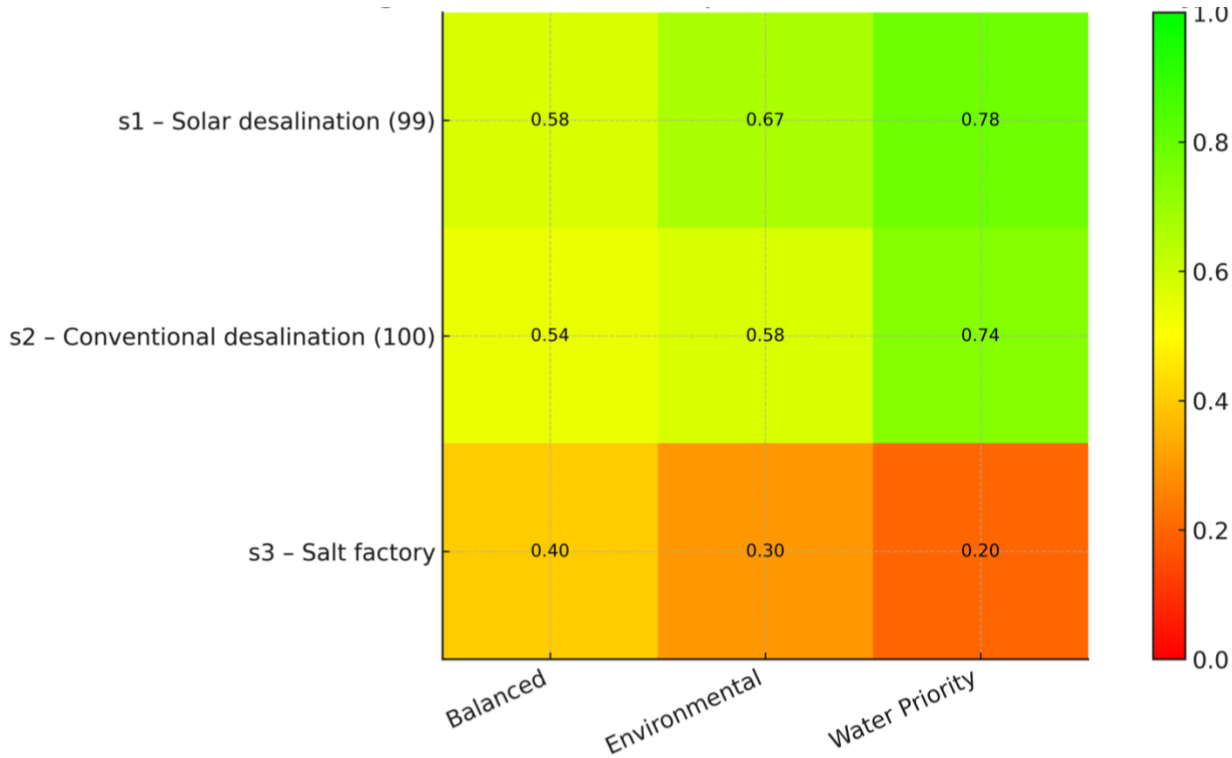
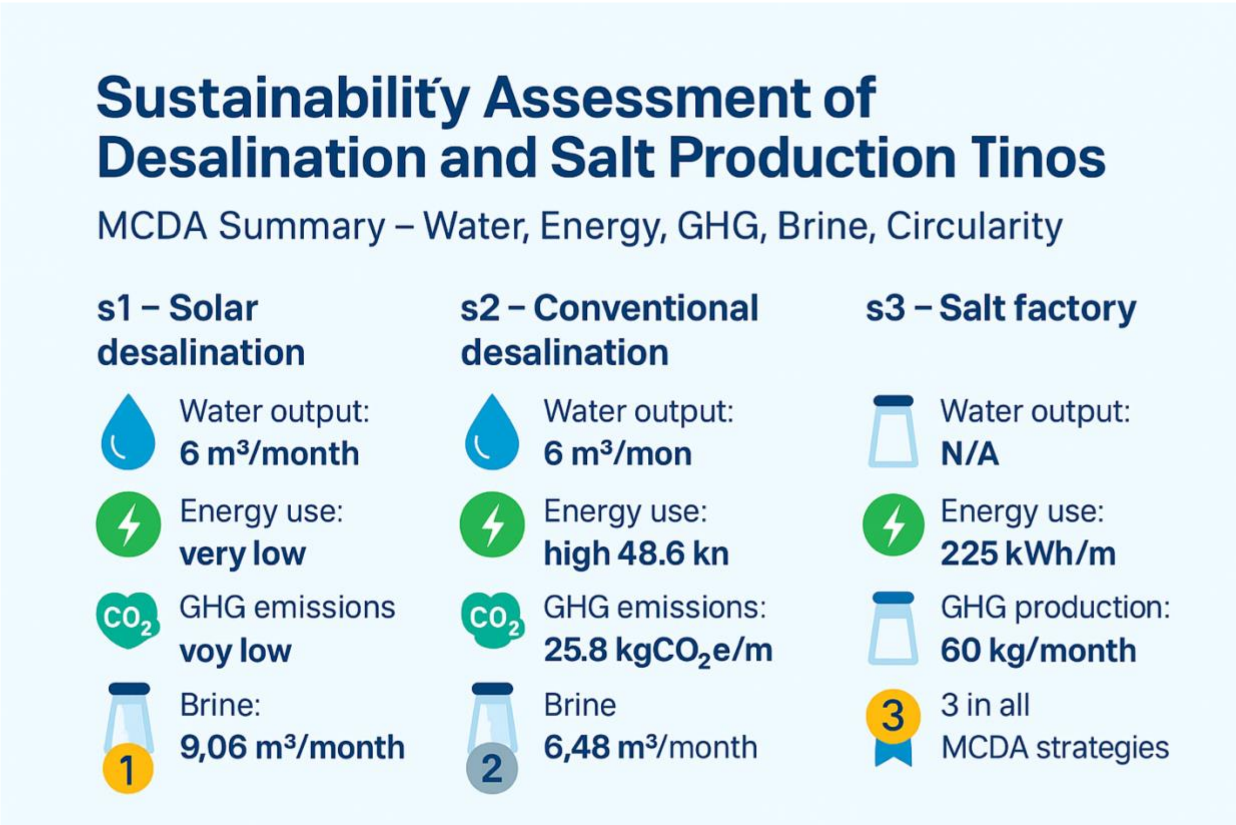


FIGURE 19. WEIGHTED MCDA HEATMAP WITH BALANCED, ENVIRONMENTAL AND WATER PRIORITY.

Dimension	S1 – Solar desalination	S2 – Conventional Desalination	S3 – Salt factory
Water contribution	✓ Reliable	✓ Reliable	✕ None
Energy demand	**Very low**	High	**Very high**
GHG emissions	**Lowest**	High	**Highest**
Brine discharge	Moderate	Lower	N/A
Circular economy value	None	None	✓ Salt production
Operational costs	Low	High	Very high
Best policy use	**Primary desalination strategy**	Backup / non-preferred asset	Industrial by-product process (not water supply)



4.4 AI WEFE Nexus Trade-Off Analysis

The Δ-heatmap (Figure 20) provids a direct visualization of trade-offs by quantifying how each scenario deviates from the solar desalination baseline (S1). Solar desalination performs best overall, so deviations represent losses (red) or gains (green) relative to the most sustainable option.

Conventional desalination (S2) shows large positive deltas in both energy (+36 kWh/month) and GHG emissions (+22 kg CO_2e/month), clearly indicating a **deterioration in environmental performance compared with the solar option**. The only improvement is slightly lower brine discharge (–2.6 m^3/month), though the difference is small. Since water output is identical to S1, the environmental penalties dominate the trade-off analysis. The **salt factory** (S3) shows the strongest negative environmental deltas: extremely high energy consumption (+212.4 kWh/month) and the largest GHG footprint (+63.7 kg CO_2e/month). It does not generate water or brine discharge (N/A), so its only advantage is a positive delta in salt production, which positions it as a circular-economy asset rather than a water-supply solution. The Δ-heatmap clearly reveals this functional role difference.

Overall, the Δ-heatmap demonstrates that **solar desalination consistently outperforms the other scenarios, with S2 and S3 showing substantial negative deltas in key WEFE indicators.** This supports policy recommendations favoring **solar desalination as the primary option and treating the salt factory solely as an industrial by-product recovery system.**

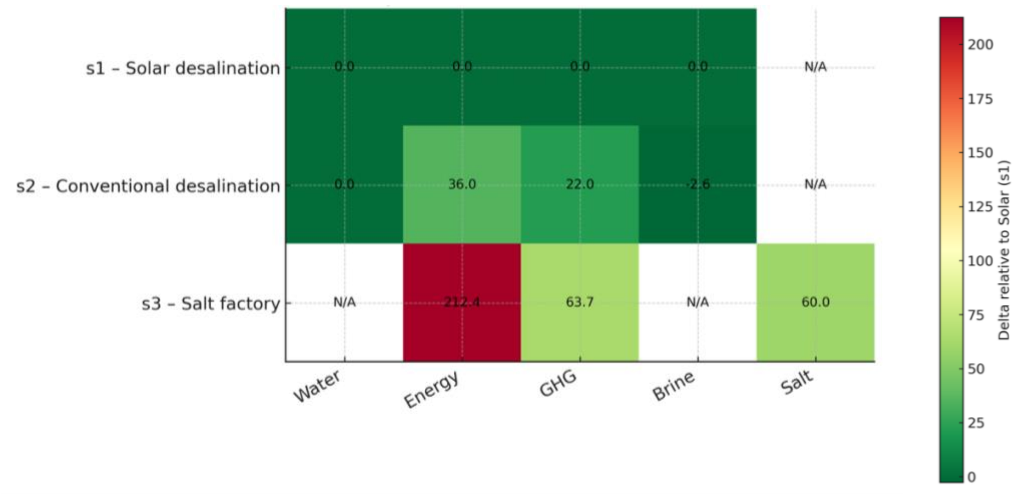


FIGURE 20. DELTA-HEATMAP REVEALING TRADE-OFFS RELATIVE TO SOLAR DESALINATION