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Techno-Economic Assessment and Energy Generation Potential of a Coastal Hydropower Plant Utilizing a Depression in the Libyan Desert

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Abstract

This study examines the proposed use of Mediterranean seawater to generate hydroelectric power by directing it into a hyper-arid depression in the Libyan desert. The concept is assessed using a steady-state water-balance approach, in which the incoming seawater flow is limited by the basin's estimated evaporation rate. The baseline scenario assumes an evaporation rate of 7.2 mm/day, a basin surface area of approximately 7,800 km^2, a continuous flow rate of 650 m^3/s, and an effective hydraulic head of 50 m. Applying the stated hydraulic parameters gives an initial theoretical output of 261.43 MW; the manuscript adopts a nominal capacity of 255.06 MW after allowing for additional losses. At a 95% capacity factor, this corresponds to approximately 2.12 TWh of annual electricity generation. The preliminary economic scenario estimates capital expenditure at US$3.25 billion, a levelized cost of electricity of US$54.20/MWh, and a simple payback period of 14.2 years. The assessment also considers potential environmental impacts, particularly groundwater salinization and the accumulation of salts within the receiving basin. On the assumptions used here, the concept warrants further site-specific investigation; however, the identified environmental and financial constraints indicate that dry solar photovoltaic systems combined with closed-loop pumped-hydro energy storage may offer a more sustainable pathway for Libya.

Keywords: Depression hydropower; seawater; Libya; Marada depression; water balance; techno-economic assessment

1 Introduction

Libya's electricity sector faces persistent infrastructure constraints, including grid instability, dependence on fossil-fuel generation, and recurring power interruptions. At the same time, parts of the country contain coastal and inland depressions situated below Mediterranean sea level. The possibility of using such basins as terminal reservoirs for hydroelectric generation has been discussed in engineering literature since the early twentieth century [1]. In the proposed arrangement, seawater would be conveyed from the Mediterranean coast through an intake channel or underground tunnel. The elevation difference between sea level and the depression could drive the flow through hydraulic turbines, potentially providing a relatively continuous source of electricity [2].

This paper presents a preliminary assessment of a coastal-depression hydroelectric scheme in the Marada area of Libya. It considers the geographic and hydraulic assumptions, estimates the potential power output, and reviews indicative project costs and environmental concerns. The Egyptian Qattara Depression proposal is used as a point of comparison because it provides a historical example of a similar large-scale concept. The manuscript also refers to a 2026 account of changes to the Qattara proposal (Ministry of Electricity and Energy, 2026); The existence and technical

characteristics of the proposed site should be independently verified before any definitive conclusions are drawn. The present assessment combines simplified hydraulic calculations with preliminary economic estimates to provide an initial evaluation of the project's feasibility and potential for electricity generation.

2 Technical and geological framework

The feasibility of a depression-based power scheme is governed principally by the available elevation difference, the surface area of the receiving basin, and the local evaporation rate. For the basin to remain at a stable water level, the volume of seawater entering it must, over the long term, be balanced by evaporation and any other water losses. If inflow persistently exceeds the basin's capacity to lose water, the water level will rise and the available hydraulic head will diminish. This water-balance condition is central to the operating concept discussed in earlier work on the Qattara Depression (Salem, 2012)[4]. The concept is illustrated in Figure 1.

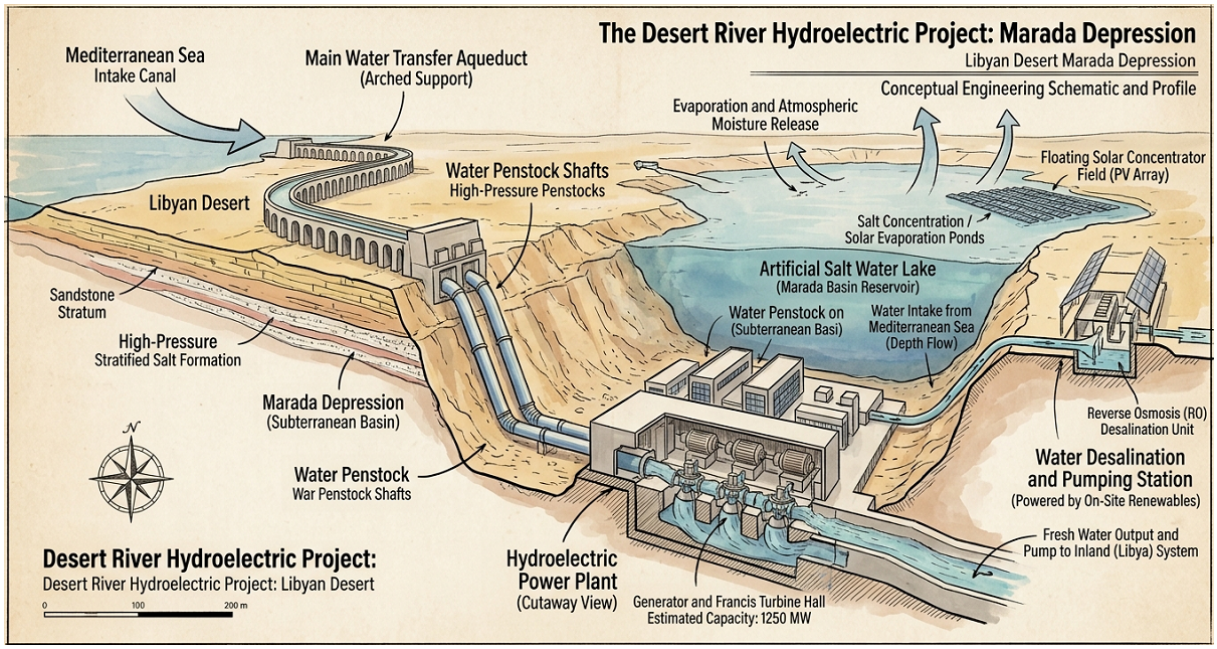


Figure 1. Conceptual schematic of the proposed Marada depression hydroelectric scheme.

2.1 Project geographic profile

Table 1 presents the geographic profile of the proposed project components.

Table 1. Geographic profile of the proposed project components.

Project Component	Location Coordinates	Elevation (MSL)	Functional Description
Coastal Intake Station	Gulf of Sirte (near El Agheila) 30.26° N, 19.20° E	0.0 m	Seawater screening and primary intake structure.
Conveyance System	120 km Southward Channel/ Tunnel	0.0 m to -5.0 m	Gravity-driven subterranean flow towards the depression rim.
Penstock & Intake Gates	Marada Northern Escarpment 29.28° N, 19.20° E	-5.0 m	Controls high-pressure flow into vertical drop pipes.

Project Component	Location Coordinates	Elevation (MSL)	Functional Description
Hydroelectric Power Station	Marada Depression Floor 29.23° N, 19.20° E	-40.0 m	Houses hydraulic turbines and generators for power production.
Evaporation Discharge Basin	Marada Salt Flats (Sabkha) 29.20° N, 19.22° E	-47.0 m	Natural low point where solar evaporation maintains the head level.

2.2 Hydraulic elevation profile

The proposed arrangement relies on the elevation difference between the conveyance system and the receiving basin. The geographic profile (Table 1) lists elevations ranging from approximately −40 m to −47 m relative to mean sea level. These values suggest a gross head in the range of about 40–47 m, before accounting for hydraulic losses. The calculation in the energy production section, however, uses an effective head of 50 m. That difference requires confirmation against a consistent site elevation profile and should be resolved before the design is treated as technically validated [3].

2.3 Hydrological equilibrium and steady-state flow

For the preliminary water-balance calculation, the manuscript adopts an average pan-evaporation rate (E) of 7.2 mm/day, equivalent to approximately 8.33×10^{-8} m/s, and cites Salem (2012). A peak summer value of 10 mm/day is also reported. The assumed stabilized water-surface area (A) is 7,800 km^2, or 7.8×10^9 m^2. Under the simplifying assumption that evaporation is the only balancing outflow, the maximum steady-state inflow (Q) is estimated from the continuity relationship below:

$$Q = A \cdot E = \left(7.8 \times 10^9 \mathrm{m}^2\right) \times \left(8.333 \times 10^{-8} \mathrm{m/s}\right) \approx 650 \mathrm{m}^3/\mathrm{s} \quad (1)$$

On these assumptions, 650 m^3/s is the calculated inflow that would balance the stated average evaporation over the assumed basin area. This value is therefore a scenario estimate rather than a verified operating limit. Its reliability depends on confirming the basin area, the representative long-term evaporation rate, and whether seepage, precipitation, and other water-balance terms can reasonably be neglected [6].

Unlike traditional river-fed hydroelectric dams where water discharges downstream, a depression power plant operates as a terminal closed sink. The water must evaporate completely into the atmosphere, transforming the basin into an engineered hyper-saline lake over time.

3 Energy production potential

The theoretical hydraulic power is estimated using the conventional relationship for a turbine-generator system:

$$P = \rho g Q H \eta \quad (2)$$

where ρ is the seawater density (1,025 kg/m^3), g is gravitational acceleration (9.81 m/s^2), Q is the assumed volumetric flow rate (650 m^3/s), H is the effective hydraulic head (50 m), and η is the combined turbine–generator efficiency (0.80).

Substitution of the assumed values into the hydraulic power equation gives the following theoretical output:

$$P = 1025 \times 9.81 \times 650 \times 50 \times 0.80 \approx 2.614 \times 10^8 \mathrm{W} = 261.4 \mathrm{MW} \quad (3)$$

The calculation above produces 261.43 MW. The manuscript then applies an additional allowance for secondary penstock losses and seasonal variation and adopts 255.06 MW as the nominal plant capacity. The basis for this adjustment should be documented—for example, by providing the assumed loss factor or a more detailed hydraulic model. Using the adopted nominal capacity and a capacity factor of 95%, annual electricity production is estimated as follows:

$$E_{annual} = 255.06\text{MW} \times 8760\text{h} \times 0.95 \approx 2.12 \times 10^{6}\text{MWh} = 2.12\text{TWh} \quad (4)$$

4 Economic feasibility analysis

The proposed facility would require substantial civil and electromechanical infrastructure. The cost scenario includes a seawater intake, a conveyance route from the Mediterranean coast, penstocks, and a powerhouse equipped with Francis-type turbines. The manuscript gives a conveyance length of 32 km in the economic assessment, whereas the geographic profile in Section 2.1 specifies a 120 km southward channel or tunnel. The route length must be checked and made consistent before the capital-cost estimate is relied upon[5].

4.1 Capital and operational expenditure estimates

The preliminary capital-cost breakdown is presented in Table 2. The estimates are described as being informed by international infrastructure benchmarks and historical Qattara project studies; the underlying benchmark sources, price year, contingency allowance, and estimation method should be supplied to make the figures reproducible.

Table 2. Preliminary capital cost breakdown.

Cost Component	Estimated Investment	Percentage of Budget
Tunnels & Intake Channels (32 km excavation)	$1,850,000,000	56.9%
Powerhouse & Electro-Mechanical Equipment	$650,000,000	20.0%
Grid Integration & Transmission Lines	$350,000,000	10.8%
Environmental Mitigation & Permitting	$400,000,000	12.3%
Total Initial CAPEX	$3,250,000,000	100.0%

Annual operating expenditure is estimated at US$45 million. The stated cost allowance includes maintenance associated with seawater intake and the control of salt deposition within the turbine and hydraulic equipment. This estimate should be supported by a maintenance plan and a clear statement of the assumed operating conditions.

4.2 Financial indicators and LCOE

The financial assessment assumes a 40-year operating life and an 8% discount rate, producing a stated levelized cost of electricity (LCOE) of US$54.20/MWh. It also assumes an electricity sale price of US$0.075/kWh (US$75/MWh), from which the manuscript reports a simple payback period of 14.2 years and an internal rate of return of 6.8%. These indicators are preliminary and depend on the capital-cost estimate, annual operating expenditure, energy yield, financing assumptions, and tariff. The calculation method and cash-flow assumptions should be included so that the LCOE, payback period, and IRR can be independently reproduced [7].

5 Critical environmental challenges and alternatives

Although the concept could provide generation that is less dependent on daily solar conditions, directing seawater into an inland depression may create significant environmental risks. One concern is the possible movement of saline water through permeable geological formations and its interaction with nearby groundwater resources. The manuscript identifies the Nubian Sandstone Aquifer System as a potentially vulnerable resource (Ihfedah et al., 2025). The extent of any risk, however, cannot be established from the information presented here; it requires site-specific hydrogeological investigations, including permeability testing, groundwater-flow modelling, and an assessment of the proposed basin's geological containment [5].

Long-term evaporation would also increase the salinity of the water retained in the basin. Salt precipitation and the development of saline flats may affect local habitats and could create dust or brine-related impacts beyond the basin itself. The manuscript cites an online discussion of the Qattara project in connection with these concerns (Thoughts on the Qattara Depression Mega Project, 2023). For a peer-reviewed engineering paper, this discussion should be replaced or supplemented with authoritative environmental studies that directly address salt-pan formation, airborne salt transport, and impacts on nearby ecosystems and agriculture [7].

The manuscript further states that Egypt discontinued its Qattara scheme in May 2026 and shifted toward a different development approach (Qattara Depression Project, 2026; Ministry of Electricity and Energy, 2026). This historical claim and the cited government publication require independent verification. As an alternative, the paper identifies dry solar photovoltaic generation combined with pumped-hydro energy storage. It reports a levelized cost of storage range of US$48.95–62.11/MWh for a desert-based pumped-hydro option, citing a 2026 study listed as a ScienceDirect source. The full bibliographic details and the applicability of that cost range to Libya should be checked before the comparison is retained [7].

6 Conclusion

Under the assumptions adopted in this preliminary assessment, the proposed coastal-depression scheme has a nominal generation capacity of 255.06 MW and an estimated annual output of 2.12 TWh. The indicative capital cost is US$3.25 billion. These figures suggest that the concept merits further investigation at the screening-study level, but they do not establish technical or commercial feasibility. In particular, the assumed hydraulic head, basin area, evaporation rate, conveyance length, and cost inputs require confirmation. Potential groundwater impacts and the long-term accumulation and dispersal of salts are also major unresolved issues. A defensible decision would therefore require detailed topographic, hydrological, geological, environmental, and financial studies. The comparison with dry solar photovoltaic generation and closed-loop pumped-hydro storage should be developed using verified, directly comparable data.

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