View on Lake Tiberias from Jordan toward the northwest ©Klein

Large-Scale Hydropower Plant at Lake Tiberias in the Context of Transboundary Water Transfer

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KEY FINDINGS

A hydropower plant could make use of the elevation gradient of ca. 200 m between a seawater desalination plant at the Mediterranean Sea and Lake Tiberias.

Depending on the water production scenario and flow system, the hydropower plant could recover 11 to 16% of the electricity used by the desalination plant.

Intermittent operation of the hydropower plant in combination with the use of solar energy could increase the share of renewable electricity generation.

MOTIVATION

Renewable freshwater resources in Israel, Palestine, and Jordan are already mostly depleted. While Israel increases its freshwater production by seawater desalination, this option is not immediately available for Palestine and Jordan because of the restricted access to the sea.

Until 2050, large freshwater deficits are to be expected for both countries [Future Freshwater Deficits in Palestine and Jordan, p. 18]. An innovative and cost-effective water production and transfer alternative consists in desalinating seawater north of Haifa and transferring it via Lake Tiberias to Jordan and Palestine, using the lake as a regional water reservoir [Water Production and Transfer Strategies, p. 22]. Today, based on bilateral agreements, the lake already provides Jordan with 50 Mio. m^3 of water per year, increasing to 100 Mio. m^3 per year according to recent agreements in 2021. An additional volume of 200 Mio. m^3/a of freshwater is planned to be exchanged for Jordanian solar energy in the context of a Water-Energy-SWAP.

According to the above solution, water will be conveyed by a supply line to the lake (Figure 1), which is located at an altitude of -209 m asl. In a country where hydropower resources are limited, supplying from the Mediterranean coast the deeper-lying Lake Tiberias with desalinated water presents a potential for hydropower generation. This

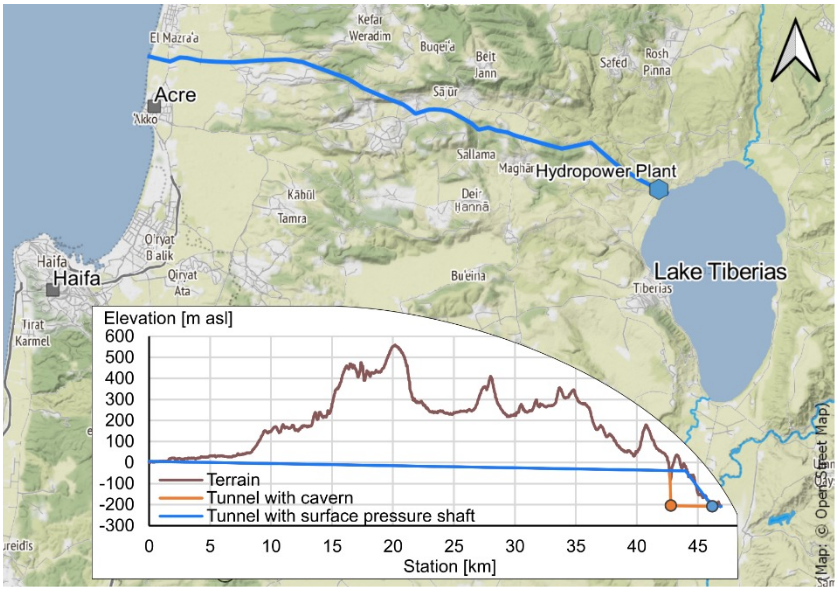

Figure 1: Overview and longitudinal cut of a tunnel between the coast and a hydropower power plant at Lake Tiberias

hydropower plant would also be a contribution to Israel's energy policy by reducing its high dependence on fossil fuels (Ashwarya, 2022). In 2020, around 94% of Israel's produced electricity was generated from coal, oil, or gas. In order to reduce the use of fossil fuels and to achieve the climate protection commitments, 17-20 % of the electricity supply is to be provided by renewable energies by 2025, which is to be achieved primarily by expanding solar energy. This expansion is flanked by an expansion of pumped hydro-storage capacity to keep the power grid stable and to absorb peaks in demand.

The objective of this study is to conduct a hydraulic and energy analysis of the hydropower potential at Lake Tiberias in conjunction with seawater desalination and the use of solar power in order to quantify potential cost reduction of water conveyance and the potential increase in the production of renewable energy in Israel.

METHODOLOGY

Several aspects, such as water production in the desalination plant as well as hydraulic and energy boundary conditions, must be considered to estimate desalinated seawater-driven hydropower potential. These boundary conditions are, for example, the hydraulic capacity and discharge system of the supply tunnel. The current Israeli energy policy with the expansion of solar energy should also be considered in the analysis.

Regarding the hydraulic system, two flow systems of gravity flow and pressure pipe are analyzed. In the context of the Water-Energy-SWAP already agreed with Jordan and prospective additional agreements in the future, a range between 200 Mio. m^3 and 1,000 Mio. m^3 per year is being studied as water production and transfer options. Assuming an operational shutdown of 14 days per year, the inflow to the hydropower plant ranges between Q = 6.6 and 33.0 m^3/s for 351 operating days. In order to combine the advantages and disadvantages of different energy sources such as the day-night cycle of solar energy production, a time-delayed electricity generation by the hydropower plant is also analyzed.

The route of the 47 km conveyance tunnel with a slope of J = 0.001 is adopted from the SALAM pilot study (Bensabat et al., 2018). The usable effective energy height heff [m] of the hydropower plant at gravity flow corresponds to the elevation difference between the inlet of the pressure shaft and the water level of the lake. At the pressure pipe, the effective energy head is calculated based on the elevation difference between tunnel entrance at the coast and lake water level, plus energy losses. Because of this conceptual approach, the determination of energy losses is limited to pipe friction losses due to the roughness k [m] along the tunnel length; local losses are neglected. For both hydraulic systems, the integral efficiency coefficient of the hydropower plant is assumed to 0.85.

RESULTS

Between a desalination plant at about 5 m asl and Lake Tiberias at -209 m asl, potential energy is h_{pot} = 214 m. Figure 1 shows the longitudinal cut cross-section of the tunnel with two potential locations for a hydropower plant. While the effective energy height for the gravity flow option is independent of a tunnel diameter, the diameter of the pressure pipe strongly effects the usable energy height due to energy losses. A sensitivity study (Figure 2) shows, that flow velocities and energy losses decrease with increasing diameter. For pressure discharge, high effective energy heads can thus be achieved at low flow velocities and large tunnel diameters.

For the approximation of the produced energy for the pressure pipe, two examples are analyzed with respect to

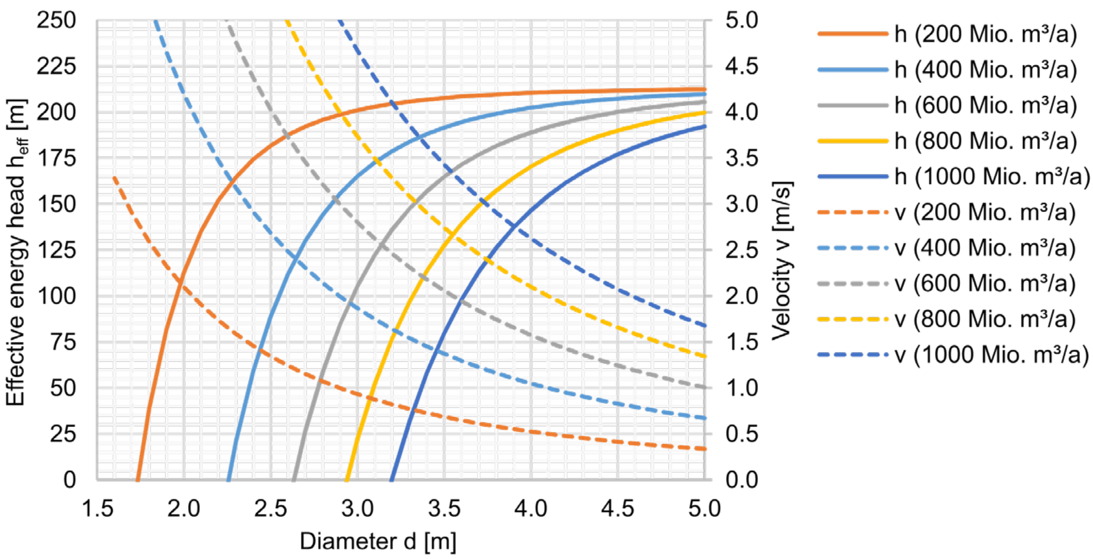

Figure 2: Effective energy head and flow velocity as a function of water production and diameter of the pressure pipe

the diameter. First example with a constant diameter of d = 4.4 m for all water production options and a second with a diameter determined individually for a target flow velocity of v = 2.5 m/s. To avoid disproportionately high energy losses for the water production options of 200 Mio. m^3/a and 400 Mio. m^3/a, a minimum diameter of d_{min} = 3.0 m is maintained.

The resulting power ranges, depending on the discharge system, between 9 MW and 47 MW, while the electricity generated ranges between 78 GWh/a and 400 GWh/a (Figure 3). The hydraulic system of a pressure pipe with constant diameter achieves highest energy output for all water production options. Considering an energy consumption of the desalination plant of about 3 kWh/m^3, the hydropower plant could recover, depending on the hydraulic system and the water production, 11 to 16% of the total electricity demand of the desalination plant. The results thus show that a hydropower plant at Lake Tiberias would be able to produce substantial quantities of electricity.

For a time-delayed energy production, desalinated water is stored during the day, while alternative energy sources such as solar power are used by the consumer. The reservoir required for temporary storage of the continuously flowing water should be located as close as possible to the pressure shaft. During the night, the hydropower plant would use the incoming and stored water to produce electricity. For the examples of 12 h/d and 15 h/d turbine operation, the resulting power is calculated between 15 and 95 MW (Figure 4).

An intermittent operation would thus lead to an increase in power of the hydropower plant for the same magnitude of electricity produced, with the consequence of increased investment and operating costs. However, synergies created by partially compensating the disadvantage of intermittent solar energy production could justify increased costs.

CONCLUSIONS

The above analysis shows that the elevation difference between the seawater desalination plant on the

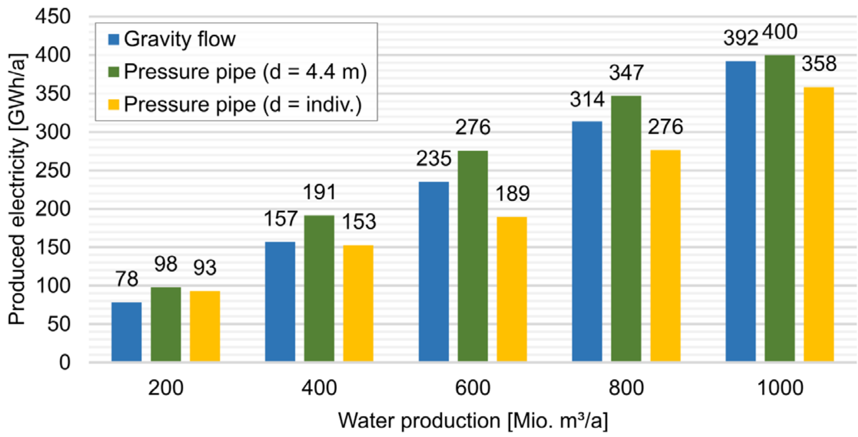

Figure 3: Comparison of produced electricity from gravity flow and pressure pipe for different water productions

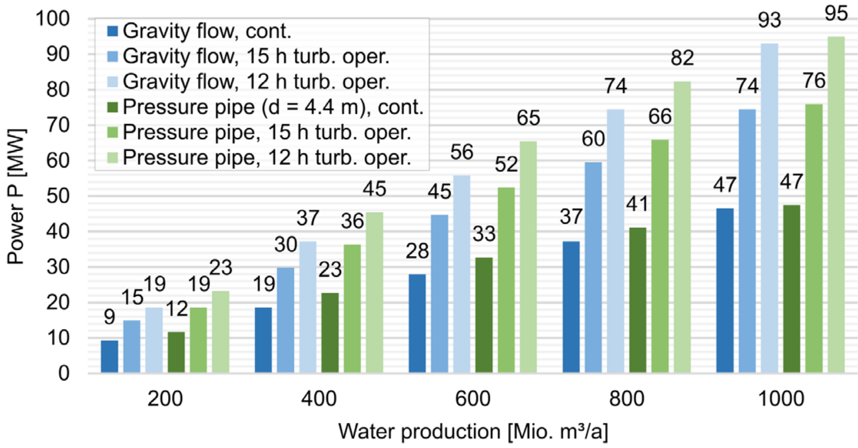

Figure 4: Comparison of generated power from gravity flow and pressure pipe for different water productions in continuous and intermittent turbine operation

Mediterranean coast and Lake Tiberias can be used to generate significant amounts of electricity. The relevance of the conducted analysis is emphasized by the agreement between Israel and Jordan related to the exchange of water and energy. Therefore, different capacities of desalination plants were investigated for hydropower generation. The resulting power ranges between 9 MW and 47 MW, depending on the water production and the hydraulic system of the supply tunnel. The magnitude of electricity produced ranges between 78 GWh/a and 400 GWh/a. A hydropower plant at Lake Tiberias could thus recover between 11 and 16% of the amount of electricity required by the desalination plant. A tunnel to supply the lake has to be constructed for storage purposes independent of the option of hydropower production, so, in economic terms, only investment cost of the power plant itself would have to be considered.

An additional storage option for intermittent operation of the hydropower plant could also achieve synergistic interactions with other energy sources such as solar energy. This would contribute to increasing grid stability and be in line with current Israeli energy policy.

HYDRAULIC CALCULATIONS

For the gravity flow option, a tunnel diameter was selected for a maximum water depth of 80% of the diameter, intended to prevent the pipe from hydraulic blocking. For the largest desalinated sea water production option of 1,000 million m^3, the resulting diameter is d = 4.4 m. This diameter was assumed for all water production options, since the profile then has no influence on the effective energy head.

Unlike the gravity flow, the diameter and the associated flow velocity are included in the calculation of energy losses for the pressure pipe. The individual defined diameters for a flow velocity of 2.5 m/s at production options 200 – 1,000 Mio. m^3/a are d = 3.0 m (d_{min}), d = 3.0 m (d_{min}), d = 3.2 m, d = 3.7 m, and d = 4.1 m. For the pressure pipe option with constant diameter for all water production options, the diameter of d = 4.4 m is determined according to the diameter of the gravity flow.

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References

Ashwarya, S. (2022). Israel's renewable energy strategy: A review of its stated goals, current status, and future prospects. Perceptions: Journal of International Affairs (26), 321–340.

Bensabat, J., Tamimi, A., Salman, A., Al-Karablieh, E., Rusteberg, B., Salameh, E., Walter, F., Guttman, J., Subah, A., Samhan, S., Lange, T., & Sauter, M. (2018). Sustainable management of available water resources with innovative technologies: Management of highly variable water resources in semi-arid regions. Subproject SALAM in SMART-MOVE, Deliverable No. 4.