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# Green Hydrogen Production at Rosires Hydropower Plant

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## 1- Abstract

According to Sudan's significant hydropower infrastructure, this approach uses untapped energy resources for Green Hydrogen Production**.** The approach not only investigates the feasibility of utilizing surplus energy in Rosires Hydropower Plant to produce Green Hydrogen, but also aimed to maximizes the efficiency of existing renewable infrastructure. Rosires Hydropower Plant contribute about 20% of total energy supply to Sudan National Grid, a round 19% of available energy not use so, it will be available for green hydrogen production. The study will support Glob efforts to decrease the emission of Carbon Dioxide Gases and fill the research gap in usage of hydropower to produce green hydrogen. Average annual surplus energy at Rosires Hydropower Plant reach to 384GWH, this is available energy will produce approximately 780 Tons of hydrogen yearly. The Economical Study of Rosires Green Hydrogen Project reflects the huge forecast sales which will be expected around 6 Million USD yearly in minimum scenario.

## 2- Introduction

The escalating challenges of climate change and the increasing urgency for sustainable energy solutions have accelerated the development of green technologies worldwide [1]. The Paris Agreement, aimed at limiting global warming to 1.5 ◦C, underscores the critical need for decarbonization across all sectors, with a particular emphasis on reducing greenhouse gas emissions from energy production [2,3]. Achieving these ambitious goals requires, a shift from fossil fuels to renewable sources, along with scalable energy storage solutions that can support the stability of power grids heavily integrated with renewable energy [1]. Green hydrogen has the potential to replace fossil fuels across all applications. Its adoption is growing in several countries, including Japan, South Korea, the United States, Australia, and various European nations, where hydrogen-powered cars and buses are already in use.

## 3- Objectives

1- Identify the surplus electrical power generated in Rosires Hydropower Plant during off peak.
2- Calculate the surplus energy at Rosires Hydropower Plant from 2026 up to 2030.
3- Calculate the expected Green Hydrogen Production at Rosires Project from surplus energy in the next five years.
4- Reflect the economic impacts of the Rosires Green Hydrogen Project .

## 4- Project Review

The Rosires Dam is a concrete buttress dam on the Blue Nile in Sudan, originally commissioned in 1966 to provide water for irrigation and electricity. Later dam heightening finished in 2013 to increase its reservoir capacity from 3 to 7 Millard cubic meter. The dam contains 7 spillway and 5 deep sluices gates used for flood discharge. Also the dam contains 2 irrigation canals under progress with 8 gates. Rosires Power plant commissioned during 1971 to 1989. 7 units install capacity 280 MW by 40 MW for each unit. For 2 irrigation canals the plan recommended to install generating units with capacity 38 MW for each intake at Dindir Canal and 45 MW at Kenana Canal respectively.

The hydropower plant generates 2,000 GWH of energy annually. This will increase up to 3,000 GWH after uprating of existing units. According to Hydropower Strategic Plan, 2 Power Plant will installed at Kenana and Dindir irrigation canals east and west of the concrete dam and will expected to add 1000 GWH yearly. This study considered the first approach focus on utilizing surplus power at Rosires Hydropower for green hydrogen production. Not all the potential energy in Rosires dam used due to operation strategies and generating units capacities. Green hydrogen production from surplus hydropower at Rosires dam avoids energy losses by discharging water through dam's gates without utilize in power generation.

**5- Research Problem**

Rosires Hydro Power plant not utilized all the potential energy available due to several causes such as fluctuation in daily demand, lack of finance budgeting uprating and upgrading units in addition to install generating units at Kenana and Dindir Canals. Due to these causes much water evacuated through dam gates without utilizing in power generation. This approach search for utilizing available potential energy by maximizing the energy generated efficiently and used the surplus to produce Green Hydrogen.

**6- Research Hypothesis**

The hypothesis underlying this approach is that focusing on surplus electric power generated at existing Rosires plant and utilizes the surplus power to produce green hydrogen according to the proton exchange membrane electrolysis. Estimation of Surplus energy of Rosires Hydropower Plant based on the National Grid Actual Demand and Infrastructure Availability The study consider the current price of Gray Hydrogen as a price of Green Hydrogen forecast Sales.

**7- Methodology**

The methodology based on calculation of the forecast and actual energy generation at Rosires hydropower plant. The derivative data and collective data from the data sheets of Rosires hydro power plant from 1971 to 2025. Statistical analysis and load forecast will use to justify the surplus energy availability and assess its potential for green hydrogen production. Actual current information for hydrogen prices are confirmed to calculate the economic impacts of Hydrogen Production Project.

**8- Technical Study**

Technical study has been carried out to implement the production of green hydrogen in Rosires Dam. According to the globe practices combine hydropower and green hydrogen production is well-suited to utilize surplus energy.

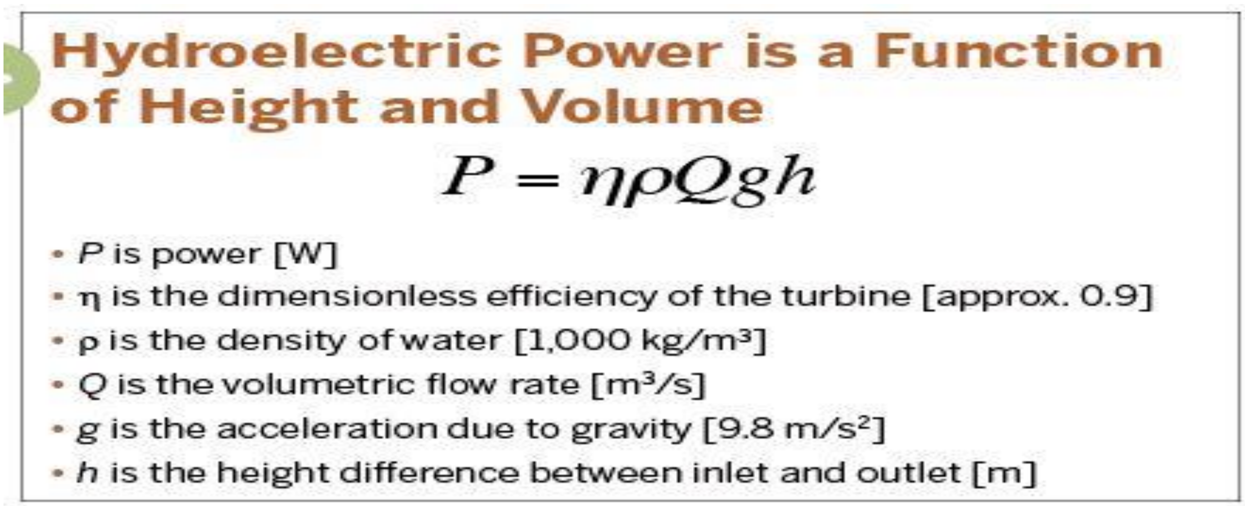
selection the suitable type of the electrolyzer, based on the productivity and efficiency to achieve excellent feasibility of the project. The study highlights the potentiality for integrating green hydrogen in national energy strategies through a cost-effective electrolyzer system.

**(1) Estimation of Surplus Hydroelectric Energy**

Using historical data from 1971 to 2025, a statistical model was applied to estimate future surplus availability through 2030, taking into account the load demand forecasts and availability of water supply for hydroelectric generation. The findings indicate that Rosires surplus hydropower peaked in 2026, the general trend shows a decline due to progress in general security and rehabilitation of Sudan National Grid.

The analysis of surplus energy potential begin with the collection of data from the last 5 stable years except the years of war. To calculate the maximum generation for each unit to reach to the highest generation and calculate the theoretical energy generated according to installed capacity while put into consideration the energy losses ratio's due forced trips and operation and maintenance circumstances. The verification of yearly data on the inflow (Qi), measured in m3/s, and the net energy (Et), in GWH produced by the main hydroelectric plants from 1971 to 2025. The assessment then considers Qi as the volumetric flow rate of water available to power the turbines, which is essential for calculating the maximum theoretical energy.

The next step involves evaluating the vertical distance between the upstream water level in the reservoir and the downstream water level, knows as H (m). For the hydroelectric plant selected through different upstream and downstream water level to generate maximum unit capacity. The respective H values are fluctuated between 27 m to 50 m. The assessment then incorporates constants such as the density of water (1000 kg/m3) and the acceleration due to gravity (9.81 $m/s^2$) . Additionally, average efficiency values for turbines $(\eta)t$ and generators $(\eta)g$ were set at 95% [4]. Finally, the annual theoretical energy was calculated using Equation (1):




Subsequently, the surplus energy (E surplus) was determined as the difference between the available theoretical energy (E teo) and the energy actually generated by the turbines (Et), as shown in Equation (2).

$$E\ surplus = E\ teo - Et \qquad (2)$$

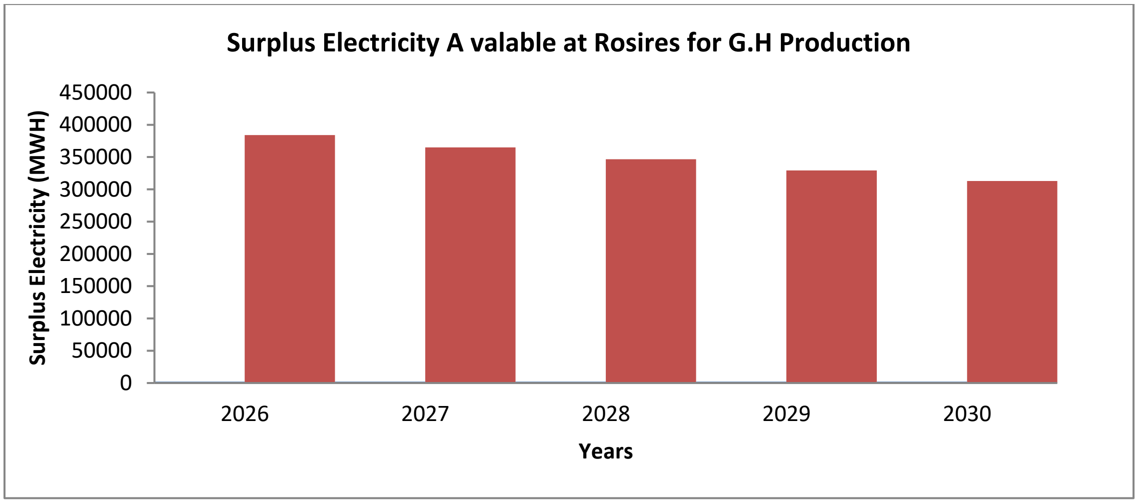
**(1) Annual Energy Production at Rosires**

| Year | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|
| Theo. Energy(MWH) | 2,330,160 | 2,330,160 | 2,330,160 | 2,330,160 | 2,330,160 |
| Min. RCD Energy(MWH) | 1,946,036 | 1,946,036 | 1,946,036 | 1,946,036 | 1,946,036 |
| Max. Act. Energy (MWH) | 2,008,031 | 2,008,031 | 2,008,031 | 2,008,031 | 2,008,031 |

**(2) Annual Rosires Surplus Energy Forecast**

| Year | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|
| Min. Surplus Energy(GWH) | 216,443 | 205,621 | 195,340 | 185,573 | 176,294 |
| Max. Surplus Energy(GWH) | 384,124 | 364,918 | 346,671 | 329,337 | 312,872 |

**Max. Surplus Energy = Max. Energy - Min Energy**




### (2) Estimation Forecast for Green Hydrogen Production

The potential for green hydrogen production from surplus energy can be determined using three key methods:

- Proton Exchange Membrane (PEM) electrolysis.
- Alkaline Electrolysis.
- Solid Oxide Electrolysis (SOEC).

Each of these technologies has distinct efficiency levels and energy consumption rates, which directly influence the amount of hydrogen that can be generated from a fixed amount of surplus energy.

Table(1) Energy consumption of methods for green hydrogen production.

**Table 1.** Energy consumption of methods for green hydrogen production.

| Methods | Energy Consumption [1] (GWh/ton) |
|---|---|
| Proton exchange membrane (PEM) electrolysis | 0.0500–0.055 |
| Alkaline electrolysis | 0.0550–0.060 |
| Solid Oxide Electrolysis (SOEC) | 0.0400–0.050 |

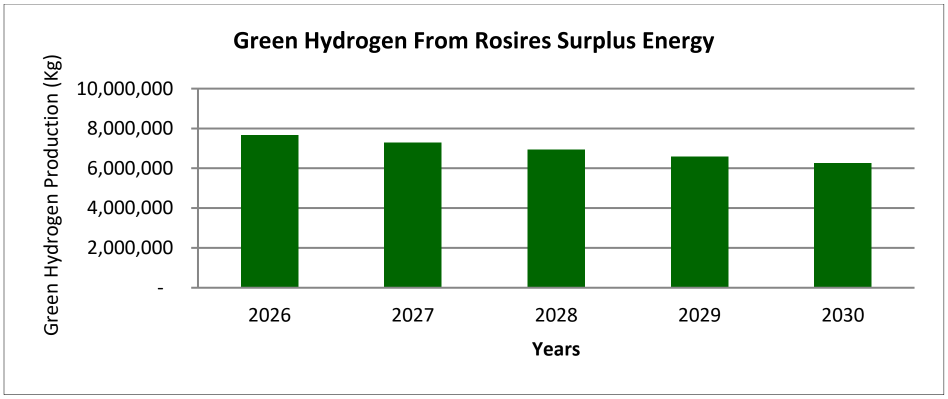
[1] References: [23,62,63].

### (2) Annual Green Hydrogen Production Forecast

| Year | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|
| Max. Green Hydrogen(Kg) | 7,682,484 | 7,298,360 | 6,933,442 | 6,586,770 | 6,257,431 |
| Min. Green Hydrogen(Kg) | 4,328,860 | 4,112,417 | 3,906,796 | 3,711,456 | 3,525,884 |

❖ 50 KWH Generate 1 Kg of Green Hydrogen

- = (Surplus Energy /0.05)




**(3) Electrolysis Process**

The electrolysis process is the core technology to split water ($H_2O$) into hydrogen ($H_2$) and oxygen ($O_2$) using (DC) current. Pure water is fed into the electrolyzer system and direct current is connected to the water using two electrodes. Water Splitting Reaction at the anode, water molecules are split to release oxygen gas ($O_2$) and protons ($H^+$). The protons travel through a membrane (in PEM electrolyzers) to the cathode. At the cathode, the protons combine with electrons to form hydrogen gas ($H_2$). The separated hydrogen and oxygen gases are collected at their respective outlets.

$$2H_2O \rightarrow 2H_2 (g) + O_2 (g)$$

Among the technological options for green hydrogen production, proton exchange membrane (PEM) electrolysis, alkaline electrolysis, and Solid Oxide Electrolysis (SOEC) stand out. PEM technology is particularly attractive due to its high hydrogen purity (99.99%) and efficiency, although it requires a significant initial investment [8].

In comparison, alkaline electrolysis and pyrolysis are viable alternatives but offer lower purity and efficiency levels, making them less profitable in the Sudan's context, given the country's limited industrial infrastructure for hydrogen production [5,9].

**(4) Calorific Value of Green Hydrogen**

Green hydrogen stands out for its exceptional energy efficiency. One unit of green hydrogen produces energy equivalent to three units from other sources, making it one of the most efficient energy carriers available today.

**Heating Value of different types of fuels:**

Hydrogen = 120 MJ/kg
Gasoline = 44 MJ/kg
Diesel = 43 MJ/kg
Coal = 24 MJ/kg
Natural Gas = 50 MJ/kg

Hydrogen has the highest energy per kilogram of all fuels. However, it has very low energy density by volume, making storage and transport challenging. Fossil fuels, despite lower energy per kg, are easier to store and transport.

**(3) Economic Impacts**

**1- Economical Factors of Green Hydrogen Production:**

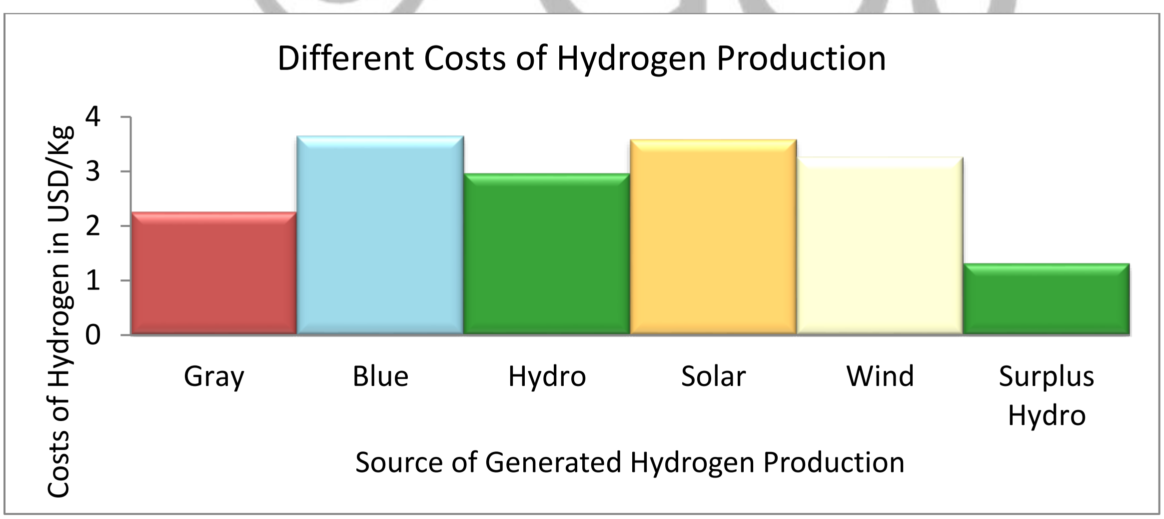
Economical study of green hydrogen production aim to evaluate the effect of each economic factors to the feasibility of the overall project. This part discuss the effect of each factor:

1- Confirm the average cost of  hydrogen productions.
2- Calculate the energy sources used for hydrogen production.
3- Processes Costs.
4- Infrastructure Costs.
5- Operation and Maintenance Costs.
6- Forecasting sales.

**2- Each Hydrogen Types Costs:**

Estimation costs to generate one kilogram of hydrogen considering the energy cost, water treatment cost, O&M cost, process cost

| Hydrogen Type | | Electricity Cost USD/Kg | Water Treatment USD/Kg | O/M Costs USD/Kg | Process Costs USD/Kg | Total Costs USD/Kg |
|---|---|---|---|---|---|---|
| Gray | | 0 | 0.1 | 0.65 | 1.5 | 2.25 |
| Blue | | 0 | 0.1 | 1.15 | 2.4 | 3.65 |
| Green | Hydro | 1.65 | 0.01 | 0.05 | 1.25 | 2.96 |
| | Solar | 2.2 | 0.1 | 0.03 | 1.25 | 3.58 |
| | Wind | 1.87 | 0.1 | 0.04 | 1.25 | 3.26 |
| | Surplus Hydro | 0 | 0.01 | 0.05 | 1.25 | 1.31 |



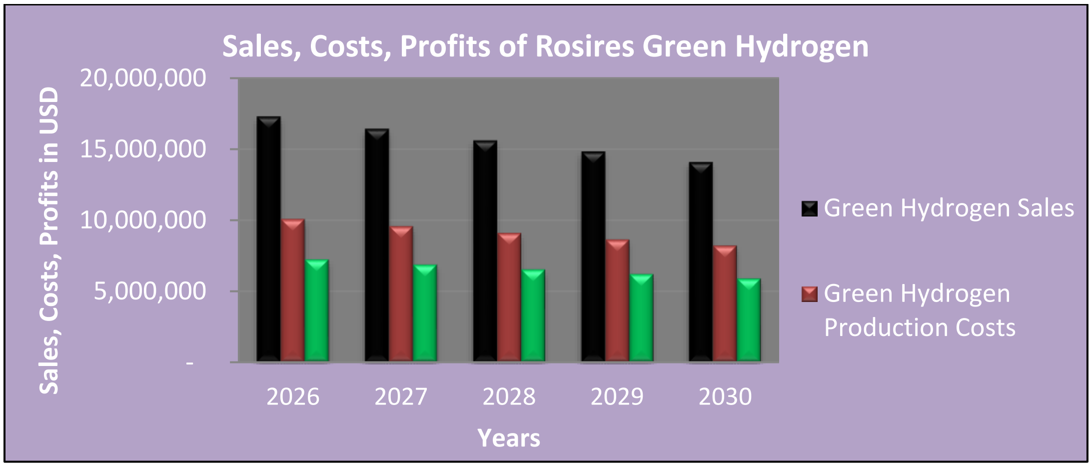

**3- Sales Forecasts:**

The table below explain the total forecast sales for green hydrogen which generated from the surplus power which will be generated at Rosires hydropower plant , in addition the table explained the overall Production Costs and net Profit of the Rosires Green Hydrogen Project.

| **Year** | **2026** | **2027** | **2028** | **2029** | **2030** |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| **Sales Forecast of Rosires Green Hydrogen Produce (MUSD )** | **17.29** | **16.42** | **15.60** | **14.82** | **14.08** |
| **Total Production Costs (MUSD)** | **10.06** | **9.56** | **9.08** | **8.63** | **8.20** |
| **Net Profit of R.GH Project (MUSD)** | **7.22** | **6.86** | **6.52** | **6.19** | **5.88** |

- 1 Kg of Green Hydrogen = 2.25 USD (According to Gray Hydrogen Production Costs).






**Project 4- Evaluation Of**

Base on the study describes the total installed costs of a GW green hydrogen plant according to European Union [10]:

3100 €/(kg/day) for Alkaline technology.
4400 €/(kg/day) for PEM technology.

Accordingly, Rosires Green Hydrogen Project the study used PEM technology to install electrolysis by 22 Million Euro to produced 780 tons of hydrogen per year.

The calculations indicate positive indicators for the project feasibility:

Net Present Value (NPV) = 14 Million Euro.
Internal Rate of Return (IRR) = 25% .

**9- Results**

According the potential of hydrogen production from Rosires Hydropower Plant we expect Sudan thus has promising potential to become a green hydrogen producer, enhancing both regional energy security and carbon reduction goals when used other potential in other hydropower plants.

This study explored the feasibility of producing green hydrogen using surplus energy from Rosires Hydropower Plant. By integrating water electrolysis with renewable electricity sourced from hydropower, the research quantified both the hydrogen production capacity and the potential economic return from hydrogen sales.

Based on the plant's average annual surplus energy of 384GWH, the system was estimated to produce approximately 780 Tons of hydrogen per year through electrolysis. This translates into a potential annual revenue of 22 Million USD, assuming a market price of 2.25 USD per kg of green hydrogen.

## 10- Discussions

These results demonstrate that Rosires Hydropower Plant has significant potential not only to contribute to the green hydrogen economy but also to generate additional income, thereby improving the overall sustainability and profitability of the facility.

While the findings are promising, the study assumes consistent surplus power availability and market demand for green hydrogen, which may vary in real-world scenarios. Additionally, capital costs, maintenance, and storage considerations must be further analyzed for full-scale implementation.

Future research should focus on optimizing electrolyzer efficiency, incorporating seasonal variations in hydropower output, and exploring partnerships with industries that could act as off-takers for the produced hydrogen.

## 11- Conclusion

This study explored the feasibility of producing green hydrogen using excess energy from Rosie's Hydropower Plant. By integrating water electrolysis with renewable electricity sourced from hydropower, the research quantified both the hydrogen production capacity and the potential economic return from hydrogen sales.

Based on the plant's average annual surplus power of 384 GWH, the system was estimated to produce approximately 780 Tons of hydrogen per year through electrolysis. This translates into a potential annual revenue of 22 Million USD, assuming a market price 2.25 USD per kg of green.



## 12- Recommendations

1- Add the facility of Green Hydrogen to Hydropower plant infrastructure to utilize each surplus energy generated.

2- Motivates the investment to use the green hydrogen produced to produce green Ammonia and Fertilizers.

3- Encourage the investments in Green hydrogen for existing and planned Hydropower projects.

4- Support the Scientific Approach in the field of renewable and green technology.

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