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MINARET II
Empowering Municipal Governance for Climate Resilience Using WEF Nexus Approach

nexus

EMPOWERING THE COMMUNITY: A SUSTAINABLE AND RELIABLE ELECTRIC POWER SOLUTION FOR CHOUF DISTRICT

A TECHNO-ECONOMIC STUDY FOR A HYDROELECTRIC POWER PLANT AT SAFA - DAMOUR RIVER

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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PREFACE

The techno-economic study of Safa-Damour river hydroelectric power plant aims to provide a comprehensive analysis of the feasibility and potential of a renewable energy source. The study is based on a detailed analysis of the hydro power plant site, the surrounding energy landscape, and the regulatory and economic factors that influence the development of renewable energy sources.

The motivation behind this study is the need for sustainable and reliable sources of energy as Lebanon faces significant challenges in meeting its energy needs, with limited domestic energy resources and a high dependence on imported fossil fuels. The lack of reliable and affordable electricity has had a negative impact on the country's economic and social development, with businesses and households struggling to meet their energy needs.

The study is based on a rigorous methodology that combines data collection, modelling techniques, and economic analysis. The study team consulted with experts in the field and used best practices to ensure the reliability and accuracy of the results.

We would like to acknowledge the contribution of the funding agency and the support provided by local partners who provided data and information. We also extend our thanks to the experts who provided valuable insights and feedback throughout the study.

The findings of this study are significant and provide valuable insights for policy-makers, industry leaders, and researchers. The study highlights the potential for hydro power plants to contribute to the renewable energy mix and identifies the key economic and regulatory factors that influence their development.

We hope that this study will contribute to the ongoing efforts to promote renewable energy sources and inform decision-making in Lebanon energy sector. We welcome feedback and comments from readers and look forward to the continued development of renewable energy sources as a key element of a sustainable and reliable energy system.

INTRODUCTION

Water resources, especially rivers, have long played a crucial role in the development of human civilization. Today, as we grapple with the challenges of climate change, the transition to renewable energy sources has become more critical than ever. Hydropower, which harnesses the power of flowing water, is one of the most promising solutions to meet our growing energy needs sustainably. In this context, the Safa-Damour River at Chouf District - Lebanon, a vital watercourse in Lebanon, offers significant potential for hydropower generation. This techno-economic study aims to explore the feasibility, benefits, and challenges of developing hydropower projects along the river.

The primary objective of this study is to provide a comprehensive understanding of the hydropower potential along Safa-Damour River by examining the technical aspects, economic viability, and environmental implications of potential projects. We aspire to offer a balanced analysis that takes into account the diverse perspectives of various stakeholders, including governments, private entities, local communities, and environmental advocates.

The first section of this study provides an overview of the climate, resources, and infrastructure of Chouf district. This includes an analysis of the climate patterns, natural resources such as water and land, and the existing infrastructure in the area. The analysis is based on a review of available data and literature related to the district.

The second section of this study focuses on the technical aspects of the proposed hydroelectric power plant. It presents the results of site investigation, potential analysis, the design parameters of the hydro turbine, and the electricity generation outcomes. Additionally, this section discusses the power distribution plan and the technical feasibility conducted for the project.

In the third section, we assess the economic aspects of the project. This includes capital and operational costs, market dynamics, investment opportunities, and financing mechanisms. The role of government policies and international cooperation in promoting the development of the hydropower sector in Lebanon is also discussed, emphasizing the need for a supportive environment to drive renewable energy initiatives.

As we embark on this journey to uncover the hydropower potential of Safa - Damour River, we hope that our findings and insights will serve as a valuable resource for decision-makers, academics, and professionals alike. The challenges we face in achieving a sustainable future are vast, but with a collective effort and a clear understanding of the opportunities and limitations of our renewable energy options, we can steer Lebanon and the world towards a cleaner, more resilient, and prosperous tomorrow.

The findings of this study underscore the significant potential of hydropower generation along the River and highlight the importance of adopting a sustainable, collaborative approach to harness this renewable energy source. By providing valuable insights and recommendations, this study aims to contribute to Lebanon's transition towards a cleaner, more resilient, and prosperous energy future.

CHOUF – CLIMATE, RESOURCES AND INFRASTRUCTURE

GEOGRAPHICAL LOCATION

Chouf is a district in the Mount Lebanon Governorate of Lebanon. It is located to the south-east of the capital city Beirut and encompasses a large area of the southern part of the Mount Lebanon range.

Chouf's geographic location can be defined by its latitude and longitude coordinates, with its center located at approximately 33.63° N latitude and 35.58° E longitude.

Figure 1: Chouf Geographical Location

CLIMATE CHARACTERISTICS

The weather data available is for "Beit ed Dine area," which is being used to represent the weather patterns of Chouf district.

In Beit ed Dine, the summers are long, warm, arid, and clear and the winters are cold, wet, and partly cloudy. Over the course of the year, the temperature typically varies from 4°C to 27°C and is rarely below 1°C or above 30°C.

The warm season lasts for 4.0 months, from June 7 to October 6, with an average daily high temperature above 24°C. The hottest month of the year in Beit ed Dine is August, with an average high of 27°C and low of 19°C.

The cold season lasts for 3.3 months, from December 6 to March 15, with an average daily high temperature below 14°C. The coldest month of the year in Beit ed Dine is January, with an average low of 5°C and high of 11°C.

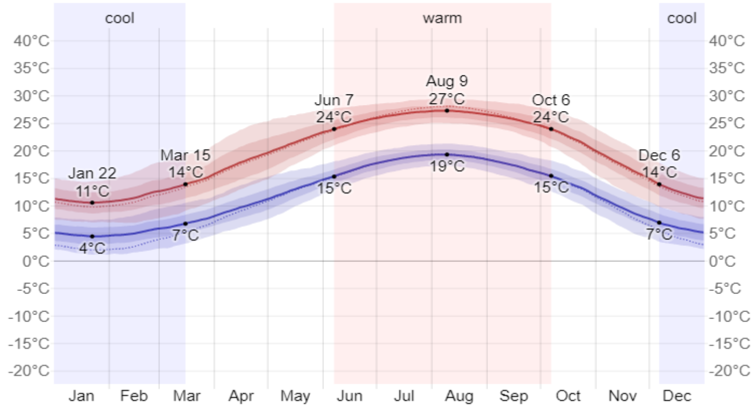


Figure 2: Temperature chart

<u>PRECIPITATION</u>

A wet day is one with at least 1.00 millimeters of liquid or liquid-equivalent precipitation. The chance of wet days in Beit ed Dine varies significantly throughout the year.

The wetter season lasts 5.0 months, from October 29 to March 29, with a greater than 15% chance of a given day being a wet day. The month with the most wet days in Beit ed Dine is January, with an average of 8.9 days with at least 1.00 millimeters of precipitation.

The drier season lasts 7.0 months, from March 29 to October 29. The month with the fewest wet days in Beit ed Dine is July, with an average of 0.0 days with at least 1.00 millimeters of precipitation.

According to the available data, the month with the highest number of days experiencing rain alone in Beit ed Dine is January, with an average of 8.7 days. The predominant form of precipitation throughout the year in this area is rain alone, with the highest probability of occurrence being 30% on January 17. It should be noted that precipitation patterns can vary annually, and while these statistics apply specifically to Beit ed Dine, they can provide a general understanding of the typical precipitation in Chouf district of Lebanon.

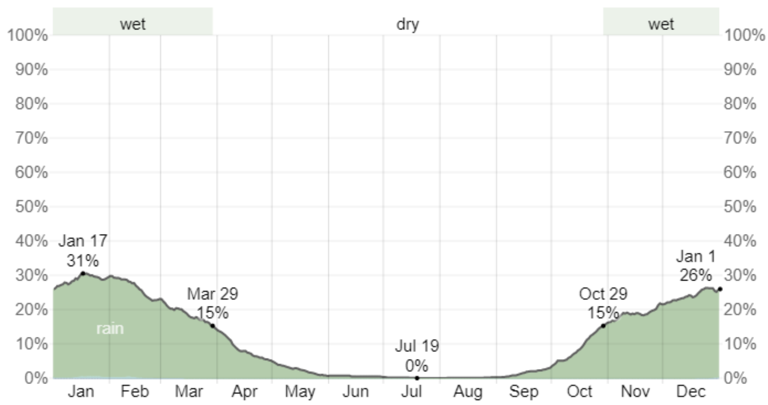


Figure 3: Daily chance of precipitation

RAINFALL

Beit ed Dine experiences significant seasonal variation in rainy months The rainy period of the year lasts for 6.3 months, from October 11 to April 20, with a sliding 31-day rainfall of at least 13 millimeters. The month with the most rain in Beit ed Dine is January, with an average rainfall of 73 millimeters.

The rainless period of the year lasts for 5.7 months, from April 20 to October 11. The month with the least rain in Beit ed Dine is August, with an average rainfall of 0 millimeters.

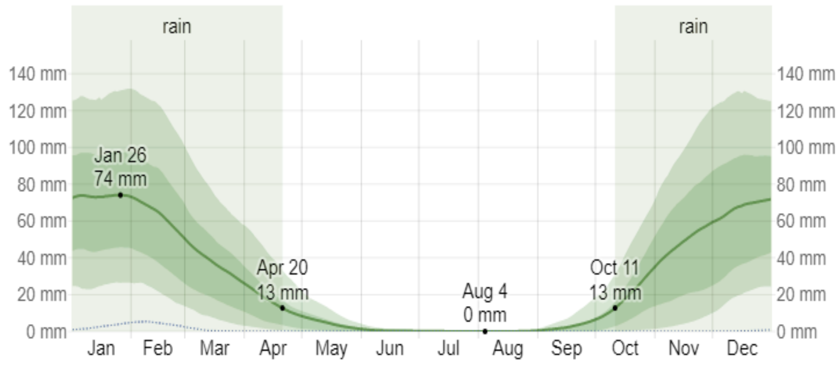


Figure 4: Average monthly rainfall

HUMIDITY

The humidity comfort level is based on the dew point, as it determines whether perspiration will evaporate from the skin, thereby cooling the body. Lower dew points feel drier and higher dew points feel more humid. Unlike temperature, which typically varies significantly between night and day, dew point tends to change more slowly, so while the temperature may drop at night, a muggy day is typically followed by a muggy night.

Beit ed Dine experiences significant seasonal variation in the perceived humidity. The muggier period of the year lasts for 2.6 months, from July 2 to September 19, during which time the comfort level is muggy, oppressive, or miserable at least 10% of the time. The month with the muggiest days in Beit ed Dine is August, with 11.7 days that are muggy or worse.

The least muggy day of the year is March 5, when muggy conditions are essentially unheard of.

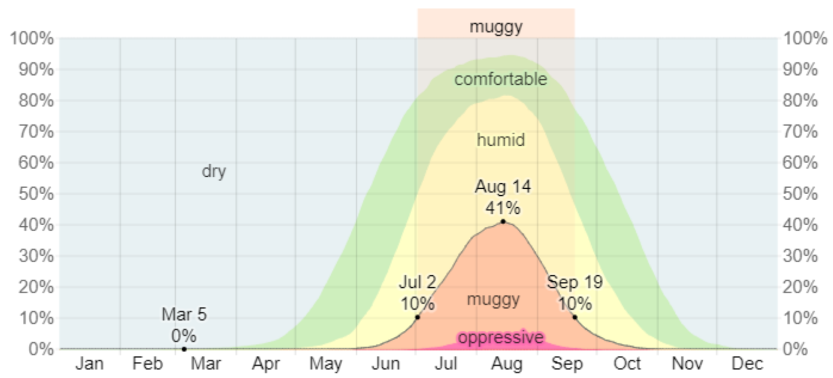


Figure 5: Humidity Comfort Levels

WIND

The wind experienced at any given location is highly dependent on local topography and other factors, and instantaneous wind speed and direction vary more widely than hourly averages.

The average hourly wind speed in Beit ed Dine experiences mild seasonal variation over the course of the year. The windier part of the year lasts for 3.7 months, from December 13 to April 3, with average wind speeds of more than 3.3 meters per second. The windiest month of the year in Beït ed Dîne is February, with an average hourly wind speed of 3.8 meters per second.

The calmer time of year lasts for 8.3 months, from April 3 to December 13. The calmest month of the year in Beit ed Dine is October, with an average hourly wind speed of 2.9 meters per second.

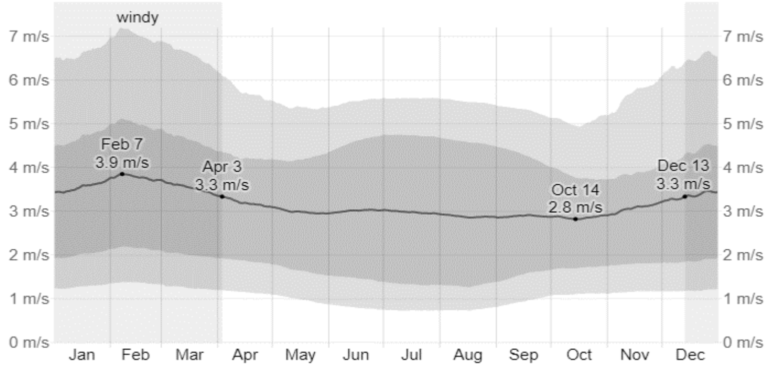


Figure 6: Average wind speed

WATER TEMPERATURE

The time of year with warmer water lasts for 3.3 months, from July 2 to October 11, with an average temperature above 26°C. The month of the year in Beit ed Dine with the warmest water is August, with an average temperature of 28°C.

The time of year with cooler water lasts for 4.0 months, from December 29 to April 30, with an average temperature below 19°C. The month of the year in Beit ed Dine with the coolest water is March, with an average temperature of 17°C.

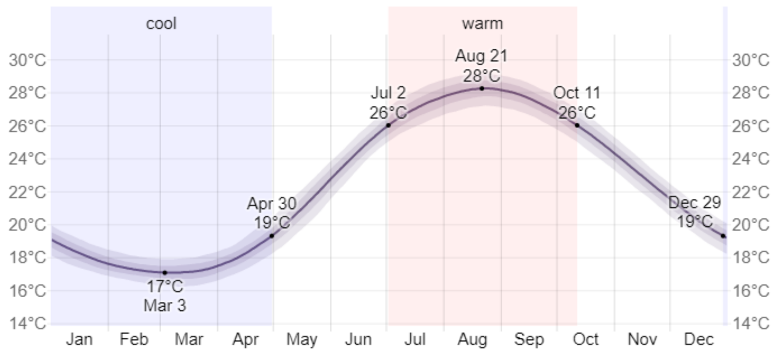


Figure 7: Average Water Temperature

SOLAR ENERGY

The average daily incident shortwave solar energy experiences extreme seasonal variation over the course of the year. The brighter period of the year lasts for 3.5 months, from May 8 to August 26, with an average daily incident shortwave energy per square meter above 7.5 kWh. The brightest month of the year in Beit ed Dine is June, with an average of 8.6 kWh.

The darker period of the year lasts for 3.4 months, from November 5 to February 17, with an average daily incident shortwave energy per square meter below 3.8 kWh. The darkest month of the year in Beit ed Dine is December, with an average of 2.7 kWh.

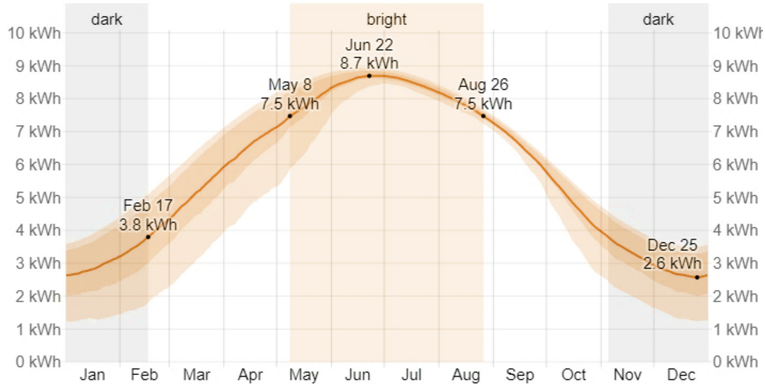


Figure 8: Average Solar Energy

ELECTRICITY SECTOR INFRASTRUCTURE

Lebanon has been facing severe power supply problems for several years now. The country's electricity grid is outdated and inefficient, leading to regular power outages and rationing of electricity to different regions. The situation has been exacerbated by the economic crisis, political instability, and a lack of investment in the power sector.

The country's power supply is mostly generated from thermal power plants, which are expensive to operate and rely on imported fuel. Lebanon also has hydroelectric power plants, but they generate only a small fraction of the country's electricity needs.

The power supply problems in Lebanon and accordingly in Chouf district have had a significant impact on daily life, with residents experiencing frequent blackouts and having to rely on private generators/ solar photovoltaic systems to meet their energy needs. Many people in the district, especially those living in poverty, have found it difficult to afford the high cost of running generators and maintaining solar systems. This has resulted in limited access to basic necessities such as lighting, refrigeration, and heating, making life more challenging, particularly during extreme weather conditions. The situation has also disrupted economic activities and impacted the education sector, as many schools are unable to provide a consistent power supply for students and staff. The power supply issues in Chouf district highlight the urgent need for sustainable and affordable energy solutions that can improve the quality of life for residents and promote social and economic development in the area.

SAFA - DAMOUR RIVER HYDROELECTRIC POWER PLANT / TECHNICAL ASPECTS

Hydropower plants, also known as hydroelectric power plants, are facilities that generate electricity by harnessing the power of falling or flowing water. They use the kinetic energy of water to generate electricity through a process called hydroelectricity.

Hydropower plants typically consist of several key components:

1. **Dam:** A dam is a barrier constructed across a river or a reservoir, which helps to store water and create a height difference or "head" of water. The height of the head determines the potential energy of the water and the amount of electricity that can be generated.
2. **Reservoir:** A reservoir is a large artificial lake, which serves as a storage facility for water. It helps regulate the flow of water, ensuring a steady supply of water to the power plant and allowing for control over the electricity generation.
3. **Intake Structure:** An intake structure is a system that allows water to flow from the reservoir into the power plant. It typically includes gates or screens to prevent debris from entering the plant, and channels or tunnels to direct water to the turbines.
4. **Penstock:** A large pipe or conduit that carries water from the intake of a hydro power plant to the turbines.
5. **Turbines:** Turbines are large machines that are driven by the force of flowing water. They convert the kinetic energy of water into mechanical energy by rotating a shaft.
6. **Generators:** Generators are connected to the turbines and convert the mechanical energy from the rotating shaft into electrical energy, which can be used to power homes, businesses, and industries.
7. **Power Distribution Lines:** Distribution lines are used to transport the electricity generated by the hydropower plant to consumers through the grid.

Hydropower plants are considered a renewable energy source, as they rely on the natural water cycle and do not produce greenhouse gas emissions during electricity generation. They can provide a reliable and sustainable source of electricity, with the potential for large-scale power generation. However, the construction of reservoirs for hydropower plants can have environmental and social impacts, such as altering ecosystems, displacing communities, and affecting water quality and fish habitats. Proper planning, management, and environmental mitigation measures are important in the development and operation of hydropower plants to minimize these impacts.

HYDRO POWER POTENTIAL IN SAFA-DAMOUR RIVER

The Safa-Damour River is a river in Lebanon that flows from the slopes of Mount Lebanon through the towns of Safa and Damour before emptying into the Mediterranean Sea. The river passes through Chouf district and known for its potential for hydroelectric power generation

Water flow is a crucial factor that requires careful consideration while evaluating the hydropower potential of a site. The quantity of water that flows through a river or stream directly determines the energy that can be harnessed for power generation. The flow rate, water level, and velocity of water are all pivotal factors that play a critical role in determining the potential energy that can be utilized for power generation.

A high flow rate and velocity of the water are desirable for hydropower generation since they indicate a greater potential for energy production. However, it is also important to consider the variability of the flow over time. Fluctuations in flow can impact the power output of a hydroelectric power plant, so it is essential to assess the potential impact of these fluctuations on the plant's operation.

The team assigned to has collected the data related to the flow rates of the river, as follows:

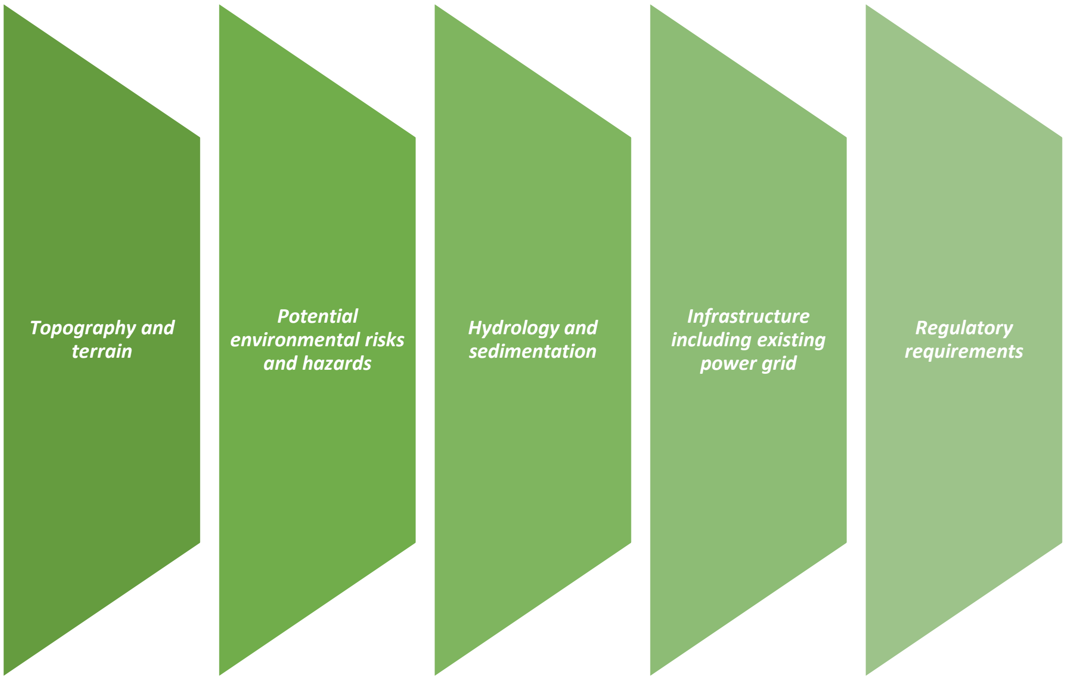
Table 1: Damour River Flow Rates

DAMOUR RIVER - FLOW POINT OF MEASUREMENT: JISR ALQADI		
YEAR	*MEAN FLOW*	
2015-2016	2.978	*m^3/SEC*
2016-2017	3.125	*m^3/SEC*
2017-2018	1.952	*m^3/SEC*
2018-2019	5.088	*m^3/SEC*
2019-2020	4.803	*m^3/SEC*
SIX YEARS SPAN AVERAGE	3.589	*m^3/SEC*

The river flow values were found to be within the range necessary for successful hydropower generation. This indicates that the river has a good potential for the construction of a hydropower plant. This suggests that the river can support the construction of a hydropower plant that is capable of generating significant amounts of electricity. With this potential, the construction of a hydropower plant in the area can be considered a viable option for sustainable energy generation.

SITE SUITABILITY

It is essential to conduct a thorough assessment before constructing a hydroelectric power plant. This ensures that the site is suitable for power generation and that the project is environmentally sustainable and compliant with regulatory requirements. Therefore, the team assigned has conducted a comprehensive assessment for Safa - Damour river site evaluating the following factors:



The site assessment conducted has found that the river is suitable for hydropower generation. Specifically, the terrain and topography of the site are favorable for power generation, with steep terrain, elevation changes, and fast-moving water. These factors indicate that the site has a high potential for energy production. Additionally, the hydrology of the river is suitable for hydropower, with sufficient water flow, velocity, and depth to support power generation. Based on these findings, the river is a promising location for the construction of a hydropower plant.

Following the assessment conducted, the team assigned has prepared indicative sketches for the proposed hydropower plant. The sketches are based on the findings from the site assessment and take into account the topography, terrain, and hydrology of the site. The sketches provide a preliminary concept for the layout and design of the plant, including the location of the reservoir, turbine, powerhouse, and spillways.

These sketches serve as a starting point for further design work and engineering analysis, which will refine the details of the proposed hydropower plant. The team will continue to work closely with stakeholders and regulatory agencies to ensure that the design is in compliance with all relevant regulations and environmental considerations. Overall, the indicative sketches are an important milestone in the project's progress towards the eventual construction of a hydropower plant at the river site.

It is worth noting that the proposed Safa-Damour hydro power plant is designed as a run-of-river plant, which means that a dam will not be included in its construction. Instead, water from the river will be diverted into a reservoir and directed through turbines to generate electricity. This design is intended to minimize the environmental impact of the project by allowing the river to flow freely and avoiding the need for a large dam that could affect the ecosystem and local communities. The run-of-river design also has the potential to provide a more consistent and reliable source of renewable energy compared to traditional hydropower plants that rely on seasonal water storage in large reservoirs.

Figure 9: General Sketch for the proposed hydropower plant

Figure 10: Top View

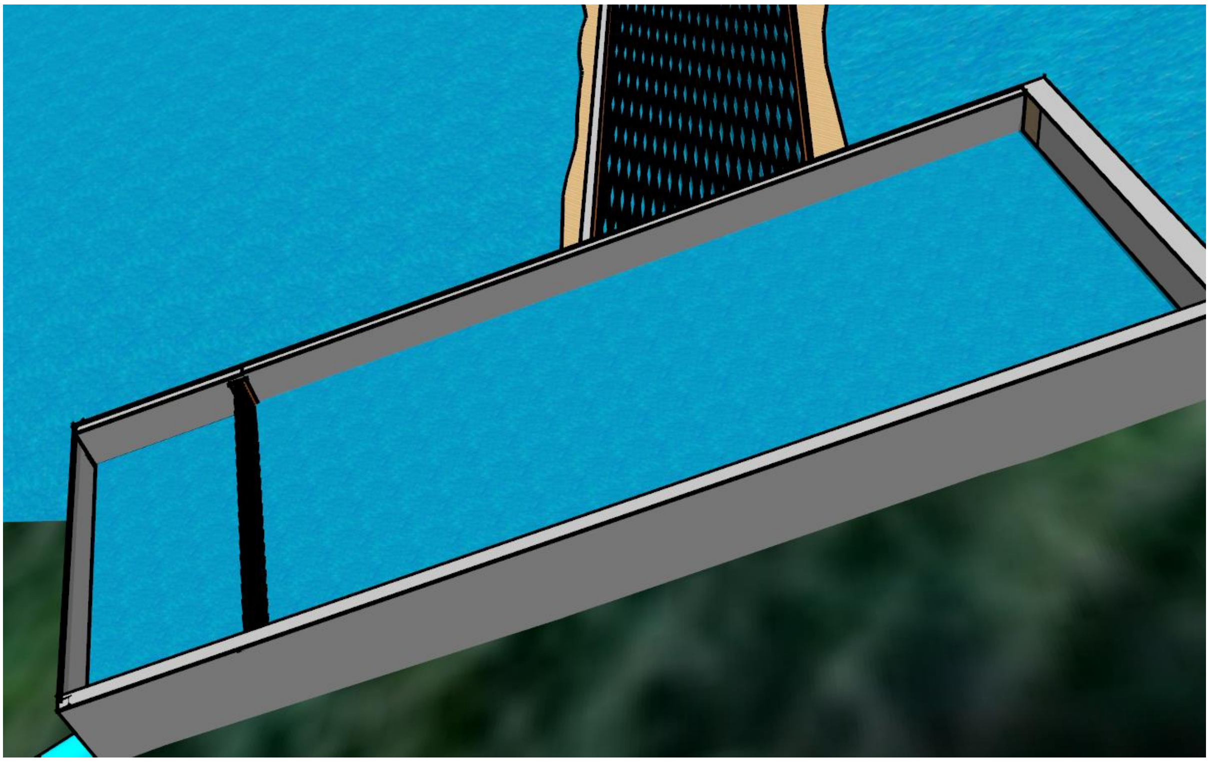


Figure 11: 2-stage reservoir (To be constructed at 33°42'22.1"N 35°31'14.3"E)

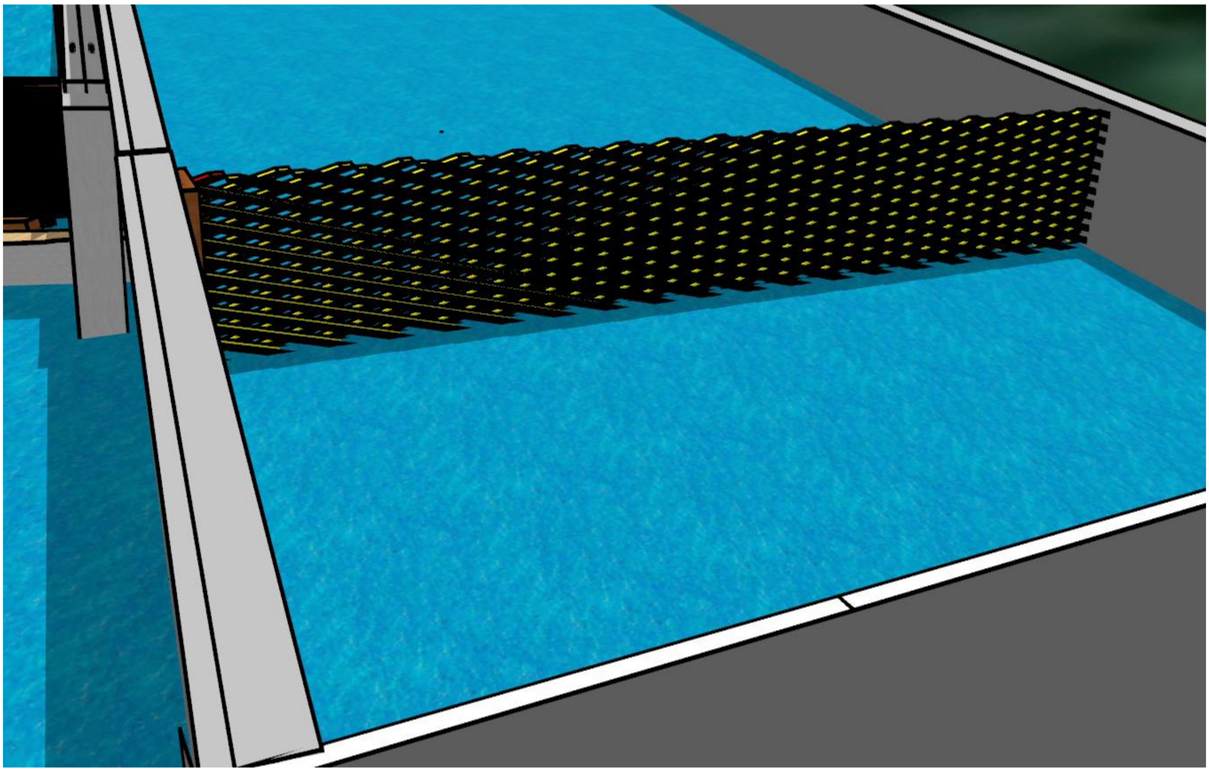


Figure 12: Reservoir Filtration System

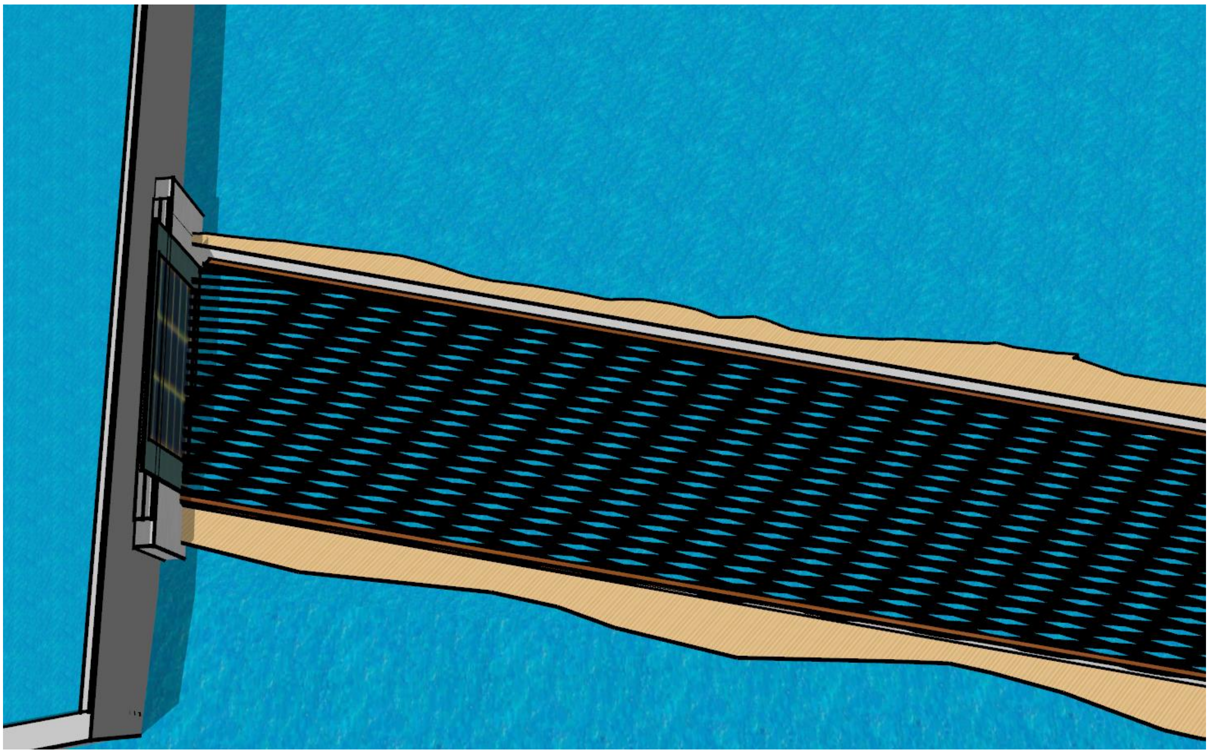


Figure 13: Ditch

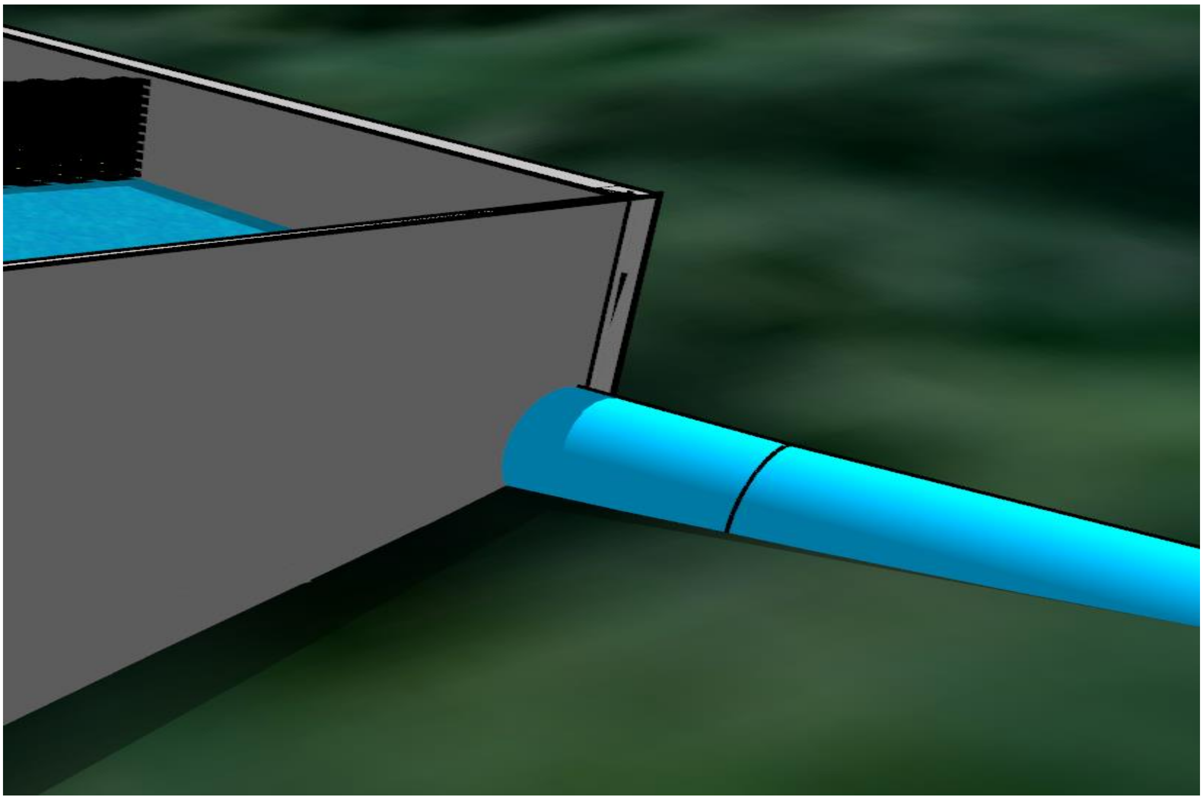


Figure 14: Penstock

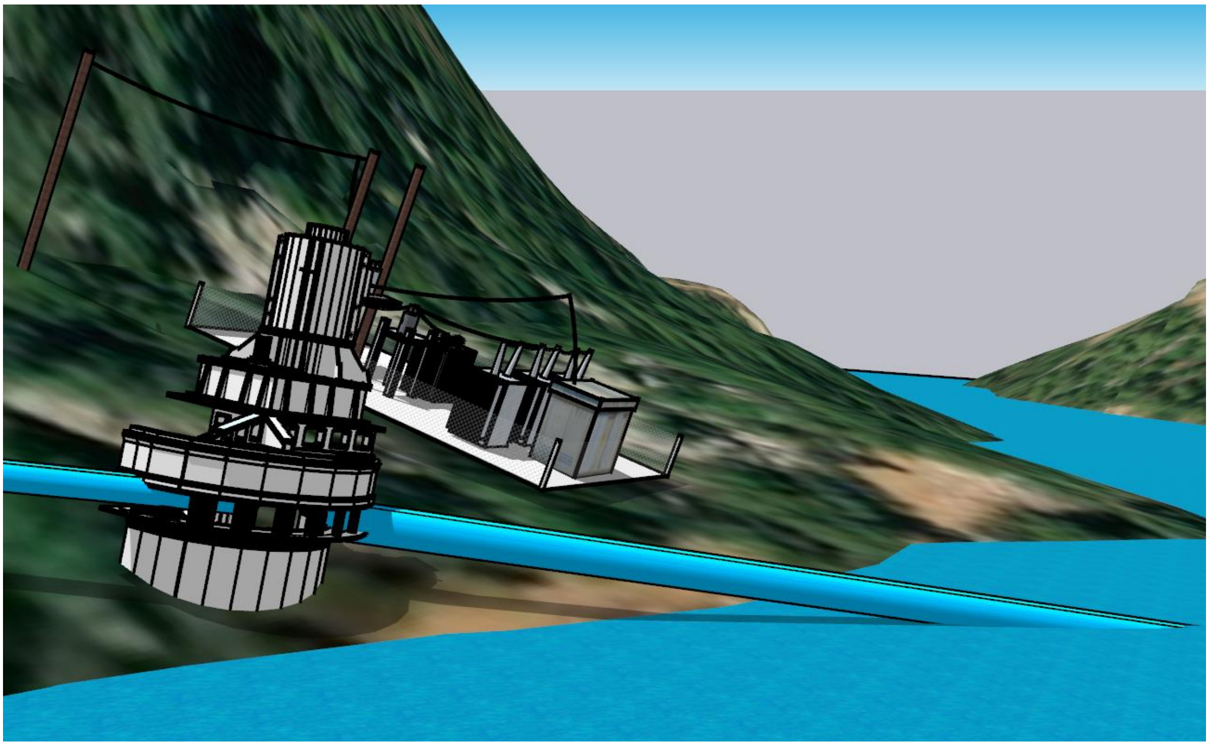


Figure 15: Hydro Turbine and Generator (to be installed at 33°42'22.0"N 35°31'00"E)

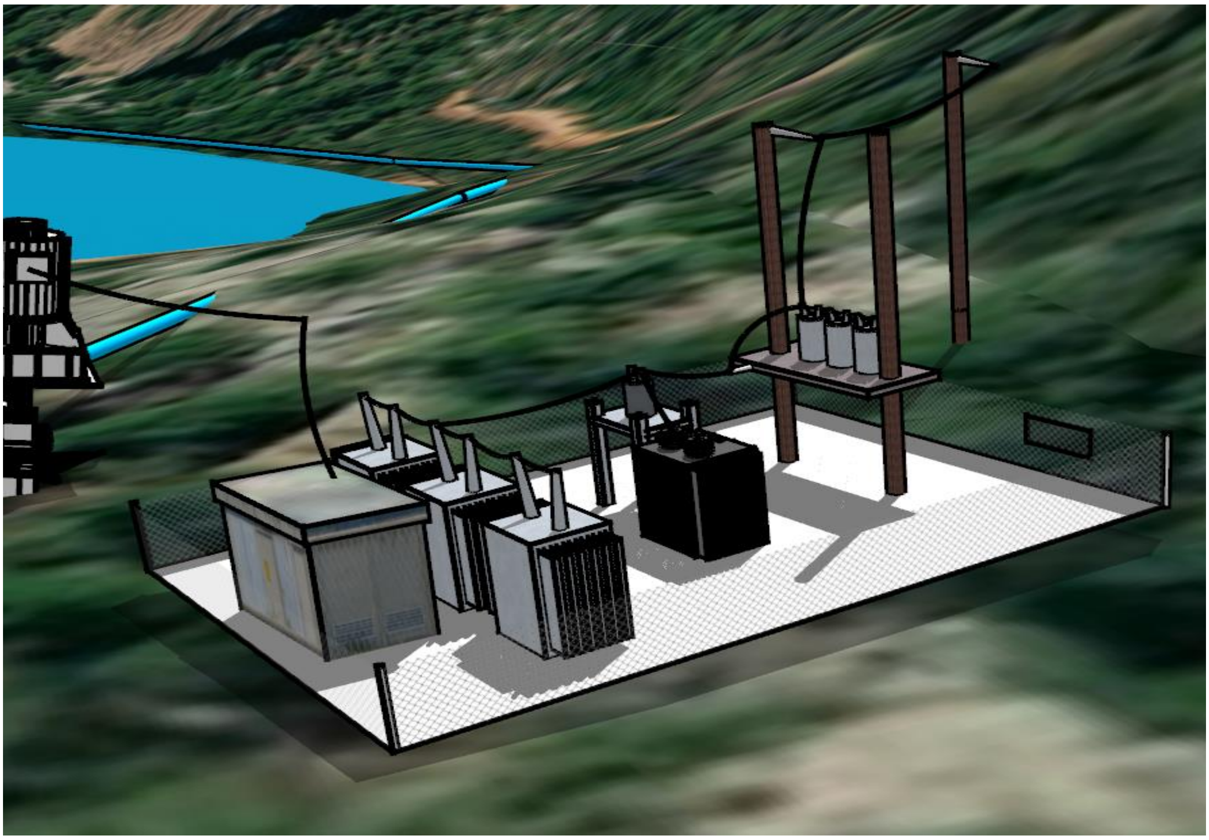


Figure 16: Transformer and Substation

HYDRO-TURBINE DESIGN

Hydro turbine design is a critical aspect of the design of a hydropower plant. It directly affects the plant's efficiency and power output. The design parameters of a hydro turbine include the type of turbine, rated capacity, head and flow rate, and efficiency. A careful analysis of these parameters is essential to optimize the hydro turbine's design and maximize the power output of the plant.

During the course of the hydro turbine design analysis, the team thoroughly evaluated the interdependence of the critical design parameters. The results of the study revealed that the type of turbine, rated capacity, head and flow rate, and efficiency are all closely interrelated and have a substantial impact on the overall efficiency and power output of the hydro power plant. To assess the suitability of different turbine types, including Pelton, Francis, and Kaplan turbines, the team considered the specific site conditions. Following a comprehensive analysis, it was determined that the Francis turbine was the optimal choice for the site, given the available head and flow rate of water.

The full hydro turbine design analysis that was conducted yielded several important outcomes including exact turbine rated capacity, turbine diameter, input speed, propeller angles and overall performance grade. The following table provides a comprehensive overview of the hydro turbine design parameters and outcomes:

Table 2: Turbine Design

VERTICAL HYDRO TURBINE DESIGN						
A/A	DATA			RESULTS		
1	Flow	*V* (m^3/SEC)	1.79	Cordier Number	*σ*	1.395
2	Head	*H (m)*	22.00	Cordier Number	*δ*	0.784
3	RPM	*n (rps)*	27.83	Diameter	*D2 (m)*	0.260
4	DENSITY	*ρ* (Kgr/m^3)	1,000.00	Diameter	*D1 (m)*	0.099
5				Turbine Height	*h (m)*	0.224
6				Channel Width	*bo (m)*	0.103
7				Channel Width	*b1 (m)*	0.113
8				Channel Width	*b2 (m)*	0.206
9				Circular Speed	*u1 (m/sec)*	8.680
10				Circular Speed	*u2 (m/sec)*	22.731
11				Absolute Velocity	*c1m (m/sec)*	84.576
12				Absolute Velocity	*c2m (m/sec)*	18.763
13				Absolute Velocity	*c1u (m/sec)*	24.865
14				Propeller Angles	*β1 (grad)*	-79.207
15				Propeller Angles	*β2 (grad)*	39.557
16				Input Speed	*ca (m/sec)*	20.776
17				Supply Factor	*μ*	11.155
18				Suction Diameter	*Da (m)*	0.099
19				Torsion Coefficient	*v*	0.418
20				Specific Speed Number	*ny*	0.662
21				Number Of Wings	*z*	9.799
22				Overall Performance Grade	*η*	0.720
23				Power	*N (Watt)*	278,816.538
24				High Energy	*Ψ* (m^2/sec^2)	215.820
25				Specific Number Of Revolutions	*nq*	220.224
26				Medium Diameter	*D2m (m)*	0.185

The designed capacity of the turbine (279 kW) is sufficient to power a village of 320-350 houses. The ability of the hydro turbine to provide sufficient electricity to power a village with such number of houses is a positive outcome of the hydro turbine design analysis. It demonstrates the potential for the hydropower project to make a significant impact on the local community by providing reliable, sustainable, and affordable energy.

Furthermore, during the turbine design process, it was decided that only 50% of the river flow would be used for the hydro turbine design. This decision was made due to the fact that the river flow rate in the summer months is significantly lower than during other times of the year. By utilizing only 50% of the river flow rate, it was ensured that the system could operate effectively even during the dry season

The hydro turbine was designed to be highly efficient to ensure maximum performance even at lower flow rates. In addition, the turbine was designed to be adjustable, allowing it to adapt to changes in the river flow rate and maintain optimal performance.

POWER GENERATION AND TRANSMISSION

One of the key benefits of hydro power generation is its ability to provide a consistent and reliable source of energy. Unlike solar or wind power, which can be affected by weather conditions, hydro power plants can generate electricity continuously as long as there is a sufficient flow of water.

In addition to being a clean and renewable source of energy, hydro power generation also has minimal negative impact on the environment. While the construction of a hydro power plant can have some impact on the surrounding area, the operation of the plant itself does not emit greenhouse gases or other harmful pollutants.

The following table illustrates the amount of electricity generated from the proposed hydro power plant and the number of houses that can be powered (as a demonstration of the plant's powering capacity), considering different operational scenarios:

Table 3: Power Generation

SAFA - DAMOUR RIVER HYDROELECTRIC PLANT POWER GENERATION								
OPERATION SCENARIO	*DESIGN CAPACITY (KW)*	*WORKING HOURS PER ANNUM*	*OVERALL PERFORMANCE GRADE*	*GENERATED ELECTRICITY PER ANNUM (KWH)*	*TRANSPORTATION LOSSES PER ANNUM (KWH)*	*NET GENERATED ELECTRICITY PER ANNUM (KWH)*	*GENERATED ELECTRICITY PER DAY (KWH)*	*NO. OF HOUSEHOLDS POWERED*
SCENARIO ONE (0 MAINT. SHUTDOWN)	279	8,760	0.720	1,758,351	50,727	1,707,624	4,678	334
SCENARIO TWO (1 MAINT. SHUTDOWN)	279	8,592	0.720	1,724,630	50,727	1,673,902	4,586	328
SCENARIO THREE (2 MAINT. SHUTDOWNS)	279	8,424	0.720	1,690,908	50,727	1,640,181	4,494	321

The proposed hydropower plant will play a significant role in providing sustainable and reliable electricity to the surrounding community. All the electricity generated by the plant will be transmitted to the utility grid and will be credited to the local community "deploying the wheeling scheme". This will enable the community to benefit from the full generation capacity of the plant and support them in meeting their energy needs, without the need to consume all the energy on-site.

The wheeling scheme is a valuable tool in facilitating the distribution of electricity from renewable energy sources to local communities. By allowing for the easy transmission of energy to the grid and the crediting of local communities, the scheme can support the adoption of sustainable energy solutions and help to build a more resilient and sustainable future for all.

The implementation of the wheeling scheme will have several advantages for the local community. First, it will provide a reliable and sustainable source of electricity to meet the energy needs of the community. Second, it will help to reduce the cost of electricity and create opportunities for economic growth and development. Third, it will reduce the community's reliance on fossil fuel-based power generation, thereby reducing their carbon footprint and contributing to the fight against climate change.

It is worth noting that the wheeling scheme is not yet legislated in Lebanon, although this is set to change in the near future. The Lebanon Electricity Company has advised that the framework for the wheeling scheme is expected to be finalized by this year. This is a positive development, as it will provide a legal and regulatory framework for the implementation of the wheeling scheme in the country. Once the scheme is legislated, it will become an important tool for promoting the development of renewable energy sources, such as hydropower, and for enabling local communities to benefit from these sources. The implementation of the wheeling scheme will also help to reduce transmission losses and increase the efficiency of the electricity grid, which will ultimately benefit all electricity consumers in Lebanon.

SAFA - DAMOUR RIVER HYDROELECTRIC POWER PLANT / ECONOMIC ASPECTS

The economic aspects of a hydroelectric power plant are crucial for determining its feasibility and viability as an investment. Some of the key economic considerations for a hydroelectric power plant include:

- **Capital costs:** These are the costs associated with building the power plant, including the cost of constructing the reservoir, installing the turbines, and building any necessary infrastructure such as transmission lines. These costs can be substantial and are a major factor in determining the overall economic feasibility of the project.
- **Operating costs:** These are the ongoing costs associated with running the power plant, including maintenance, repairs, labor…etc. Operating costs will vary depending on the size and complexity of the plant, as well as local labor and material costs.
- **Electricity prices:** The price of electricity can have a major impact on the economic viability of a hydroelectric power plant. In general, higher electricity prices will make the plant more profitable, while lower prices may make it difficult to recoup the initial investment.
- **Depreciation:** Refers to the decrease in the value of an asset over time due to wear and tear, obsolescence, and other factors. For a hydroelectric power plant, the main assets that may depreciate over time are the turbines, generators, and other equipment used in the generation of electricity.
- **Financing:** The cost and availability of financing are also important economic considerations for a hydroelectric power plant. Financing costs can add significantly to the overall cost of the project, and securing financing may be more difficult for projects in certain regions or with certain characteristics.
- **Environmental and social costs:** Hydroelectric power plants can have significant environmental and social costs, such as the displacement of communities or impacts on local ecosystems. These costs may not be immediately apparent but can have a significant impact on the long-term economic viability of the project.

A detailed feasibility study and financial model was conducted for the proposed hydroelectric power plant. The study included an assessment of the economic feasibility of the project and aimed to determine whether the project was financially viable and could generate a return on investment for the stakeholders involved. The study also analyzed the financial risks associated with the project, such as fluctuations in the price of electricity, unexpected construction costs, and changes in interest rates, to ensure that the project's financial viability was thoroughly evaluated.

The financial model was based on a 100% equity scheme and considered various inputs, including the capital cost of the project, the operating costs, and current electricity prices in Lebanon. The model was used to estimate the project's cash flows, net present value, and internal rate of return. Sensitivity analysis was also performed to identify the key factors that could impact the project's financial performance.

Table 4: Financial Model Inputs

FINANCIAL MODEL INPUTS - 279 KW HYDROELECTRIC POWER PLANT FULL EQUITY FINANCING SCHEME		
SIZING		
System size	279	kW
INVESTMENT		
System Cost/kW	5,739	$
Design, Engineering, Bidding and Supervision	242,000	$
Hydropower Plant (Installed)	865,000	$
Grid Connection Including Transmission Lines	233,000	$
Electrical Substation Including Transformers	160,000	$
Contingency / Lands Compensation / Others	100,000	$
Total Investment	1,600,000	$
TOTAL INVESTMENT		$ 1,600,000.00
Debt/Loan	0.0%	-
Equity	100%	$ 1,600,000.00
ENERGY		
Annual Energy Generation	1,690,908	kWh
Electrical bill	-	$
Average Tariff	0.30	$/kWh
Fuel price difference	-	$/kWh
Lifetime	30	years
Energy generation first year/kW	6,065	kWh
System degradation/year	0.0%	-
Annual growth rate in tariff	0.0%	-
Annual Grid Service Fees	0.0%	
OPERATION AND MAINTENANCE (OPEX)		
O&M (Including cleaning, spare parts and insurance)	6.0%	Ratio from system cost
Escalation in O&M	1.0%	
COST OF MONEY		
Equity		**Weight**
Inflation (Country of Financing: Europe)	6.0%	11.00%
Bank Rate	2.5%	
Risk Premia	2.5%	
Loan		
Annual Reducing Interest Rate	0.0%	0.00%
Discount Rate Capital	0.0%	11.00%
Loan Period	-	
Payments per Year	-	
DEPRECIATION AND LAND RENT		
Electromechanical (EM) components for depreciation	90.0%	Ratio from system cost
Depreciation using declining method	5.0%	-
Land rent	-	$/year/Dunam

After conducting the financial model for the hydro power plant, the estimated annual operational expenditure (OPEX) for the plant for 30-year period and the savings that can be achieved by the plant over the same period were observed. The following table illustrates the financial model outcomes:

Table 5: Financial Model Outcomes

YEAR	ENERGY			INITIAL REVENUE	OPEX	DEPRECIATION		ULTIMATE OPEX	NET REVENUE	FINANCIAL FLOW	
Year	***Energy Yield*** *kWh*	***Transportation Losses*** *kWh*	***Annual Net Energy*** *kWh*	***Initial Revenue*** *Real-time Value $*	***O&M*** *Real-time Value $*	***EM Components Value Subject for Depreciation*** *Real-time Value $*	***Depreciation Loss Amount*** *Real-time Value $*	***Ultimate O&M Including Insurance and Depr. Amount*** *Real-time Value $*	***Net Revenue*** *Real-time Value $*	***Profit for Owner*** *Real-time Value $*	***Profit for Owner*** *Present Value $*
Construction Period	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
1	1,690,908	50,727	1,640,181	492,054	0	859,500	42,975	42,975	449,079	492,054	443,292
2	1,690,908	50,727	1,640,181	492,054	0	816,525	40,826	40,826	451,228	492,054	399,362
3	1,690,908	50,727	1,640,181	492,054	0	775,699	38,785	38,785	453,269	492,054	359,786
4	1,690,908	50,727	1,640,181	492,054	59,036	736,914	36,846	95,882	396,172	433,018	285,242
5	1,690,908	50,727	1,640,181	492,054	59,627	700,068	35,003	94,630	397,424	432,428	256,625
6	1,690,908	50,727	1,640,181	492,054	60,223	665,065	33,253	93,476	398,578	431,831	230,875
7	1,690,908	50,727	1,640,181	492,054	60,825	631,811	31,591	92,416	399,639	431,229	207,705
8	1,690,908	50,727	1,640,181	492,054	61,433	600,221	30,011	91,444	400,610	430,621	186,858
9	1,690,908	50,727	1,640,181	492,054	62,048	570,210	28,510	90,558	401,496	430,007	168,100
10	1,690,908	50,727	1,640,181	492,054	62,668	541,699	27,085	89,753	402,301	429,386	151,223
11	1,690,908	50,727	1,640,181	492,054	63,295	514,614	25,731	89,026	403,029	428,759	136,038
12	1,690,908	50,727	1,640,181	492,054	63,928	488,884	24,444	88,372	403,682	428,126	122,376
13	1,690,908	50,727	1,640,181	492,054	64,567	464,439	23,222	87,789	404,265	427,487	110,084
14	1,690,908	50,727	1,640,181	492,054	65,213	441,218	22,061	87,274	404,781	426,841	99,025
15	1,690,908	50,727	1,640,181	492,054	65,865	419,157	20,958	86,823	405,231	426,189	89,075
16	1,690,908	50,727	1,640,181	492,054	66,524	398,199	19,910	86,433	405,621	425,531	80,124
17	1,690,908	50,727	1,640,181	492,054	67,189	378,289	18,914	86,103	405,951	424,865	72,071
18	1,690,908	50,727	1,640,181	492,054	67,861	359,374	17,969	85,829	406,225	424,194	64,826
19	1,690,908	50,727	1,640,181	492,054	68,539	341,406	17,070	85,610	406,445	423,515	58,309
20	1,690,908	50,727	1,640,181	492,054	69,225	324,335	16,217	85,441	406,613	422,830	52,445
21	1,690,908	50,727	1,640,181	492,054	69,917	308,119	15,406	85,323	406,731	422,137	47,171
22	1,690,908	50,727	1,640,181	492,054	70,616	292,713	14,636	85,252	406,803	421,438	42,426
23	1,690,908	50,727	1,640,181	492,054	71,322	278,077	13,904	85,226	406,828	420,732	38,157
24	1,690,908	50,727	1,640,181	492,054	72,035	264,173	13,209	85,244	406,810	420,019	34,318
25	1,690,908	50,727	1,640,181	492,054	72,756	250,965	12,548	85,304	406,750	419,298	30,864
26	1,690,908	50,727	1,640,181	492,054	73,483	238,416	11,921	85,404	406,650	418,571	27,757
27	1,690,908	50,727	1,640,181	492,054	74,218	226,496	11,325	85,543	406,511	417,836	24,962
28	1,690,908	50,727	1,640,181	492,054	74,960	215,171	10,759	85,719	406,335	417,094	22,449
29	1,690,908	50,727	1,640,181	492,054	75,710	204,412	10,221	85,931	406,124	416,344	20,188
30	1,690,908	0	1,640,181	492,054	76,467	194,192	9,710	86,177	405,878	415,587	18,154
Total	**50,727,240**	**1,471,090**	**49,205,423**	**14,761,626**	**1,819,550**	**13,500,360**	**675,018**	**2,494,568**	**12,267,058**	**12,942,076**	**3,879,886**

The outcomes of the feasibility study and financial model showed that the hydroelectric power plant was financially viable and had the potential to generate a significant return on investment for the stakeholders. The model indicates a positive net present value (NPV) of $3,879,886 which indicates that the project will generate a revenue more than the initial investment. The internal rate of return (IRR) is 13%, which is higher than the discount rate capital, indicating that the project is financially feasible. The payback period is 4.4 years, which means that the initial investment will be paid back in less than 5 years.

The economic feasibility of the project was further supported by the fact that the cost of electricity generated by the hydroelectric power plant was competitive compared to other sources of electricity in the region. Additionally, the project had the potential to generate additional economic benefits, such as employment opportunities and increased economic activity in the surrounding area.

Table 6: NPV, IRR and Payback period

NPV	**$3,879,886**
Payback Period	**4.44 years**
IRR (Project)	**13.0%**

The chart below illustrates the projected profits of the hydro power plant over a period of 30 years. As can be seen, the hydro power plant is expected to be profitable over the long term, providing a reliable source of income for investors and contributing to the development of sustainable energy sources in the region.

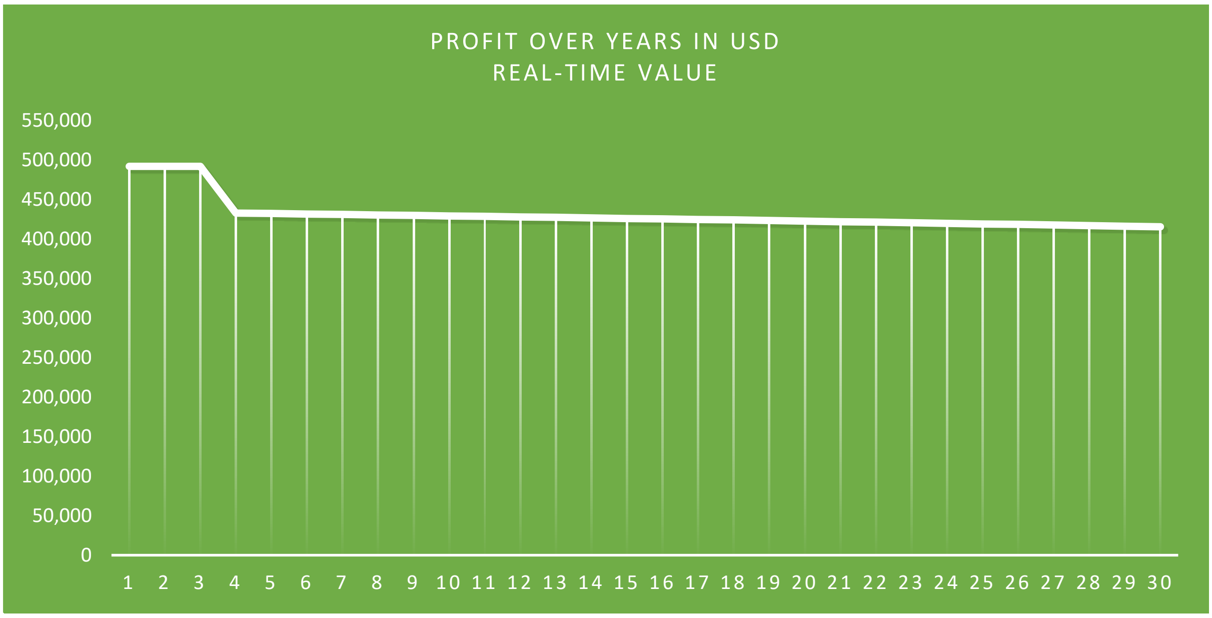


Figure 17: Projected Profits (Real-Time Values)

Overall, the feasibility study and financial model provided a comprehensive evaluation of the economic aspects of the hydroelectric power plant project, demonstrating that it was a financially viable and economically attractive investment opportunity.

CONCLUSIONS

After conducting the detailed techno-economic study for Safa-Damour hydropower plant, it can be concluded that the site has significant potential for power generation. The analysis of river flow rates and water head suggests that a suitable capacity of turbine can be installed, which can generate electricity for surrounding areas. Moreover, the financial model of the project showed promising results, indicating that the project is financially viable. The analysis of the project showed that it can generate significant profits for the investors, with a positive net present value, internal rate of return, and attractive payback period.

Furthermore, the analysis of the surrounding area showed that the site is highly suitable for the construction of a hydropower plant, due to the availability of suitable land and nearby infrastructure. The proposed project site is located at latitude 33°42'22.1"N and longitude 35°31'14.3"E to 33°42'22.0"N and longitude 35°31'00"E which is an ideal location for hydropower generation due to its significant water flow rates. Moreover, the site is located in an area with high demand for electricity, which makes the project highly feasible and potentially profitable.

In conclusion, the techno-economic study of the hydropower plant shows that the project has significant potential for power generation and financial profitability. The analysis indicates that the site is highly suitable for the construction of a hydropower plant, with sufficient water flow rates and suitable land availability. The financial model of the project indicates that it can generate significant profits for the investors, making the project a viable and potentially lucrative investment opportunity.

However, despite the significant potential and profitability, the development of hydroelectric power plants in Lebanon may face a number of regulatory risks that could impact their viability and profitability. One such risk is related to permitting and licensing requirements. Hydroelectric power plant developers may require various permits and licenses from government agencies at local, regional, and national levels, and delays or denials in obtaining these permits can significantly delay or even prevent project development. To mitigate this risk, developers must engage with government officials and regulatory agencies to understand specific regulatory requirements and build relationships with key stakeholders.

Another significant regulatory risk that could impact hydropower development in Lebanon is the lack of legislation for the wheeling scheme. The absence of a legal and regulatory framework in place could lead to uncertainties and delays in implementing the wheeling scheme, which could increase the cost of electricity transmission and limit the ability to sell generated energy to the grid. Moreover, the lack of the wheeling scheme could hinder the promotion of renewable energy sources and the ability of local communities to benefit from these sources. Therefore, the delay in legislating the wheeling scheme represents a risk to the successful implementation of hydropower projects in Lebanon.

Furthermore, land use and ownership can be another regulatory risk. Hydroelectric power plant development requires access to land, which can be subject to ownership disputes or conflicting land-use regulations. Developers may need to work with local landowners and government agencies to ensure legal access to the necessary land. Compliance with environmental regulations is also a critical factor, as failure to comply can lead to significant fines and penalties. As such, hydroelectric power plant developers must comply with these regulations to avoid any legal and financial liabilities. Considering these regulatory risks, developers need to carefully assess the legal and regulatory landscape in Lebanon before investing in hydropower projects.

Therefore, while hydroelectric power plant development in Safa-Damour offers significant potential and profitability, developers must carefully consider and manage the regulatory risks associated with the process to ensure the success of their projects.