HYDROPOWER from Non-River Sources The potential in Lebanon

2013

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Country Energy Efficiency and Renewable Energy Demonstration Project for the Recovery of Lebanon

Hydropower from Non-River Sources; The potential in LEBANON

May 2013

LEBANESE REPUBLIC MINISTRY OF ENERGY AND WATER

MINISTERIO DE ASUNTOS EXTERIORES Y DE COOPERACIÓN aecid

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This study has been prepared by Entec for the UNDP-CEDRO Project.The study has been initiated and guided by Mr. Karim Ossairan, Power Generation Advisor to the Ministry of Energy and Water.

Republic of Lebanon
Ministry of Energy and Water
The Minister
May 2013

The challenges of the Lebanese Electricity sector are not limited to meet the Energy demand through the timely increase of the installed generation capacity but also to enhance a diversified mix of energy sources in which the sustainable Renewable Energies play a major role. In line with the 'Policy Paper for the Electricity Sector' approved by the Lebanese Council of Ministers in 2010, the Ministry of Energy and Water is investing all needed efforts to ensure that the 12% of the electricity production in 2020 is based on renewable energy sources.

In this regard, the Ministry of Energy and Water has investigated most types of renewable energy sources available in the country. With the support of the UNDP-CEDRO project, the national wind atlas for Lebanon was published in 2010. The efforts of the CEDRO project were also instrumental in the development of the national bioenergy strategy for Lebanon, as well as the potential for hydro power, solar energy, geothermal power and Waste to Energy from Sludge.

Following the review of the Lebanese rivers Hydro potential of Lebanon by Sogreah-Artelia, another untapped potential of renewable energy in Lebanon has been investigated by UNDP-CEDRO, and that is energy produced from Micro-Hydro on Water Irrigation Channels & Conveyors, Water Distribution Networks, Waste Water Treatment Plants Inlets & Outlets, and Electric Power Plants Outfalls.
This current report has identified 13 promising pilot sites which have been evaluated technically and economically. Their total electrical power potential amounts to an estimated 5 MW. This figure is a clear indication that even outside the river streams, there is a significant Micro-hydro potential that can be harvested.
For this purpose, the current pilot study is a milestone that is inviting all the stake holders in Lebanon to take in the near future further steps for assessing more thoroughly the complete Micro-hydro potential of the public utilities & networks in view of making a significant share of renewable energies a living reality in every establishment.
With the present report, we hereby reconfirm the commitment of the Ministry of Energy and Water to turn every stone & track every path in the search of every useful MW of renewable energy that we can spare in view of partially relieving our environment from the burdens of conventional means of power production.

On behalf of the Ministry of Energy and Water, I would like to thank all those who contributed to the development of the report, hoping that its findings and recommendations will find their way to execution in the very near future.

Gebran Bassil
Minister of Energy and Water

United Nations Development Programme
Beirut, Lebanon
May 2013

In recognition of both the growing calls for global action on climate change and its own intensifying energy challenges, Lebanon has made an ambitious pledge several to meet at least 12% of its energy supply from renewable resources by 2020. UNDP has since been supporting the Ministry of Energy and Water in elaborating a road map to reach this target based on a series of renewable energy assessments.

This report marks on of the several major renewable energy assessment for Lebanon in the two past years that we at the United Nations Development Programme have had the honor to undertake in partnership with the Ministry of Energy and Water. This comes in the context of the Sustainable Energy for All initiative, launched last year by the Secretary-General, which calls upon governments, businesses and civil society to double the share of renewable energy in the global energy mix.

Identifying renewable energy from non-conventional sources in Lebanon is one of the main objectives of the UNDP CEDRO initiative. In this report, the significant potential of an important and largely untapped source of power, hydropower from non-river sources, is explored and confirmed. From the cooling systems of power plants on-shore, to irrigation networks, water networks and wastewater treatment plants, at least 5 MW of additional clean, renewable power has been identified. And this is just tip of the iceberg. With efforts to upgrade information available on water and irrigation networks in Lebanon, the known potential will likely grow even further.

I would like to take this opportunity to thank the Ministry of Energy and Water for their unique vision and commitment in seeking alternative and clean sources of power. We at UNDP look forward to continuing this innovative partnership with the Ministry of Energy and Water for a better future for all Lebanese.

Robert Watkins
UNDP Resident Representative

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ABBREVIATIONS AND ACRONYMS

CDR	Council for Development and Reconstruction
CEDRO	Country energy efficiency and renewable energy demonstration project for the recovery of Lebanon
EDL	Electricité du Liban
E & M	Electro-mechanical
GPS	Global Positioning System
IRR	Internal Rate of Return
kW	Kilowatt Unit of Electric Power
kWh	Kilowatt-hour Unit of Electric Energy
LBP	Lebanese Pound
LEB	Lebanon
MHP	Mini Hydropower
MoEW	Ministry of Energy and Water
UNDP	United Nations Development Programme
USD	US Dollar
WWTP	Wastewater Treatment Plant

APPLIED SYMBOLS

Existing infrastructure	Symbol
Irrigation system	A
Wastewater treatment plant	B
Thermal power plant	C
Drinking water distribution network	D

Exchange Rate: 1,485 LBP = 1 USD (Oct 2012)

EXECUTIVE SUMMARY

The development of renewable and clean energy sources is a priority for the Lebanese Government, a priority also advocated by the United Nations Development Programme (UNDP). Accordingly, the UNDP supports the Lebanese government initiative in achieving 12% of its total energy needs from renewable energy sources by 2020. For this purpose, the UNDP, in collaboration with the Ministry of Energy and Water (MEW), has commissioned the assessment of the hydropower potential within different non-river water systems, namely: Irrigation systems, drinking water systems, electrical power plant outfall pipes and wastewater treatment plants.

On behalf of the UNDP, the contracted Consultant, Entec AG, carried out an inception visit to 20 sites across Lebanon. To identify the most promising sites and to meet the study's objective, an initial site evaluation has been conducted. As a result, 7 sites have been found not to qualify for further action: these sites either have only minor potential (within the range of pico-hydro) or they are technically not feasible. The remaining 13 sites selected for further action have been evaluated from a technical and economic perspective. Their total electrical power potential amounts to an estimated 5 MW. As presented in Figure 1, more than 50% of this identified hydropower potential was found in currently established thermal power plants. Besides having a high energy potential, they require a relatively low investment and thus have short payback periods. They can be implemented in the course of potential rehabilitations of these power plants. Drinking water systems turned out to have a theoretically high hydraulic potential in Lebanon yet the current distribution pipelines have high friction due to their small diameter at relatively high flow. This property could be an advantage in a water supplying system and it works as a pressure breaker for high head water sources, but it is a disadvantage for hydropower generation in case the existing pipelines would be integrated into the hydropower plant. The high friction losses in the pipe results in reduced energy production.

Wastewater treatment plants do not have significant potential for power generation, but may be subject to substantial energy efficiency measures. Some of them are still under construction or review and this gives the opportunity for more investigation into hydropower potential and to carry out any necessary adjustments on the design of the treatment plants in order to integrate the proposed hydropower plants.

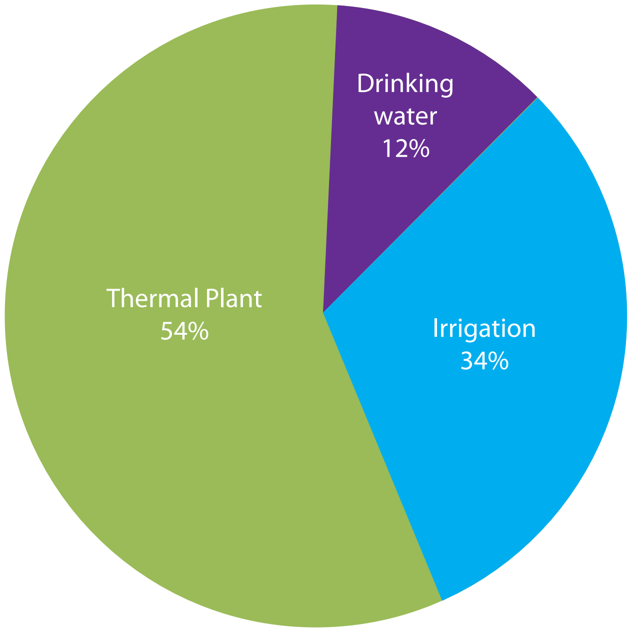


Figure 1 Energy potential of the visited sites in Lebanon (only non-river sources)

A sensitivity analysis for the investment cost was conducted for the sites. The presented results of the financial analysis show that investment in hydropower from thermal power plants' outfall in Lebanon is an economically viable option.

1 Introduction and background

1.1 Country Profile

Lebanon, officially the Lebanese Republic, is a country in the East Mediterranean, located in Western Asia between latitudes 33^0 and 34.7^0 N, and longitudes 35.1^0 and 36.6^0 E. The population of Lebanon is approximately 4.2 million (2008 estimate). Lebanon is a parliamentary democracy that has six governorates (Mohafaza) which are subdivided into 28 districts (qadaa) which in turn are divided into several cadastral zones and municipalities, each enclosing a group of cities and villages.

Lebanon consists of four physiographic regions, the coastal plain, the Lebanon mountain range, the Beqaa valley and the Eastern Lebanon Mountains. The country's surface area is 10,452 square kilometres of which 1.6% is water. The highest point in Lebanon is Qurnat al Sawada (at 3,088 meters above sea level) in North Lebanon which gradually slopes to the south before rising again to a height of 2,695 meters in Mount Sannine.

Seasonal torrents and rivers drain the mountains of Lebanon. An important water source in southern Lebanon and even in the country as a whole is the Litani River. The river originates from the Bekaa Valley, west of Baalbek, and flows into the Mediterranean Sea north of Tyre. Exceeding 140 km in length, the Litani River is the longest river in Lebanon and represents a major source for water supply, irrigation and hydroelectricity.

1.2 Energy Sector in Lebanon

Power outages are a daily occurrence in Lebanon. The demand for electricity exceeds the power supply capability of Electricité du Liban (EDL) (see Figure 2). The demand for electricity in Lebanon is likely to reach over 4,000 MW by 2015[1], which would correspond to a capacity increase of at least 1,500 MW. Since the realization of the two combined cycle power plants Zahrani & Beddawi (commissioned in 1998), no new power plant has been added to cover the electricity demand. Moreover, since 1996, the electricity tariffs in Lebanon have not been effectively adjusted to cover the cost of power generation. The overall average tariff for 2006, based on billed energy, was LBP 141/kWh ($c9.4/kWh) and remains unchanged today. The current tariff is based on an out-dated oil price of $25/barrel, meaning it has not been adjusted to take into consideration the increase of the national oil price and inflation since that time. Consequently, the present selling tariff is too low to cover the electricity generation costs, which are currently at least $c19/kWh on average.

Outages are frequent and costly private generators, who adversely affect the competitiveness of the economy, especially the energy-intensive manufacturing sector, meet much of the excess demand. Lebanon's electricity tariff level is high by regional standards and in relation to service quality, but too low to cover EDL's costs.

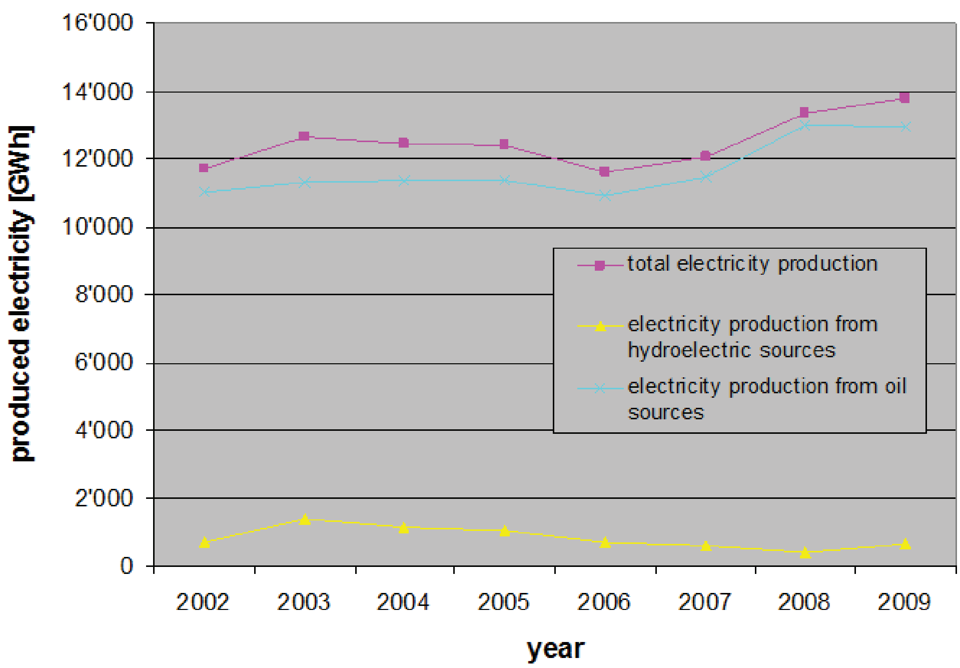


Figure 2 Electricity production in Lebanon (2002 – 2009)

1 Document of the World Bank, Republic of Lebanon, Electricity Sector, January 31, 2008

Electricité du Liban (EDL), the state's electric utility, operates seven thermal plants fuelled by gasoil, fuel oil, and natural gas. It also runs six hydro-electric power plants. The national utility enjoys a quasi-monopoly over the power sector in Lebanon. However, for reasons ranging from inefficient operation and management to a freeze-of-tariffs government policy, the electricity company has to rely on significant subsidies from the Ministry of Finance to cover its deficit. During 2011, for example, approximately USD 1.57 billion were transferred from the state treasury to EDL, 93% of which was allocated to purchase oil. This subsidy constitutes one fifth of total public expenses, and according to a 2009 social impact analysis by the World Bank, this is "putting macroeconomic stability at risk".

Law No. 462 provided for the unbundling of the vertically integrated single monopoly sector, at first, into three state owned joint-stock separate companies, denominated "Privatized companies" (one for generation, a second for transmission, the third for distribution). Within two years, a maximum of 40% of the shares of generation and distribution companies will be sold to private investors, while the transmission company remains permanently state-owned. At a later stage, the remaining shares owned by the Lebanese State shall be offered to investors from the private sector.

In this law, the logic and requirements of a liberalized market, through the separation of policy, ownership and regulation are approached but not quite developed, and although ratified in the year 2002, the law has not yet been put into application. EDL is still functioning in compliance with the old 1964 law[2].

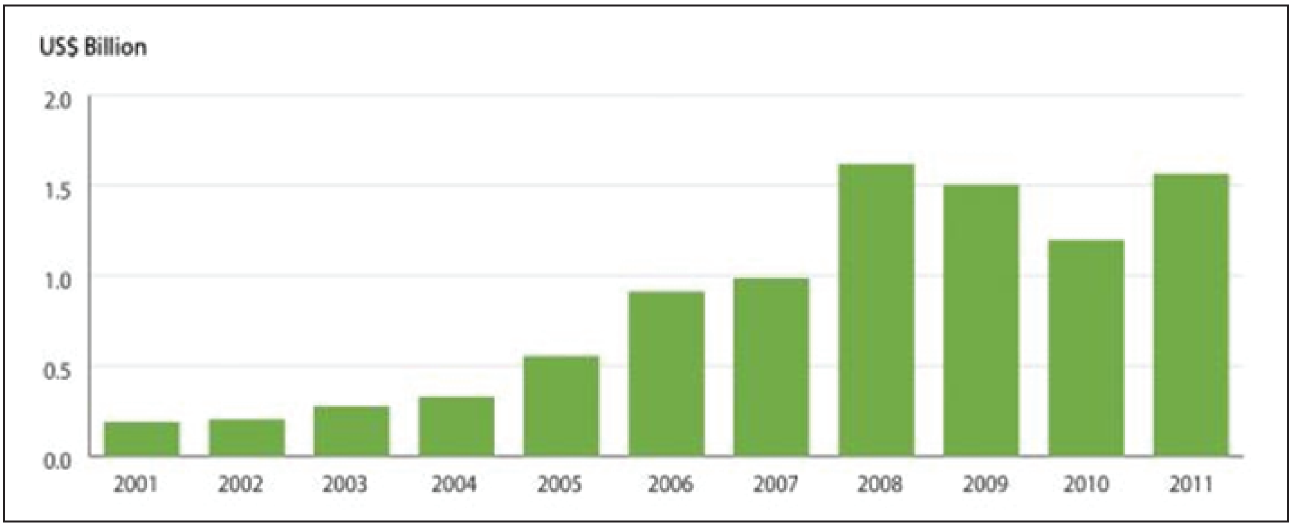


Figure 3 Ministry of Finance transfers to EDL (in USD Billion) Source: Ministry of Finance

2 http://webfea.fea.aub.edu.lb/fea/research/erg/web/Policy%20Paper%20lebanon.pdf

2 Project objectives and scope of the study

The electricity demand in Lebanon exceeds the supply capacity of the existing plants. Many local communities, enterprises and private households have resorted to the installation of their own diesel generators to cover their demand during scheduled blackout times of the grid supply. The Lebanese Government plans to use further potential sources for electricity generation, anywhere they are technically and economically feasible, particularly focusing on renewable energy sources. The objective of the current consultancy service is to assess the potential of generating micro-to-small hydropower from non-river based water sources, namely:

(1) Irrigational Channels and Conveyers

The primary function of this source is irrigation, which needs to be maintained at the required minimum pressure and flow. The production of electricity is only ranked second and must not undermine the primary function in any way. The hydropower plant has to be designed in a way to make optimum use of available head and flow at different irrigation regimes.

(2) Wastewater treatment plants inlet and outfall pipes

There are two possibilities for using the hydropower potential in such systems:
One is to install a turbine at the inlet of the wastewater treatment plant, using untreated wastewater. The other is to use the potential of the treated wastewater before it is returned into the receiving water.

(3) Thermal power plants' outfall pipes

Large thermal power plants require significant amounts of cooling water. Cooling water is normally taken from the sea, pumped to a heat exchanger, and returned via the outfall pipes to the sea. The available hydropower potential depends on the specific situation / topography at the respective thermal power plant. For example, a turbine can be installed at the outlet of the discharge cooling water system at a thermal power plant.

(4) Drinking water distribution networks

The primary function of these systems is to supply drinking water to the consumers at a specified supply pressure. Where there is a need for pressure reduction, the excess pressure can be used to drive a hydroelectric system.
There are different possibilities to produce electricity within drinking water systems. One concept is to install a turbine at the entrance of the reservoir or the storage tank at the water distributing station.

Another option is to install it within the supply networks. In that case, normally a certain residual pressure - as required for the distribution network - has to be maintained.

3 Assessment of micro to small hydropower energy potential in Lebanon

The assessment of the micro to small hydropower energy potential in Lebanon within the scope of the current project resulted in the following main conclusions:

• Generally, a hydropower potential estimated to be 8 – 15 MW is available from non-river resources, in particular from thermal power plants and drinking water systems. Today this potential is largely, if not completely, untapped.

• The most significant potential is found in the five thermal power plants that are built on the coastline. Their cooling systems work with pumps that convey the cooling water through a condenser. Thereafter, the water flows back to the sea with a height difference of about 4 to 13 meters. Consequently, it was found that these plants have an appealing hydropower potential.

• Drinking water systems have remarkable potential. However, the existing systems are often designed with high friction losses in the pipeline system. Integration of power generating turbines must be thoroughly evaluated. Furthermore, the requirements for drinking water supply have the highest and foremost priority, and this may, in some cases, conflict with power production.

• Wastewater systems have no remarkable potential in Lebanon. Technically the water flow is not regular and relatively small. Head differences are mostly not sufficient and sometimes even pumping is required. However, there may be an energy saving potential, for example, for pumps that are not well dimensioned as was observed. Furthermore, wastewater treatment in Lebanon is under development. Therefore, the issue of generating energy from the inlet and outlet of wastewater treatment plants should be revisited in the future.

• Irrigation systems with large channels are not common in Lebanon due to the topography. The latter is characterized by mountains which rise abruptly from the sea shore thus not giving space to flatter land appropriate for vast irrigation areas. According to the available data, no remarkable system of irrigation channels with potential steps for power generation exists.

• Conventional river based hydropower is not part of the present analysis and is left to other studies and assessment undertaken mainly by the Ministry of Energy and Water and the UNDP-CEDRO project.

4 Theoretical introduction: hydropower from non-river based water sources

Usually a hydropower system converts the power from flowing water by using a head difference into mechanical and finally into electrical energy. Such power plants can be run off river plants or systems with storage lakes / reservoirs.

Typical example of a diversion type run-of-the-river hydropower plant.

The **hydraulic potential** is defined as:

$$P_{hy} = rho * g * H * Q$$

Where P_{hy} = potential hydraulic power (W)
rho = density of water = 1000kg/m^3
g = acceleration due to gravity = 9.81m/s
H = head difference of water levels at inlet and outlet (m)
Q = water flow (m^3/s)

To calculate the resulting electric power at the consumer side, the various efficiencies of the system components have to be considered. These efficiencies take into account losses in the water conveying system (intake, headrace channel, thrash rake, penstock), in the turbine, in the mechanical transmission and within the generator. The **generated electrical power** is:

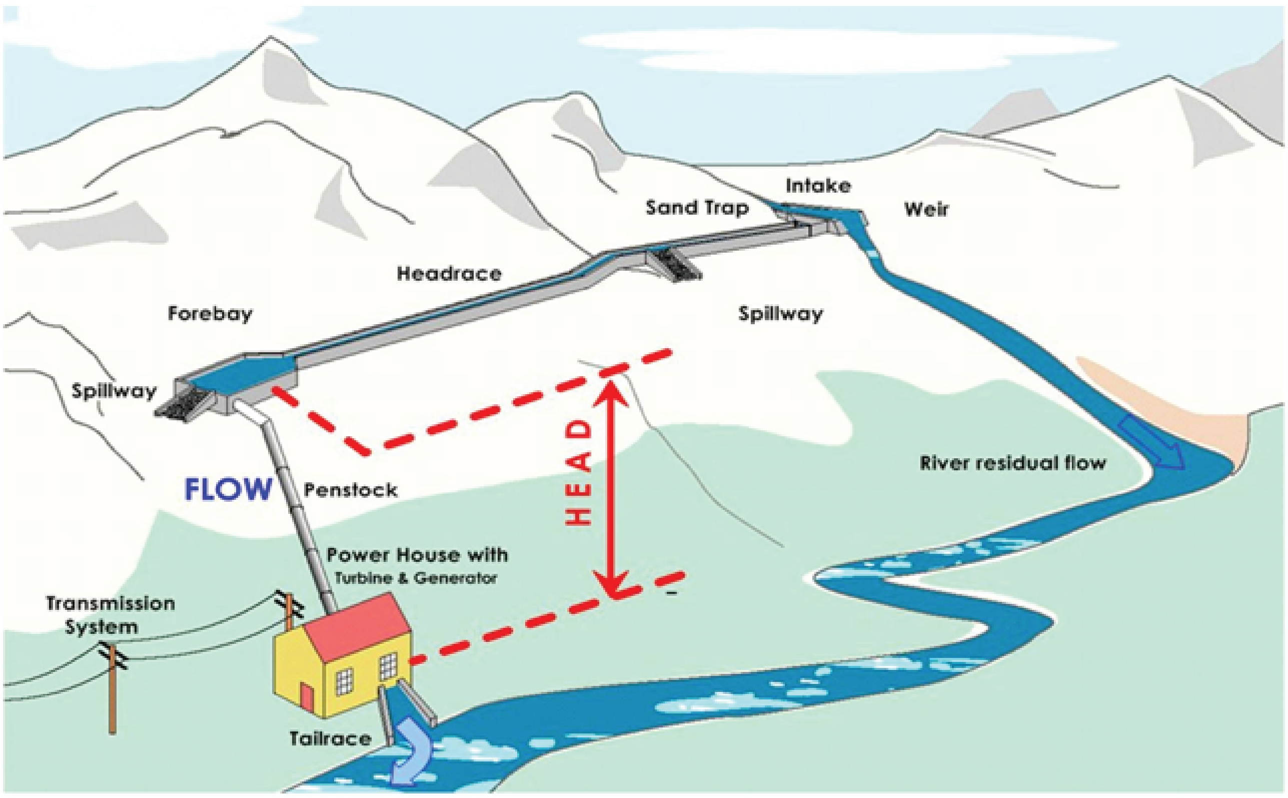
$$P_{el} = P_{hy} * eta_{hydr} * eta_{el}$$

Where P_{el} = electrical power at generator panel (W)
eta_{hydr} = efficiency considering hydraulic losses (water conveying system)
eta_{el} = generation efficiency
= Turbine efficiency * mech. Transmission eff. * Generator eff.

In the case the electricity is not consumed at a location close to the power house, losses provoked by transformer(s) and transmission lines have to be considered as well.

Although the current study does not deal with such conventional hydropower plants, the main principles in non-river based hydropower plants are very similar.

In such cases, the geodetically head drop in drinking water supply, wastewater treatment systems, irrigation systems or of cooling water in thermal power plants and the respective available flow have to be determined to assess the hydropower potential.



Typical example of a diversion type run-of-the-river hydropower plant

5 Hydropower conversion options, technical and financial Analysis and possibilities for grid connection

Existing infrastructure	Symbol	color
Irrigation system	A	white
Wastewater treatment plant	B	black
Thermal power plant	C	red
Drinking water distribution network	D	blue

5.1 Methodology

The methodology describes the key issues required to assess the hydropower potential and to identify the most promising sites. The selection process comprises the following main stages:

- **Stage I:** Establishment of a list of potential sites based on the review of existing documents and studies. Preparation of an information sheet containing the site evaluation criteria with a questionnaire to obtain the relevant information and documentation.
- **Stage II:** Site visits to the listed locations
- **Stage III:** Analysis of the required equipment and technology (with financial analysis), and grid connection analysis.
- **Stage IV:** Provide guidance for the establishment of bidding documents including required specifications of hydropower technologies.
- **Stage V:** Presentation, covering the fundamental concepts of the study, sampling procedures, processing, analysis, and interpretation of the results.

5.2 Site visits and potential analysis

A list of different types of hydropower resources was established and 20 sites that are listed in Table 1 have been visited. The identified potential sites (Figure 4) were screened and assessed based on the available information and site visits. Annex 1 contains a summary of these visits with the main characteristics of all sites.

During the first review, the following aspects were analysed:

- Main function of the existing infrastructure,
- Location and existing layout documents for the proposed sites,
- Hydrological data: Water level (up and downstream); flow duration curve (if available); flow measuring system (available or not),
- Water quality,
- Consumption data and the sources for the drinking water system,
- Beneficiaries of a potential hydropower plant and location of a possible electrical grid interconnection point.

Figure 4 Map of Lebanon with visited sites

Table 1 lists the visited sites and their types of hydropower sources.

Site Code	Symbol	Site Name	Type	Position GPS
LEB001	A	Naher el Bared lake	Irrigation System	N34 28.775 E35 59.131
LEB002	A	Brak spring	Irrigation System	N33 28.649 E35 19.121
LEB003	A	Wadi El Hojeir	Irrigation System	N33 16.173 E35 26.802
LEB004	A	Ain Leghwaibe (b)	Irrigation System	N34 04.075 E35 53.522
LEB005	A	Younin	Irrigation System	N34 04.765 E36 16.379
LEB006	A	Nebe Al Safa irrigation	Irrigation System	N33 45.071 E35 41.935
LEB007	A	Qasimia Irrigation System	Irrigation System	N33 19.728 E35 15.861
LEB008	A	Falouss Irrigation System	Irrigation System	N33 34.129 E35 30.906
LEB009	B	Tripoli water treatment plant	Water Treatment Plant	N34 27 23.55 E35 50 41
LEB010	B	Saida water treatment plant	Water Treatment Plant	N33 32.197 E35 21.736
LEB011	B	Jieh treatment plant	Water Treatment Plant	N33 38.561 E35 23.977
LEB012	C	Zahrani Power Plant	Electrical power plant	N33 29.832 E35 20.287
LEB013	C	Zouk Power Plant	Electrical power plant	N33 58.319 E35 36.284
LEB014	C	Jieh Power Plant	Electrical power plant	N33 38.865 E35 23.917
LEB015	C	Deir Ammar Power plant	Electrical power plant	N34 27 58.35 E35 53 40
LEB016	C	Hrayche Power Plant	Electrical power plant	N34 22.800 E35 45.521
LEB017	D	Saida water station (a)	Water Distribution Networks	N33 33.049 E35 23.369
LEB018	D	Saida water station (b)	Water Distribution Networks	N33 33.049 E35 23.369
LEB019	D	Kaa el Rim	Water Distribution Networks	N33 53.228 E35 52.300
LEB020	D	Ain Leghwaibe (a)	Water Distribution Networks	N34 04.075 E35 53.522

Table 1 List of Sites

The alphabetic categories (A, B, C, D) are used in order to have a well-structured overview on the types of the infrastructure.

After the inception visit of the listed sites, an evaluation process was conducted to assess the potential of hydropower. The evaluation process is based on the following criteria:

1. General: High benefit at low cost and a high probability of sustainable operation.

2. Technical: Power output, annual production, existing infrastructure (i.e., irrigation structures, reservoirs, etc.), head, and expected complexity of civil/E&M works.

3. Economical: Ratio of total investment costs to annual revenue. This value corresponds to the payback period. The overall average selling tariff for electricity in Lebanon is $c9.4/kWh[3]. In reality the production costs are about at least $c19/kWh or even higher. Electricity produced by hydropower systems, integrated into thermal power plants, can certainly compete with this high (real) production cost of electricity generated on the basis of fossil fuels. For power plants with their own consumption, the (lower) selling tariff has to be taken as a benchmark because it represents the avoided costs. A feed-in law for independent power producers does not yet exist.

4. Logistics and Organisation: Access to the site (existing roads, terrain), location (transport distance, distance to conflict areas, etc.), reliability of available data, beneficiary conflict, social or environmental impacts, grid development and status of regional grid and power supply, distance to existing grid.

Table 2 lists seven sites that have been eliminated during the selection process due to their minor hydropower potential or because they are technically or financially not feasible.

3 The current tariff structure is based on an oil price of (US) $25/barrel and has not been adjusted to take into consideration the increase of the national oil price in the recent years as mentioned in Chapter 1.2.

Site Code	Site Name	Symbol	Electrical Power[kW] (estimated)	Remarks
LEB002	Brak spring	A	4	Only minor production possible; eventually interesting for private developer for auto consumption
LEB003	Wadi El Hojeir	A	4	
LEB005	Younin	A	1	
LEB014	Nebe Al Safa irrigation	A	-	Insufficient potential due to limited drop in irrigation channel
LEB009	Tripoli water treatment plant	B	-	Insufficient potential; catchment area close to treatment plant is too flat; outlet pipe reaches 1Km into the sea
LEB010	Saida water treatment plant	B	-	Insufficient potential due to fluctuating discharge
LEB011	Jieh treatment plant	B	9	(small)potential at the outlet

Table 2 Sites eliminated during initial evaluation

Table 3 presents the specific technical information for those visited sites, which are considered to be appealing to micro to small hydropower systems and their respective estimated power potential.

Site Code	Site Name	Symbol	Flow [m3/s]	Gross Head [m]	Electrical power (estimated) [kW]	Remarks
LEB001	Naher el Bared lake	A	3.0	5	88	Reservoir and intake already existing
LEB004	Ain Leghwaibe (b)	A	0.9	30	168	No existing irrigation channels
LEB007	Qasimia Irrigation System	A	5.0	15	566	Power plant could only be operated outside of the 6 month irrigation period
LEB008	Falouss Irrigation System	A	1.5	90	448	During the 5 month irrigation period, power plants could be operated during daytime only (14 hours per day)
LEB012	Zahrani Power Plant	C	8.89	10	671	Existing intake. Available data and documents
LEB013	Zouk Power Plant	C	30	4	876	Existing intake. The available layout is very old and not precise
LEB014	Jieh Power Plant	C	20	5	738	Documents are not available
LEB015	Deir Ammar (Beddawi) Power plant	C	8.89	13	872	Existing intake. Available data and documents
LEB016	Hrayche Power Plant	C	3.50	10	264	Existing intake. Available data and documents
LEB017	Saida water station (a)	D	0.23	20	22	Existing reservoir and pipelines. Residual flow and pressure at consumers have to be considered

Table 3 Technical Data and estimated electrical power for pre-selected sites

LEB018	Saida water station (b)	D	0.11	20	10	Existing reservoir and pipelines. Residual flow and pressure at consumers have to be considered
LEB019	Kaa el Rim	D	0.09	140	51	Existing pipeline
LEB020	Ain Leghwaibe (a)	D	0.38	200	61	Very high friction losses in the pipeline due to small diameter
Total				4834		

In several cases the estimated electric power is relatively low because the estimated net head is much lower than the gross head indicated in the table.

5.2.1 Hydropower potential in thermal power plants

Table 3 shows that thermal power plants offer the most favourable sites. Other benefits of thermal power plants include;

- High production (capacity factor is potentially as high as that of the thermal power plant)
- Hydropower system can be integrated into existing infrastructure
- In most cases, sufficient data is available
- Easy access to the site
- Operating and maintenance can be assumed by the thermal power plant employees
- Produced power can be fed to the grid where the thermal power plant is connected

Since electricity production from hydropower leads to an immediate reduction of fossil fuel consumption in the thermal power plant, theoretically, the calculated specific costs of hydropower electricity can be directly compared with the relatively high specific production costs for electricity from the steam turbine ($c19/kWh).

There are seven thermal power plants in Lebanon. Two of them work with gas turbines. The remaining five work with steam turbines and condenser units, thus requiring an enormous water flow for the cooling process. This water flow can be utilized for the hydropower system.

The cooling water is the potential source. It is pumped from the sea to the condenser unit of the power plant (Figure 5). In the condenser the cooling water flows from the water inlet through small diameter condenser pipes, where a conventional heat exchange process takes place on the outside surface of those pipes between cooling water and steam. This is converting the steam into condensate and is heating up the cooling water, which is leaving the condenser unit with a slightly higher temperature at the water outlet (510-°C).

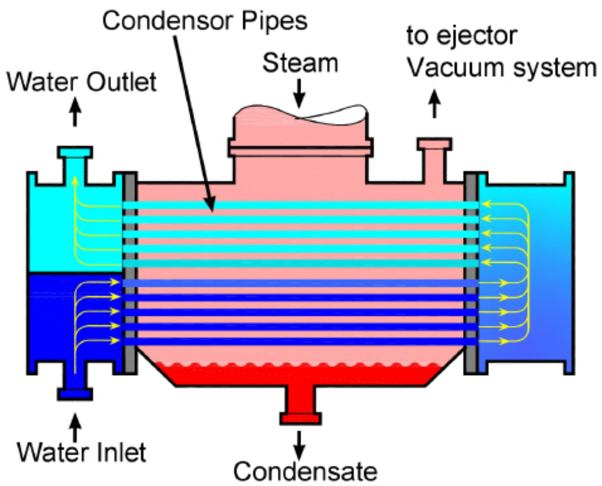


Figure 5 Condenser unit of thermal power plant

Figure 6 illustrates how a water turbine can be integrated at the water outlet of the condenser unit. The cooling water leaves the condenser unit through the water outlet pipe, (which has a diameter of more than 1 meter depending on the power plant specification). This pipe ends in the discharge channel with a water level above sea level. At this discharge channel a turbine can be installed and bypass the water back to the sea

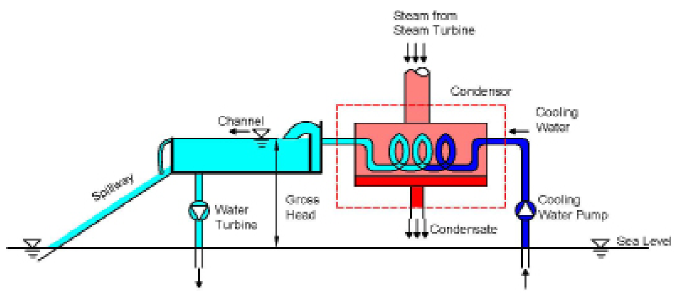


Figure 6 Schematic cross section of condenser unit with integrated water turbine in the outfall channel.

Case Study Deir Ammar (Beddawi) Thermal Power Plant

Existing Infrastructure	Electrical Power Plant
Site Code	LEB015
Site Name	Deir Ammar (Beddawi) Power Plant
Location	North of Lebanon, Tripoli City
Electrical power	872 [kW]

The outfall water at Beddawi thermal power plant discharge channel is currently conveyed to the sea without using the remaining available head, which can be made use of by installing a hydropower system. For example at the Zahrani or Deir Ammar thermal plants, a head of 10 to 13 meters (water level difference) at a flow of 8.89 m^3/s is available almost all year long. The flow variation depends on the operation time of the pumps. During rehabilitation, maintenance periods or operational breaks due to technical problems one of the pumps might be stopped but never all of them, otherwise the thermal power plant would need to be completely shut down. In general, the minimum flow at thermal power plants is about 50% of the maximum flow. Nevertheless, a water turbine type like a Kaplan turbine will still have over 90% efficiency at this flow. The relatively high water temperature and the salt content may have an influence on the cavitation limit of the turbine. Another difficulty is the fact that the turbine runner and power house must be installed close to seawater level. The fluctuating tidal water level and waves during storms must be considered for any power house design.

Figure 7 Discharge channel and outfall water, Deir Ammar (Beddawi power plant)

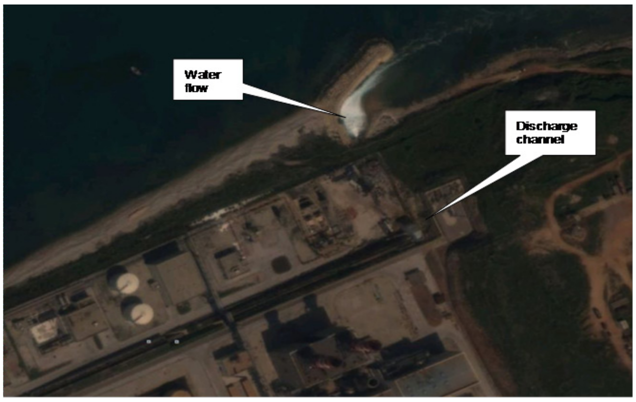


Figure 8 Satellite picture of Deir Ammar (Beddawi) power plant

5.2.2 Hydropower potential in drinking water systems

More potential can be found in drinking water distributing networks. The current distribution pipelines have high friction losses due to their small diameter at a relatively high flow. Normally, in case of high head sources, pressure breakers are used to reduce the water pressure in the pipelines. However, in most water distributing systems in Lebanon, using such pressure breakers with small pipes causes high friction losses. Solely for drinking water supply, this is actually an economical solution especially for long distance pipelines. On the other hand pipes with bigger diameters would allow using the available head for energy production. At lower consumption and thus lower flow in the pipes (e.g. during night time), the available pressure is higher. Depending on the specifications of a turbine the hydropower system would have to be shut down (in case of very low flow or very high head). A turbine, which is designed to operate with a very high pressure, can "compensate" the low flow and achieve an even higher hydraulic power.

Figure 9 shows the net head, which is available to operate the water turbine in a hydropower plant. It also illustrates the difference between the available potential head (or gross head) and the net head due to the friction losses.

Figure 9 shows how a high friction loss would reduce the net head and result in lower hydropower generation.

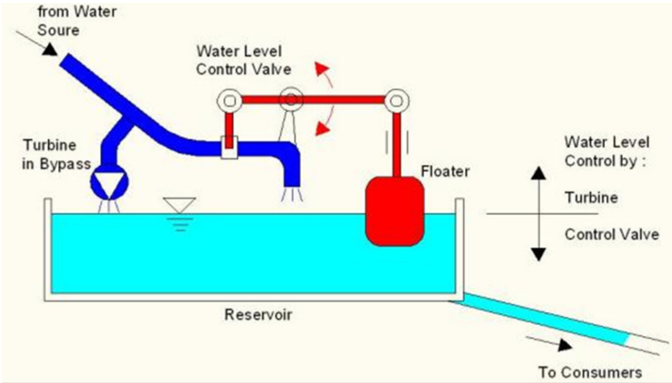


Figure 9 Pressure drop in drinking water supply or irrigation systems

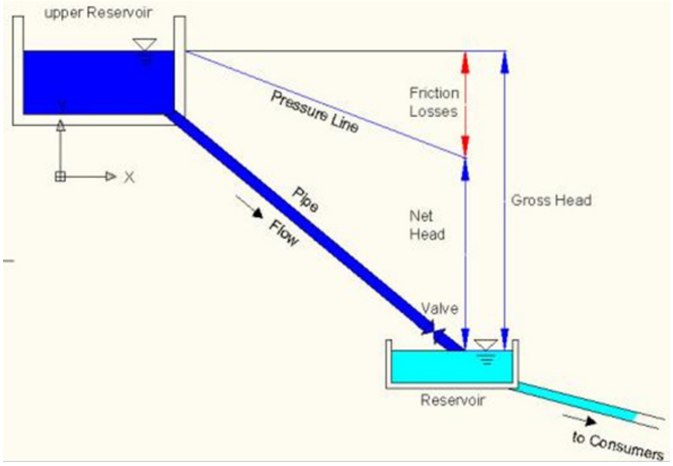
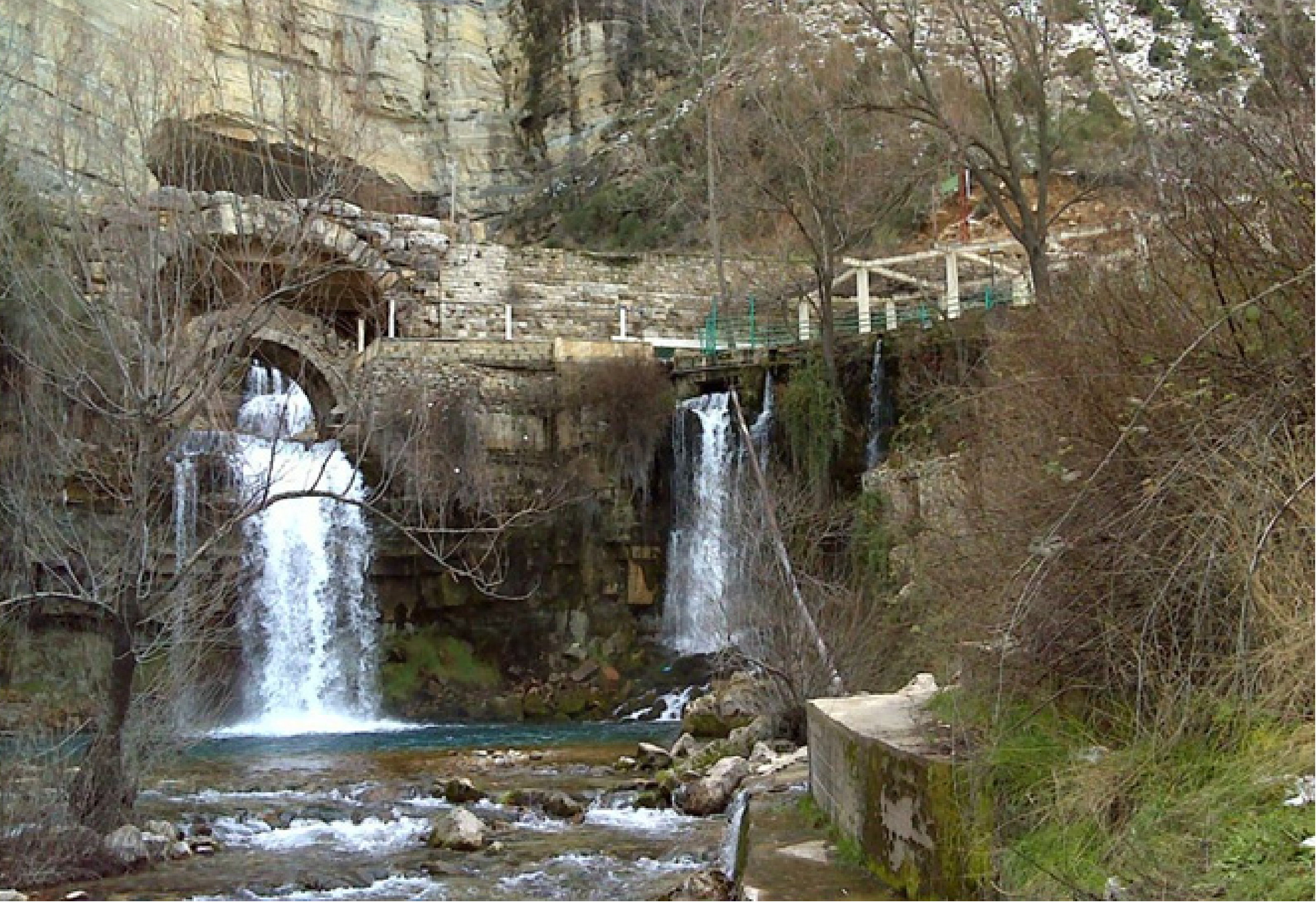


Figure 10 Arrangement of turbine in a bypass installed above the (originally pressure breaking) reservoir

Figure 10 gives an example of how to integrate a hydropower turbine into a drinking water system. An optimal position for the turbine would be close to the reservoir of the water distributing system. The existing floater controlled valve act as a bypass to the turbine and ensure the continuous drinking water supply in case the turbine has to be stopped.



Case Study Ain Leghwaibe(A) LEB020

Existing Infrastructure	Drinking water distributing network
Site Code	LEB020
Site Name	Ain Leghwaibe(a)
Location	Northeast of Lebanon
Electrical power	61 [kW] (using the existing pipeline) 500 [kW] (using a new pipe with an optimal diameter)

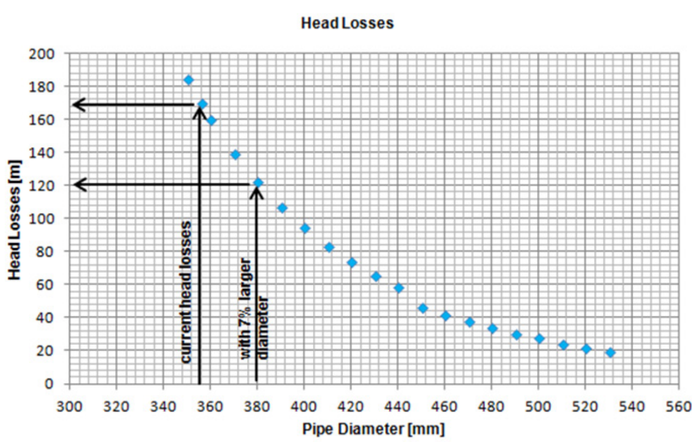


Figure 11 Head losses in pipeline of water distributing Ain Leghwaibe LEB020, (according to information available on existing pipe and flow)

Figure 11 presents the head losses in the case of using the existing pipeline of Ain Leghwaibe (LEB020) for a hydropower plant (= current head losses). The distance to the expected turbine location is 3km, with the existing pipe diameter of 14 inches the head losses at rated flow can be around 85% of the available potential (loss of 180m at a gross head of 200m), corresponding to a hydraulic efficiency of only 15%.

For example, expanding the pipe diameter by 7% would save approximately 50m of the available head and around 30% of the hydraulic losses.

Finally, using an optimal penstock diameter of 520 mm for an acceptable pressure loss of 20m or 10% would increase the cost for the penstock on one hand; however, on the other hand, this would save the available potential. With an optimal penstock size, an electrical output of more than 500 kW could be achieved for this site. An economic analysis can show which conditions the investment for a new pipeline of this diameter would be worthwhile.

Figure 12 Satellite picture of Ain Leghwaibe(a) site LEB020

5.2.3 Hydropower potential in irrigation systems

In irrigation systems the main criteria to assess the available hydro-potential is the operating time that is usually linked to the irrigation period.

For irrigation systems, often two different options for using hydropower potential exist. The first is to use a significant pressure difference in the water conveying system. Figure 13 shows the use of a head drop in the channel itself. This potential can be used without restrictions during the irrigation period or even outside the irrigation period if the channel can be used and the required flow is available. However, the survey undertaken could not identify such a site in Lebanon (This does not mean that such a site does not exist.). The second option uses a variant of this principle focusing on pipelines where pressure builds up, similar to the drinking water networks (see above). The case study of Falouss, as shown in Figure 14, represents such a site.

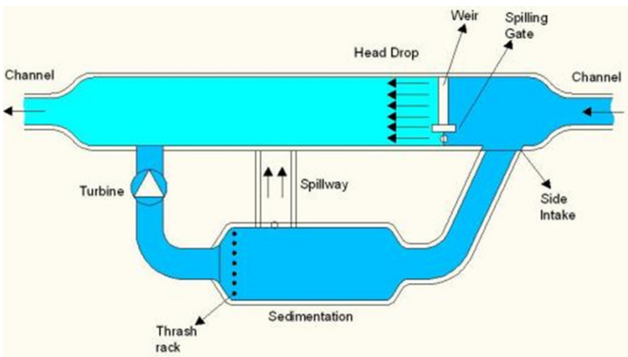


Figure 13 Turbine arrangement parallel to a drop in the irrigation channel

As explained in the preceding paragraph, the second option in irrigation systems is to use hydropower potential in a bypass leading from the channel back to the river. Such a system can only operate outside of the irrigation period (or can make use of access water during irrigation season). There exists a high risk of conflict of interest between irrigation and power production.

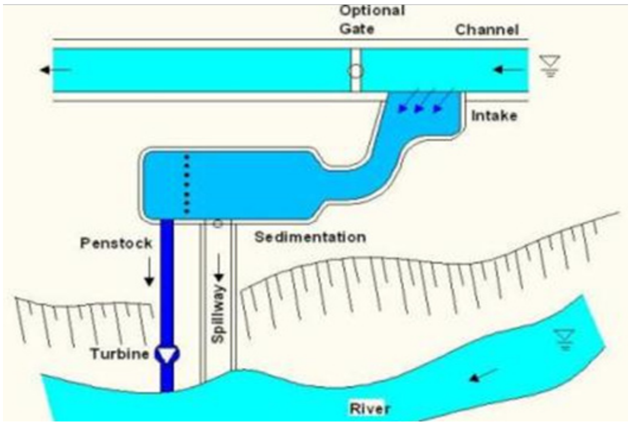


Figure 14 Turbine arrangement parallel to a drop in the irrigation channel

Case Study Falouss Irrigation System LEB008

Existing Infrastructure	Irrigation system
Site Code	LEB008
Site Name	Falouss irrigation system
Location	South of Lebanon, Saida City
Electrical power	448 [kW]

Figure 15 Falouss irrigation site– Discharge pipe at BC2 location

The Falouss irrigation system comprises pipelines and pressure breakers in different locations of the distribution system. On some sections of the pipeline system, the head loss due to friction, between two pressure breakers, is very high. The potential in the technical evaluation table for Falouss was calculated for the line BC0-BC2 (Figure 16), which has relatively low head losses compared to other connected lines in the Falouss irrigation system. In case the implementation of a hydropower system is considered for this site, it is highly recommended, first, to implement proper flow and head measurements during a period of one year. In addition, as is the case for all other sites, the level of a potential feed-in tariff would have to be clarified.

Figure 16 Satellite picture of Falouss irrigation BC0 and BC2 (The yellow line is a street route)

A potential hydropower plant could be integrated in the existing irrigation pipeline (penstock) at the location BC2 (Figure 16). The available flow could be used for hydropower and subsequent irrigation thus avoiding any conflict of interest. Water from the irrigation reservoir BC0 would still be available for irrigation. According to information from a local engineer, the irrigation period lasts 56 months. Beside this limited operation time, another constraining aspect has to be considered: An existing operational hydropower plant located Northwest to the irrigation reservoir BC0 is using the same water source which is used for irrigation (see Figure 17). However, it seems that in case of insufficient flow, additional water can be received from the Litani River.

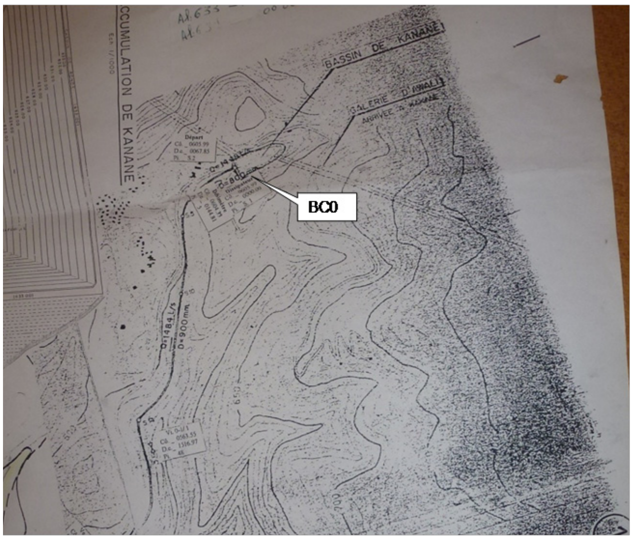
Figure 17 Falouss irrigation reservoir and an existing operational hydropower plant

Given the lack of reliable detailed information on the operational procedures of the existing hydropower plant and irrigation system, it is highly recommended to analyse the following issues more in detail.

According to the information received from a local engineer, the irrigation system of Falouss is an end-use system. This means that the discharge depends on the demand of the consumers. Therefore, the discharge in the irrigation channel during the wet season (in which the irrigation demand is low or not existing) has to be taken into consideration.

It has to be clarified with the operators of the irrigation system and the owner of the existing hydropower plant if a year-round flow in the irrigation channel could be ensured without any negative impact on the operation of the various existing structures.

Pressure and flow measurement have to be implemented at the pressure breaker to get information on head and flow during dry and wet season.



Falouss irrigation site - Pressure Breaker BC0

Falouss irrigation site - Pressure Breaker BC2

Case Study Qasimia Irrigation System LEB007

Existing Infrastructure	Irrigation system
Site Code	LEB007
Site Name	Qasimia irrigation system
Location	South of Lebanon, Saida City
Electrical power	566 [kW]

Figure 18 Qasimia irrigation intake

In the Qasimia irrigation system, the available hydropower potential could only be used outside the irrigation period. The reason for this is that the water would have to be diverted from an irrigation channel through a bypass pipe to the proposed hydropower plant and, after a turbine unit, be conveyed back into a river (and is thus no longer available for irrigation purposes upstream).

During rainy seasons the Qasimia irrigation channel gates are closed and the water flows directly back to the river.

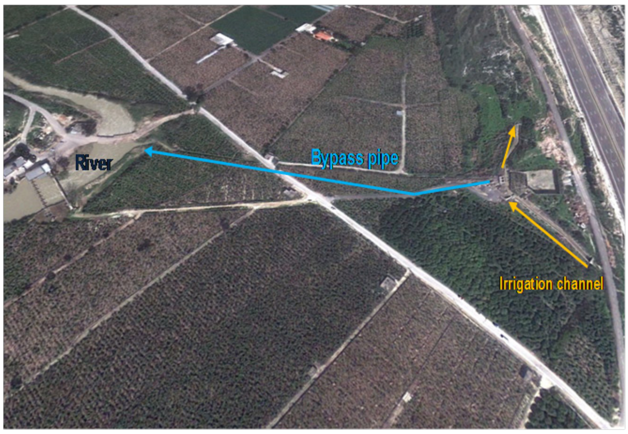


Figure 19 Satellite picture of Qasimia site

The difference in head of 15m between the irrigation channel and the river at the Qasimia irrigation station can be used by a hydropower system as long as the flow is not needed in the irrigation system. The head must be verified as the team relied on estimations of local staff and GPS measurement only. Flow capacity of the channel should be verified as well.

The Qasimia pumping station consists of four pumps which function as a standby system. In case the flow in the irrigation channel does not cover the demand, water can be pumped from the river to a reservoir to be diverted into the irrigation channel to cover water shortages.

The machinery of the pump station is electrically connected to the Public grid. This connection could be used for the hydropower plant as well. However, during the visit it was not clear what tariff would be paid for the proposed hydropower plant. There are no examples known for such an interconnection situation in Lebanon so far.

5.2.4 Hydropower potential in wastewater systems

Further visited infrastructures were wastewater treatment plants. All visited plants had been designed to reach their maximum capacity in around 20 years and they are not yet connected to the city networks. The treated water would discharge at long distance into the sea. Due to the small flow and head none of the visited wastewater treatment plants in Lebanon would offer hydropower potential of more than 10 kW (i.e., within pico-hydro capacity). For example, the Jieh wastewater treatment plant (1264 m^3/h) potential at the outlet pipe is estimated at 9 kW. The outlet pipe at this treatment plant can be connected to a bypass to the proposed hydro plant. The treatment plant is located very close to the sea; here the sea waves, especially during a storm, have to be taken in consideration. Most of the WWTP are still under construction and review, and therefore potential sites for hydropower may be re-visited for verification in the future. However, under current conditions, no remarkable hydropower potential has been identified.

Figure 20 Jieh wastewater treatment plant LEB011

5.3 Analysis of required equipment and technology

The specifications of the electro-mechanical equipment for a hydropower site are mainly defined by the nominal discharge and net head (available gross head minus losses). In case of long (pressure) pipes, the turbine characteristics have an influence on the risk of water hammer (transient pressure rise). This can happen if the turbine is closed or if it is changing its speed, for example in the case of grid failure. The equipment proposed for installation has to be integrated in the existing infrastructures taking the main purpose of the infrastructure carefully into consideration. To avoid interferences, flexible technology is required to allow a maximized utilization of the available energy potential.

Depending on the available head and water flow more than one type of turbine may be suitable as presented in Table 4, and here the primary function of the existing infrastructure will be taken into consideration.

The proposed power plant shall not have a negative impact on the water quality in a drinking water system; while in cases like wastewater treatment and thermal power plants (using seawater), more attention has to be paid to the material which might be destroyed by ingredients like acids, salt, etc.

Besides head and flow, the following criteria have to be considered when it comes to turbine selection:

- Possibility to integrate the equipment in the existing infrastructure,
- Turbine efficiency,
- Maintenance and
- Proposed system costs.

Turbine Type	Head Range [m]
Kaplan and propeller	2 – 40
Francis	10 – 100
Pelton	60 – 1000
Crossflow	5 – 100

Table 4 Turbine types and operation range

Head Range[m]	System Type			
	A	B	C	D
5 -20	5	1	5	2
20 - 40	1	-	-	-
40 - 100	1	-	-	-
100 - 200	-	-	-	2

Table 5 Available head range of the visited non-river hydro sources Lebanon

Table 5 shows that most of the visited sites have low head. Consequently, as presented in Table 4, the suitable turbine type would be a Kaplan / propeller turbine (see Figure 23) or open flume Francis turbines (see Figure 24).

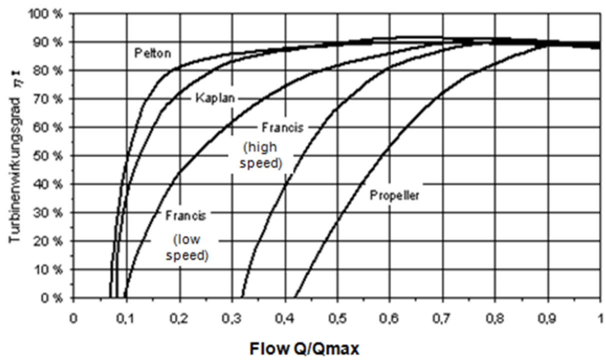


Figure 21 Turbine efficiency at different flow rates

The diagram (Figure 21) allows the optimal selection of turbine types depending on the fluctuation range of the available flow rate (Q/Qmax). Kaplan and Pelton turbines generate power with high efficiency 90%, even if the flow drops to 50% of turbine design flow. For systems with high flow variation during the year such as the drinking water systems and irrigation systems in Lebanon, Pelton and Kaplan turbines are suitable types to achieve an efficient operation over the whole year. More detailed information will be provided in the following paragraphs. Cross flow turbines may be a cheaper option for sites with 1540-m head.

The following subchapters present the main components of a hydropower plant and their design criteria. Those criteria can be used as a basis for their respective technical specification requirements.

5.3.1 Requirements for a hydropower system in a thermal power plant

Intake and pipeline system

Integration of the existing equipment and infrastructure (intake and penstock) in the proposed hydro plant makes the project economically more efficient, but this has to be without impacting the primary function of the site.

The following requirements have to be considered at the integration of the intake and pipeline system:

- The design flow of the proposed hydropower plant must not be lower than the discharge rate of the cooling water system.
- A trash rack has to be installed at the intake of the hydropower plant to protect the turbine. Generally, the distance between two bars in the screening system has to be smaller than 50% of the distance between the turbine runner wings.

The screening bars have to be vertical to enable the cleaning process if/when needed.

- The material has to be rust proof or painted accordingly.
- A spillway at the forebay is not required. Thermal power plants already have a spillway that could be integrated into the hydropower plant. The existing discharge channel can be used as a bypass channel and spillway in case the hydro turbine has to be shut down. An over-fall weir should be dimensioned in such a way that the total flow can be evacuated into the sea if the turbine is closed.
- A correctly designed overflow to the existing spillway guarantees the continuous operation of the existing infrastructures.
- If the turbine has to be shut down for maintenance or repair, separation should be facilitated by means of a gate or stop logs.

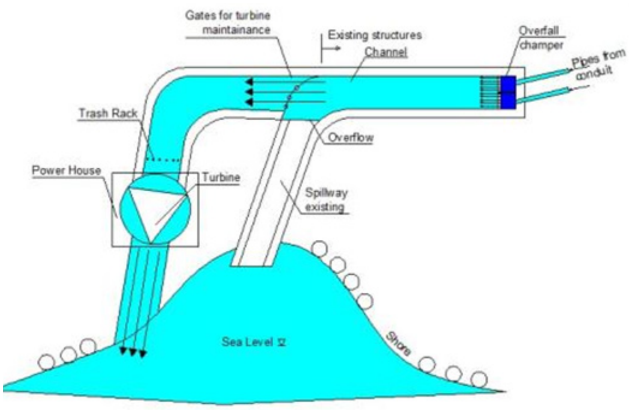


Figure 22 Turbine arrangement in parallel to the spillway structure

Turbine unit

The turbine type is defined based on the discharge and head. The flow variation during the year requires a suitable turbine design to reach the maximum annual energy production. At a given head, high energy production can be reached if the turbine provides optimal efficiency over a wide range of flow. In general, an optimal operating point for the turbine can be defined based on the flow duration curve of the respective site. For a thermal power plant the variation of the flow depends on the operation times of the pumps of the cooling system, which are in operating mode as long as the power plant is running. Normally, the power plant is operated at full capacity with all cooling pumps running. Flow variations only happen due to technical reasons (mechanical defect or maintenance).

The most suitable turbine type for a hydro plant (in a thermal power plant) is a Kaplan-S turbine or propeller turbine due to the available high flow and low head. The water flows through a trash rake (1), the turbine guide vanes (2) and the turbine runner (3) to the tail race. A generator (4) may be coupled straight to the turbine or via a gearbox. The control system (5) can adjust the flow to the available flow (see Figure 23).

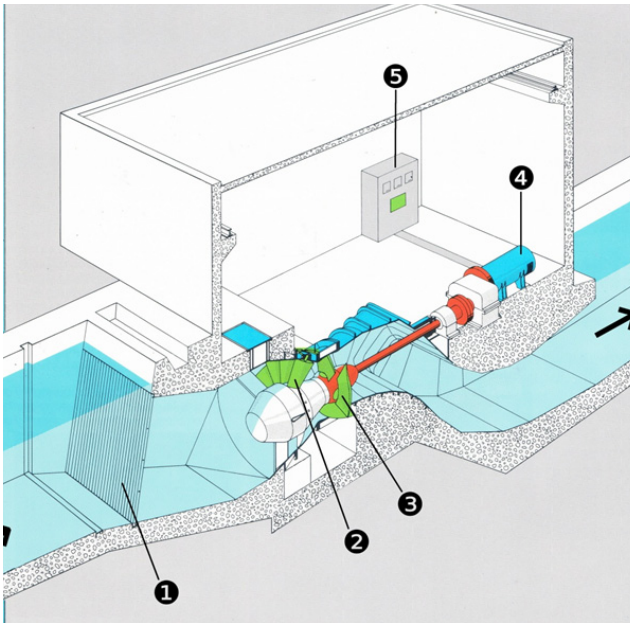


Figure 23 Arrangement with Kaplan-S turbine (source; Voith Heidenheim)

An open flume Francis turbine (Figure 24) may be an option as well. The water flows through the trash rake (1), the open Francis turbine (2) and a draft tube to the tail race. The guide vanes of the Francis turbine are adjusted by a hydraulic actuator system (4), which is controlled by the control panel (5). The generator (3) is coupled to the vertical turbine shaft by a gearbox.

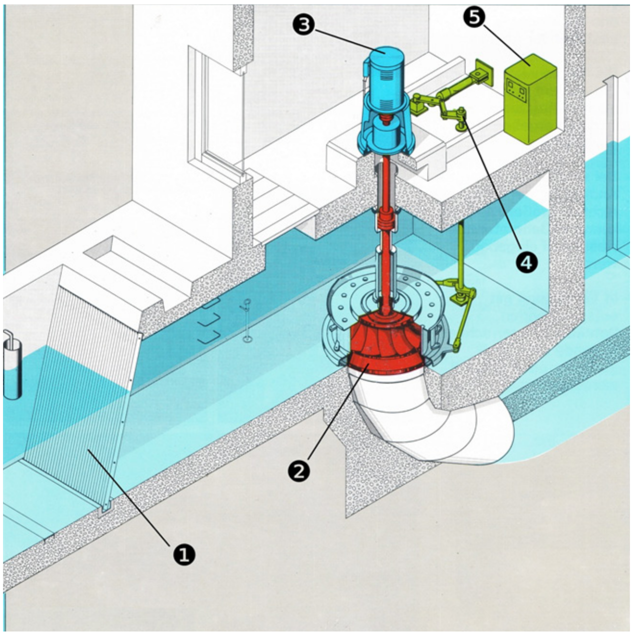


Figure 24 Arrangement with open flume Francis turbine (source Voith Heidenheim)

The following list specifies the main technical criteria for the selection of a turbine unit to be integrated in a thermal power plant infrastructure:

- Given that the cooling water is seawater, the parts that are in contact with water have to be made of corrosion resistant material that can withstand seawater.

- Seawater and salt spray impact the equipment in the power house. The housing of the controller has to be galvanized or salt resistant aluminium. It must be properly closed in order to avoid saltwater spray to settle on electrical components.

- The cooling water is required continuously as long as the power plant is in operation. To install a hydropower system, the cooling system of the thermal power plant would have to be stopped to do the work at the discharge canal. This means the heat exchange process in the condenser unit would have to be disconnected. In other words, the operation of the thermal power plant would have to be interrupted, an event which is not desirable. Therefore, the civil and electro-mechanical works have to be done in such a way that the cooling water can continue flowing without a (long) stop, for e.g., by using a bypass canal or doing most of the civil work which does not require stopping the cooling water and doing the rest as fast as possible, or during a major maintenance period of the thermal power plant.

- As described above, the turbine will be installed in a bypass and the existing discharge channel can be used whenever the turbine is shut down.
- In general, power plants, such as the Zahrani power plant, have a maintenance period of 45 days after every 50,000 hours (around 7 years) of operation. This occasion could be used to install a hydropower system. According to information provided by a local onsite engineer, the next maintenance period for Zahrani power plant will be in 2014.

- Kaplan and Francis turbines are suitable types in this instance due to the low-head and high-flow. Especially in case of low-head and high-flow characteristics, the installation of more than one turbine unit has advantages. Turbines for high flow rates can be technically more challenging. In addition, multiple turbine units allow for more flexibility to regulate the power plant, meaning that even at low flow the turbines can operate at relatively high efficiency. If 2 turbines are used, a propeller turbine (only guide vane or propeller adjustable) may be used instead of Kaplan turbines (guide vane and propeller adjustable). The main consideration especially when installing a Kaplan turbine is the cavitation[4]. Cavitation determines the elevation (suction head) of the turbine runner above tail water level (sea level). The supplier must be informed about the relative high water temperature and saltwater concentration to specify the correct suction head. Generally, a turbine shall be guaranteed against deterioration due to cavitation for the first 8,000 hours of operation.

- The discharge of the proposed power plant has to be at sufficient distance from the pumps intake area to avoid the recycling of the cooling water and increasing the seawater temperature.

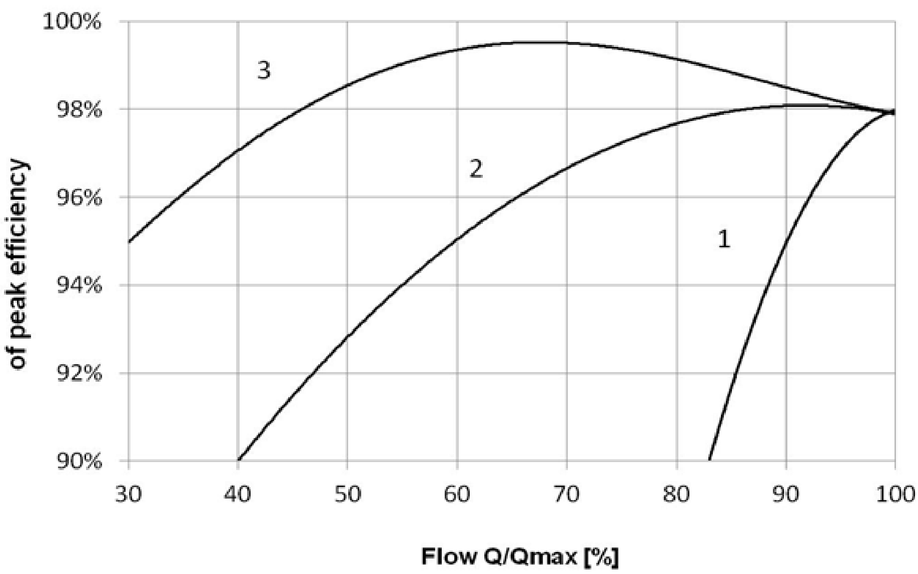


Figure 25 Kaplan and Propeller turbine efficiency for three types of regulation methods

4 Cavitation is the transformation of liquid water into steam due to the high pressure decrease.

Regulation unit

• In general, the regulation system shall feature the following functions:

1. Speed control at no load operation
2. Power output control
3. Water level control
4. Frequency control (synchronisation)
5. Emergency shutdown in case of mechanical or electrical failures

- For the visited sites of thermal power plants in Lebanon and according to the technical data, Kaplan or propeller turbines can be recommended. The regulation arrangement of such turbines depends on the design of the runner blades and wicket gates (guide vane). Three options are possible:

1. Fixed runner blades and adjustable wicket gates. This is more economical for sites with low fluctuations in the available flow. At constant head and flow variation between 80% and 100% of maximum flow the turbine efficiency is >90% of peak efficiency (Figure 25).

2. Adjustable runner blades of turbine with fixed wicket gates. It is more economical for sites with a flow variation of 40% to 100% of maximum flow. The turbine efficiency at this variation is still more than 90% of peak efficiency. But the design requires an additional shut-off device to shut down the turbine.

3. Adjustable runner blades and wicket gates (Kaplan Turbine). The turbine can be operated with more than 94% of peak efficiency for flow variation between 30% to 100% of the maximum flow.

Flexible regulation methods guarantee an efficient operation but increase the cost and design complexities of the electrical and mechanical equipment. The balance between the two factors cost and efficiency has to be done depending on the available data (flow and head).

Due to the relatively constant flow rate of the water source (cooling water system), the regulation method of fixed runner blades and adjustable wicket gates of Kaplan turbines can be applied to the hydropower plant in this infrastructure (thermal power plant).

• The general features of a regulation system include low load operation, synchronisation, water level control and shut down after load rejection (grid failure).

• Automated monitoring of the bearing temperature. Operational temperature of the bearings and generator windings should not exceed the specified temperature under unfavorable conditions.

• Safety shutdown of the turbine in case of emergency situation. This has to be an automatic shutdown taking into consideration the resulting water surge in the channel. For the disconnection of turbine and generator units from the grid during emergency shut down and grid failures, the units have to be equipped with automatic servomotors on the turbine guide vane to stop the water flow through the turbine. To assure this function, an emergency power supply must to be available. Otherwise, gravity or the oil pressure of an oil vessel has to be used.

• The controller shall be provided with supervisory instrumentation and protective devices, as necessary for operation with a high degree of safety, reliability and continuity of service; temperature monitoring; Reverse power detection; field failure detection; current unbalance; under voltage detection; over voltage detection.

• Automatic synchronization

• Water level control is required

• The switchboard has to be sealed to protect all electrical components from the saltwater dust which may penetrate into the power house during storms

Generator unit

• The generator can be directly connected to the turbine to increase the efficiency of the power transmission. This can be done if the turbine speed is compatible with the generator speed. In case of low turbine speed, a speed increaser system can be used between turbine and generator.

• The hydropower plant would be connected to the grid and would not operate in isolated operation mode. In this case a flywheel is not required for synchronization.

• The standard and preferred cooling method for the generator and the bearings is air cooling. For high loaded generators a water cooling system can be offered. The supplier shall specify the cooling method.

• The generator shall be provided with automatic voltage regulation (AVR) and temperature sensors for bearings - three stator windings, three rotor windings. It shall be designed for grid interconnection.

- Safety - All moving or turning parts (shafts, etc.) shall be covered if unintentional contact is easily possible (e.g. if shaft between generator and turbine is in the range of 0.5m).

- Maximum runaway speed shall be guaranteed. Correct design of nominal speed and maximum runaway speed is required to assure that the components withstand this speed.

- The turbine and generator units shall operate free from abnormal vibration within the range of gross heads and discharges.

5.3.2 Requirement for a hydropower plant in a drinking water system

The supply of drinking water has the highest and foremost priority. When integrating a pipeline of a drinking water system as a penstock to the hydro turbine, the water consumption rate has to be considered and investigated.

Intake and pipeline system

The following requirements have to be considered in the intake and pipeline system:

- The design flow of the hydropower plant must not be lower than the requirement to cover the drinking water demand of the consumers (after the power plant).
- A screening system is not needed at the power plant intake but a strainer could be mounted at the penstock inlet if needed. In this case, the strainer hole diameter has to be smaller than 50% of the distance between the turbine runner wings or nozzle opening - in case of a Pelton turbine.
- A spillway at the intake and discharge. For a drinking water system the turbine discharge is normally conveyed into the drinking water reservoir.
- A bypass valve has to be installed parallel to the turbine. Its reaction ensures the continuous supplying of drinking water to consumers in case the turbine is out of operation.

Friction loss in pipeline systems is a very important parameter to be considered when integrating a hydropower plant into existing drinking water infrastructures, particularly the water distribution system. In general, the friction losses depend on the internal diameter and roughness of the pipe. Usually for penstock design, the head losses at nominal discharge should not be more than 10% of the geodetic head between the water level at the intake and the expected turbine location. Increasing the pipe diameter reduces the head losses, which result in an increase of electricity production – yet also increases the investment costs due to the pipe's bigger diameter. In existing infrastructures like the drinking water distribution systems, the pipelines are generally already installed. The installation of a pressure sensor helps to get a better understanding of the energy potential at a specific site. In Lebanon, most of the drinking water supply pipelines, if not all, are going up and down through hills and flat areas and are underground. Most plans of the pipelines, unfortunately, do not exist. Theoretically, head losses can be roughly estimated but for more precise values the installation and regular reading of a pressure gauge (combined with regular flow measurements) is required.

Turbine unit

Pelton turbines are most suitable for the drinking water networks in Lebanon that have high pressure heads (for net head > 40m). This turbine type is generally easier to install than Kaplan or Francis turbines.

Figure 26 shows a typical double jet Pelton Turbine. The adjustable turbine nozzles (2) are connected to the penstock via a main valve (1). The Pelton turbine runner (3) is directly coupled to the generator/flywheel unit. If the penstock is long, a jet deflector allows fast control of the turbine speed and the turbine nozzle can slowly adjust the flow to avoid water hammer effects in the penstock.

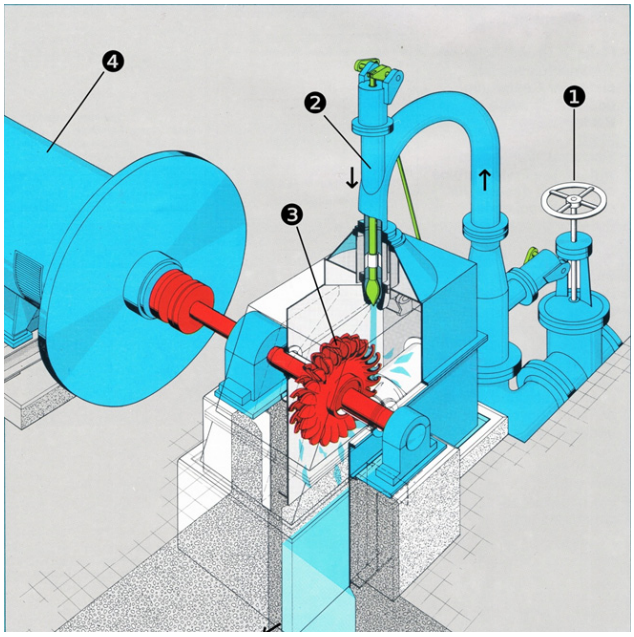


Figure 26 Arrangement with Pelton turbine (source Voith Heidenheim)

- For the turbine dimensioning the maximum available discharge (corresponding to the peak demand of the supplied consumers) has to be taken into account. To avoid conflicts of interest, drinking water demand has to be considered when fixing the design flow of the turbine.

- Vertical and horizontal types of Pelton turbines are available. For the vertical type, the generator will be directly coupled to the turbine. The rotation speed of the turbine has to be compatible with the generator speed.
- To avoid any impact on the water quality, all parts in contact with water have to be stainless steel. Contamination by lubricants must be prevented at all costs.
- To allow for more flexible regulation and thus more efficient operation (especially at sites with high flow), the Pelton turbine should be equipped with more than one nozzle.

Regulation unit

The regulation unit must take the below into account:

- As mentioned earlier, the general regulation functions are speed control at no load operation, power output control, water level control, frequency control (synchronization, island mode operation) and emergency shut-down in case of mechanical or electrical failures.
- In most drinking water systems in Lebanon and according to the technical data on hand, Pelton turbines are the appropriate turbine type for hydropower systems. The regulation arrangement for this turbine type depends on the respective number of turbine nozzles and their actuators.
- The optimal operating point for the turbine is defined based on the flow duration curve of the respective site. Pelton turbines operate at high efficiency (>70%) even if the flow decreases to 50% of the maximum flow.
- Water jet deflector: In case of an emergency, the turbine must be automatically disconnected from the water jet via a deflector.
- Application of an electrical actuator to regulate the turbine instead of oil hydraulic systems. The design has to be made in such a way that ensures the operation of the actuator in case of a power breakdown. For example, an emergency power supply of 24V DC can be installed to actuate the turbine nozzle or counterweight thus closing the turbine inlet and opening the bypass.
- The maximum water level in the discharge basin has to be lower than the turbine nozzle, to ensure that the Pelton wheel does not rotate in the water and to avoid water splashing.
- An automatic bypass valve for the hydropower plant in a drinking water system guarantees the continuous operation of the existing infrastructures (in case the hydropower system is out of operation).

Generator unit

The generator unit of a hydropower system installed in a drinking water system has to fulfil the same requirements as a generator unit of a hydropower system in a thermal power plant.

5.3.3 Requirements for a hydropower plant in an irrigation system

Intake and pipeline system

Integration of a hydropower system into an existing irrigation infrastructure should not have any negative impact on the primary function of irrigation.

The following requirements have to be considered:

- The design flow of the proposed power plant must not be lower than the irrigation water demand.
- A screening system (trash rack) has to be installed at the intake. In general (and accordingly at the visited sites in Lebanon), irrigation systems are equipped with screening gates. However at the visited site the clearance between the trash rack bars is not sufficient for the hydro turbine. Generally, the clearance between the bars has to be smaller than 50% of the distance between the turbine runner wings or the nozzle opening in case of a Pelton turbine.
- Spillway at the power plant intake: All visited open channel irrigation systems have a spillway that can be integrated in a hydropower system.
- A bypass valve and pipe at the turbine may be required to guarantee the primary function of the infrastructure. The water supply has priority above energy production and in case of grid or turbine failure the water flow must bypass the turbine without any interruption.

The hydropower potential of irrigation systems in Lebanon, which have pipelines instead of open concrete channels, is often limited due to high friction losses (similar to the case of drinking water systems). This phenomenon is described above for the case of the Falouss irrigation system. In many cases available pressure head is lost through friction losses in pipes with small diameters. If new pipelines with bigger diameter have to be installed the additional cost has to be considered in the economic analysis of the hydropower plant.

In case of open concrete channels, as e.g. in Qasimia irrigation system, a new penstock has to be mounted at the power plant intake.

Turbine unit

The turbine unit must take into consideration the following:

- An efficient use of the available potential can be achieved via operating the turbine all year long (during and outside the irrigation period).
- For a proper turbine design, a flow duration curve for the respective site is required.
- The water flow will be limited to the turbine design flow in case the turbine will be installed on the same irrigation pipeline, as is the case in the Falouss irrigation site. For the Qasimia irrigation system, the turbine will be parallel to the irrigation channel and will consequently not influence the primary function of the existing infrastructure.
- Due to the high flows, mostly Kaplan or Francis turbines are the appropriate choice.
- The recommended location to install the turbine is before the pressure breaker basin. Thus the maximum available head can be made use of and conflicts of interest can be avoided.
- In locations where enough flow is available, installation of more than one turbine unit allows for higher flexibility in operation. This means that even if the available flow for the turbine decreases (because more flow is required for irrigation), the power plant can still operate at high efficiency because one turbine unit can be switched off.
- The main consideration especially when installing a Kaplan or propeller turbine is the cavitation. In general, a turbine should be guaranteed against deterioration due to cavitation for the first 8,000 hours of operation.

Regulation unit

The same principles of regulation as described for hydropower systems in drinking water systems above can be applied here.

For most irrigation system sites in Lebanon, a Kaplan turbine is expected to be the most suitable option. The regulation of a Kaplan turbine (as mentioned in the paragraph on regulation of hydropower systems in thermal power plants) is realized in three modes depending on the fluctuation of the flow.

The flow in such systems is expected to be characterized by high variations. In such cases, the regulation mode for Kaplan turbines via adjustable runner blades and wicket gates allows to achieve efficient turbine operation.

Generator unit

The requirements for generator units as described in the chapter "hydropower plants in thermal power plants" are equally applicable here.

5.3.4 Requirements for a hydropower system in a wastewater treatment plant

Wastewater treatment plants in Lebanon do not have significant hydropower potential at present and therefore will not be taken further in this assessment.

5.3.5 Maintenance

Maintenance items to be considered are listed below;

- Access roads and doors must be designed in such a way that all equipment (Turbine generator, Switchboard) can be installed easily and without risk.
- The turbines shall be designed to allow for easy inspection, maintenance and major overhaul. It must be possible to disassemble any unit without interfering with the adjacent unit and without modifications of the powerhouse structure.
- Hand holes are required for a direct access to turbine runner or guide vanes to do the maintenance without dismantling the runner case.
- A main valve / gate or at least stop logs have to be mounted before the turbine inlet to be closed to assure safety maintenance.
- Lifting crane in the powerhouse: The equipment shall feature lifting provisions such as clevis, eyebolts, etc. in order to facilitate easy assembly and disassembly of the equipment. The capacity must be sufficient to lift the turbine and generator during installation as specified by the suppliers.

5.4 Grid connection analysis

The connection mode (stand alone or grid connected) will be determined based on an analysis of the following data:

- Expected power output of the proposed plant
- Next grid access point from the site location
- Type of the hydropower resource
- The cost of the required equipment to realize grid connection
- Sufficient electricity demand "on site" in case of isolated operation

Most visited sites are close to the public grid. All potential sites will be government owned. Isolated sites or sites developed by private developers are not the subject of this study. Clear regulations for private grid connected power plants do not yet exist in Lebanon. The absence of such a regulation is a clear obstacle for any development of grid-connected, privately owned renewable energy generation plants.

5.5 Financial Analysis

For hydropower systems in thermal power plants, the frame conditions might be relatively easy and obvious. Each kilowatt hour from the hydropower system does not have to be produced by the fossil fuel driven steam turbines. In this case, it is easy to justify that the "relevant tariff" is the production costs per kWh which are in the range of $c19/kWh (avoided cost principle). In case of a government owned thermal and hydropower plants, the government itself can save on the cost for subsidization, which is usually required to sell the expensively produced electricity (at least $c19/kWh) at a very low tariff ($c9.4/kWh) to the consumers.

In case of hydropower systems in drinking water or irrigation systems the logic would theoretically be the same in case the hydropower system belongs to the government. In case of a privately owned hydropower system however, the owner could also apply the "avoided cost" principle, but since normal consumers only pay $¢9.4/kWh, the avoided costs is much less. Meaning, if the private hydropower producer uses the electricity for his auto-consumption, he/she can only make a profit in case his hydropower production costs are below $¢9.4/kWh. If he/she tries to sell electricity via a power purchase agreement at a higher price to the national grid, he/she could increase the profitability subject to the feed-in tariff applied. So far, no regulation on the definition of a feed-in tariff exists, meaning that the feed-in tariff would have to be negotiated on a case-by-case basis with the public utility. As the government has to cover the difference between production and sales price as subsidy, it should consequently at least apply the specific production cost (for the respective plant) or even better the avoided cost based on fossil fuel plants as a feed-in tariff.

Generally, the investment cost for a hydropower plant depends not only on the costs for civil works, electro-mechanical equipment (turbine, generator, regulation) and the transmission and distribution system, but also for engineering, construction, supervision and commissioning.

Figure 27 describes the typical cost distribution for a typical run-off-river MHP system.

Cost distribution

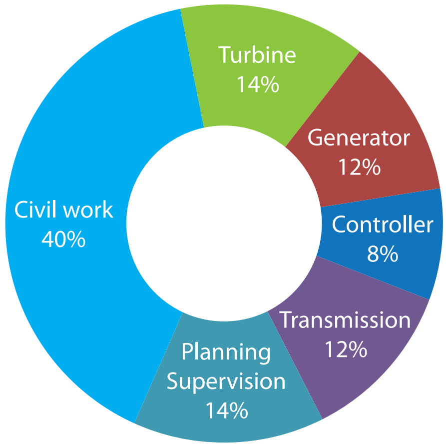


Figure 27 Average cost distribution of micro-hydro systems adopted from Indonesia experience (Source: Own diagram by Entec, 2011)

The following issues must be considered when analysing costs:

- The dimensioning of a turbine is always site specific and depends on the available head and flow. Costs are also dependent on the manufacturing quality of the turbine. The costs of turbines per kW can only be compared if they are of the same type and quality. Higher initial investment costs for a good quality turbine corresponds with lower maintenance costs and a longer operational life as compared to low quality designs.
- The cost of engineering, construction supervision and commissioning can be estimated at 12- 16% of the total costs.
- Civil works can easily make up 50% of the initial investment costs. However, regarding the cases analysed in the present study, often existing infrastructure can be used, therefore reducing the civil construction costs.

In the current phase of analysis, no detailed engineering has been carried for the visited sites so that actual costs cannot be calculated. The economic analysis will rather be based on the assumption of fixed basic specific investment costs (in USD per installed kW) for the construction of a hydropower system under Lebanese conditions.

The approximated fixed costs for the proposed systems are about 4,000 USD/installed kW. Depending on the difficulty and complexity of the specific site we introduce a correction factor (Cf) to estimate the individual specific construction costs for each site. The correction factor is a rough estimate of a percentage increase of the specific investment cost. For example, a correction factor of 30% means that the specific investment costs are about 4,000 USD x 1.3 = 5,200 USD per kW installed capacity.

Site Code	Site Name	Sym	Correction factor (Cf)	USD / kW
LEB001	Naher el Bared lake	A	10%	4,400
LEB004	Ain Leghwaibe (b)	A	5%	4,200
LEB007	Qasimia Irrigation System	A	10%	4,400
LEB008	Falouss Irrigation System	A	10%	4,400
LEB012	Zahrani Power Plant	C	15%	4,600
LEB013	Zouk Power Plant	C	35%	5,400
LEB014	Jieh Power Plant	C	35%	5,400
LEB015	Deir Ammar (Beddawi) Power Plant	C	10%	4,400
LEB016	Hrayche Power Plant	C	15%	4,600
LEB017	Saida water station (a)	D	10%	4,400
LEB018	Saida water station (b)	D	10%	4,400
LEB019	Kaa el Rim	D	5%	4,200
LEB020	Ain Leghwaibe (a)	D	10%	4,400

Table 6 Correction factor (Cf) and estimated specific cost per installed kW for selected potential hydropower sites

With these specific costs, the internal rate of return for the selected sites is calculated under the following assumptions on plant capacity factor, discount rate, inflation rate and O&M costs.

Hydropower plant in…	Plant capacity factor
Irrigation system	25%
Thermal power plant	80%
Drinking water system	50%
Other inputs	Value
Discount rate (nominal)	7%
Inflation rate	5%
Interest rate	3%
Loan duration	5 years
Service life	20 years
Operation & maintenance cost	5 % of investment cost

The analyses are made for two "energy sales options" (tariff for energy sales to the grid):

- Electricity tariff $¢9.4/kWh (= subsidized sales price in Lebanon)
- Electricity tariff $¢19/kWh (= real production price in Lebanon)

For both options, a tariff increase of 5% per year is assumed which approximates the general annual inflation rate. Table 7 presents the calculated internal rates of return (IRR) for the selected potential sites, applying the specific investment cost as presented in Table 6 and the two tariff options as described above.

Site Code	Site Name	Sym	IRR (elec. tariff 0.094 $/kWh)	IRR (elec. tariff 0.19 $/kWh)
LEB001	Naher el Bared lake	A	0%	3%
LEB004	Ain Leghwaibe (b)	A	0%	4%
LEB007	Qasimia Irrigation System	A	0%	3%
LEB008	Falouss Irrigation System	A	0%	3%
LEB012	Zahrani Power Plant	C	13%	45%
LEB013	Zouk Power Plant	C	9%	35%
LEB014	Jieh Power Plant	C	9%	35%
LEB015	Deir Ammar Power Plant	C	15%	49%
LEB016	Hrayche Power Plant	C	13%	45%
LEB017	Saida water station (a)	D	3%	23%
LEB018	Saida water station (b)	D	3%	23%
LEB019	Kaa el Rim	D	4%	24%
LEB020	Ain Leghwaibe (a)	D	3%	23%

Table 7 Internal Rate of Return (estimated) for tariffs of $¢9.4/kWh and $¢19/kWh

Based on the above specified frame conditions (load factor, inflation, etc.), a sensitivity analysis was made for the two tariff options $¢9.4/kWh and $¢19/kWh and for varying specific investment costs. The resulting graphs (see Figure 28 and Figure 29) reveal under which conditions (tariff, type of power plant, and specific investment cost) a project is financially feasible. A limit of 10% for the IRR is considered to be a threshold beyond which the investment is considered to be attractive.

In the figures, the specific investment costs vary between 2,000 and 8,000 USD/kW.

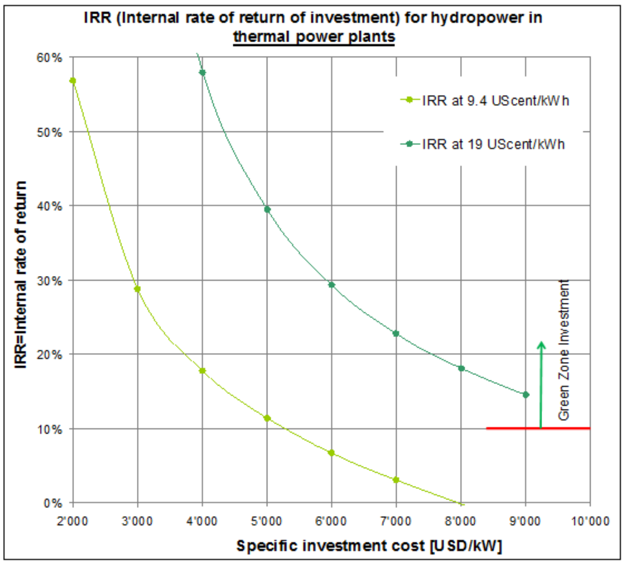


Figure 28 Sensitivity analysis for the IRR as function of the specific investment costs for a hydropower system in a thermal power plant at a tariff of 9.4 and $¢19/kWh)

Figure 28 shows the results of the sensitivity analysis for hydropower systems in thermal power plants, assuming a tariff of $¢9.4/kWh (light green) and with a tariff of $¢19/kWh (dark green). According to Table 6, the specific investment cost for Type C hydropower systems ranges between 4,400 and 5,400 USD/kW, and the IRR is almost in all cases exceeding 10%.

According to Table 7, the IRR for Type C plants is 9 - 15% for a tariff of **$**¢ 9.4/kWh and 35 - 49% for a tariff of $¢19/kWh.

The potential site of Zouk thermal power plant (LEB013) has a lower IRR compared to other power plants, because it is assessed to be more complex. Due to the low head and very high flow, a big turbine size will be required with more expensive civil works.

Deir Ammar (LEB015), Zahrani (LEB012) and Hrayche (LEB016) thermal power plant sites are the sites with the most attractive potential.

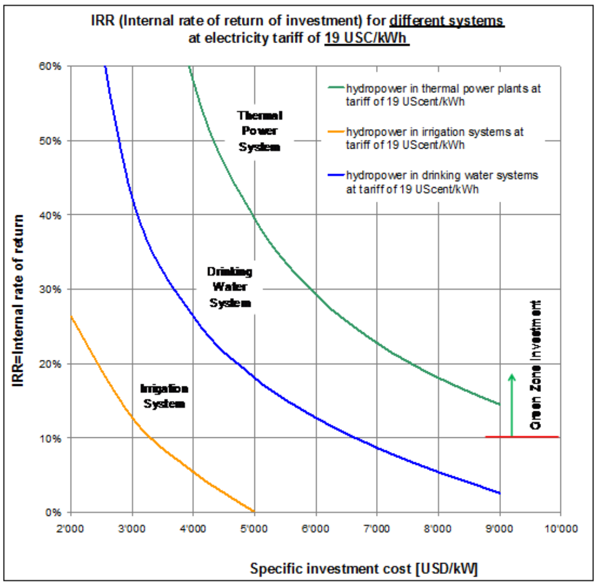


Figure 29 Sensitivity analysis IRR as a function of specific investment costs for different potential power plants (Tariff (US) 19$¢/kWh)

Figure 29 shows the IRR as a function of specific investment costs for all three types of systems (A, C and D) assuming a more attractive tariff of $¢19/kWh. The analysis shows that hydropower exploitation in thermal power plants and drinking water systems is very attractive (high IRR) whereas hydropower systems in irrigation systems seem to be only attractive in case of relatively low investment costs (< 3,200 USD/kW). The relatively low attractiveness of hydropower in irrigation systems (even at a tariff of $¢19/kWh) is mainly due to the short operation time of the hydropower plant (short irrigation period), meaning a consequent low load factor. This issue could, however, be reanalysed if the operational time could be extended.

6 Guidelines for the establishment of bidding documents

The development of any hydropower system would be under governmental responsibility and ownership until privatization takes place in Lebanon according to Law 462 or some alternative. In Lebanon, the Council for Development and Reconstruction (CDR) is responsible for tendering and procuring funding for government physical infrastructure projects (electricity, telecommunications, roads, and public transport), social infrastructure, basic services, and productive sectors. Thus, rules and procedures as defined by the Council would have to be followed. In case an international financing agency is involved, their specific tendering and procurement roles would have to be followed as well.

6.1 General procedure of project development

The scope of the present study was a general evaluation of the potential of non-river based hydropower potential. Reconnaissance visits to the sites have been conducted to roughly assess the potential. However, no detailed engineering designs could have been realized in the current stage. Before establishing tender documents a detailed design would have to be elaborated for the sites of interest. Usually, the planning process of a hydropower system includes the following steps:

1. Desk study
2. Initial site assessment / Reconnaissance visit
3. Pre-feasibility study
4. Feasibility study
5. Detailed study

The subsequent implementation includes:

6. Tendering
7. Contracting
8. Implementation
9. Testing & commissioning
10. Normal operation (Operation and Maintenance)

The different steps of the planning process are briefly described here:

Desk study

» The purpose is to become familiar with the physical, hydrologic and socio-economic profile of the project area by using maps, hydrological data etc. but without visiting the site.
» In many cases potential sites can already be preliminarily identified which makes the subsequent reconnaissance visit more efficient.
» The desk study may also reveal the absence of hydropower potential and time and resources for traveling to the proposed site can be saved.

Reconnaissance site visit

» Short visit to the proposed site to verify the findings of the desk study and to identify the existing hydropower potential.

Pre-Feasibility (FS) study

» A pre-FS will usually be conducted to determine which of several proposed projects, sites or technical options are most attractive to hydropower development.
» Preliminary assessments are reviewed and worked out with more detail. Development options are worked out and conclusions and recommendations are made in view of which of these options should be taken to FS-level.

Feasibility study

» Final assessment for the development options with more details.
» On the basis of the FS, the developer will take the final decision for or against the project and the documents shall allow him to present the project to potential lending institutions with sufficient analysis and details.

Detailed design

» Preparation of the detailed layout of the scheme, canal and structure drawings in final detail.
» The detailed design usually includes the preparation of the required tender documents.

6.2 General remarks on development of bidding documents

Final design and elaboration of bidding documents were not part of the present study. However, the following paragraphs give indications on how to proceed on these working steps later on.

In general, before preparing the bidding documents, a decision has to be taken whether the entire design and construction work is given to a general contractor or whether the design is prepared independently as a basis for one or several call/s for proposals from different contractors for the various tasks (e.g. civil construction, electro-mechanical equipment, transmission).

It is recommended to first consider the availability of an appropriate turbine for the specific cases before preparing the design of civil works.

In any case, the design of such non-river based power plants has to strictly follow the overall restriction that the operation of the existing infrastructure (irrigation, water supply, electricity production etc.) **must not** be disturbed. The respective reservations must be well defined in the bidding documents.

Civil design

A BoQ (Bill of Quantity) will be provided as result of the final design, with the specified quantities of, for example, excavation work, reinforced concrete structures, gates, trash rack, etc. As already mentioned above, especially for the case of thermal power plants, the civil design very much depends on the selected turbine.

Electro-mechanical equipment

Particularly for hydropower stations in thermal power plants, the main cost component will most probably be electro-mechanical equipment. Therefore, the selection of appropriate EM equipment merits special attention.

Turbine

A turbine has to be designed according to the following parameters:

- Design head
- Design flow
- Efficiency at different flow rates, e.g. for 100%, 75%, 50%, 25% flow rate
- Admissible suction head (especially for sites in thermal power plants which are close to sea level; during storms the tail water level may rise due to waves, it is advisable to install the turbine 4m or more above sea level).
- Water quality (for thermal power plant sites); Seawater at relatively high temperature and at 3.5% salinity is used. The turbine components, especially runner and guide vane should be made of stainless steel and covered with seawater proof painting.
- Water Temperature: the water temperature has an influence on the cavitation and the admissible water level of the turbine above the seawater level. The cooling water temperature is 5 - 10 Degrees Celsius above seawater temperature.

Month	seawater	cooling water min	cooling water max
Jan	15	20	25
Feb	16	21	26
Mar	18	23	28
Apr	19	24	29
May	21	26	31
Jun	26	31	36
Jul	27	32	37
Aug	29	34	39
Sep	28	33	38
Oct	27	32	37
Nov	22	27	32
Dec	18	23	28

Average water temperature (Lebanon sea)

Source;http://www.temperatureweather.com/mediterr/wetter/de-wetter-in-libanon-beirut.htm

Controller

Electro-hydraulic controller with synchronizing device and emergency shut-down in case of grid failure (reverse power). The controller should have a power factor (cos phi) control and water level control. The controller should be equipped with the following displays:

- Temperature of turbine and generator bearings (with alarm)
- Temperature of 3 stator windings (with alarm)
- Water level display
- Guide vane position (with opening limitation)
- Power
- Operation hours
- Three-phase voltage and ampere

Especially in case of a long penstock, the control system must avoid water hammer problems (maximum opening and closing time must be defined during final design).

Mechanical Transmission

In most cases, especially in case of low head sites, the turbine speed can be lower than the standard speed of 1,000 or 1,500 rpm for standard generators found on the market. In this case, a speed accelerator is required, which is installed between turbine and generator, to increase the speed and thus to meet the appropriate generator speed. This solution is often more economical than asking suppliers to design a generator with the required speed. The mechanical transmission can be gears or belt increasers. For high head sites the turbine speed can reach the 1,000 or 1,500 rpm standard generator speed. In that case, a direct coupling of turbine and generator is the more common solution in order to reduce losses and to minimize maintenance.

Generator

The position and size of the generator foundation as well as requirements for the power cable trenches shall be designed and indicated accordingly in the tender documents. All specifications shall be shared with the civil work contractor in order to allow him to properly design and plan the powerhouse (if required).
As mentioned before, most of the sites are close to the public grid and hence the generator has to be designed to operate in "grid-connected mode". The dimensioning of the generator shall be based on the maximum mechanical power of the turbine. Generator voltage and speed/frequency have to be specified in the tender documents. The generator should be delivered with automatic voltage control with the option of a power factor (as well called cos Phi) control. It should have PT100 temperature sensors for bearing and stator winding temperature. It should withstand the maximum possible speed defined by the control system.

Operational limits and recommendations

Thermal power plants

The flow of the cooling water must not be influenced by the operation of the hydropower plant. Other considerations are as follows;

- Even if the integrated hydropower plant is started, stopped or at power failure, the cooling water flow must always be ensured without any interruption. The civil structures of the hydropower system should therefore be designed without any movable weirs. Instead, a properly designed diversion weir at the intake of the headrace channel should be provided for. If the turbine has to be stopped due to grid failure, the flow could thus easily bypass the turbine with only a small rise of water level in the channel.
- If the cooling water flow is changing (mostly by changing the number of pumps), the water level control must react accordingly.

Water supply systems

Water supply has priority compared to electricity production.

- An automatic water level control is required in order to ensure the functionality of the reservoir (as a buffer for flow fluctuations)
- To guarantee the water flow at grid failure, in case of turbine stand still or revision, usually a controlled bypass in parallel to the turbine is required. In case of a Pelton turbine, a jet deflector may be used instead of an automatic bypass valve.
- Due to the long pipeline system, special care has to be taken concerning water hammer problems.

Irrigation systems

Irrigation is the first priority.

- Option 1: The hydropower system is installed in a step within the irrigation channel. Then, the hydropower plant has to be designed in a way that irrigation is not influenced by power production.
- Option 2: The hydropower system is diverting water from an irrigation system back into a river. Then, once the turbine is in operation, the water flow in the irrigation channel is fully or partially diverted to the turbine. If the turbine is closed and the water is not required for irrigation a bypass or spillway has to ensure a safe discharge of the flow.

7 Social and environmental aspects

Conventional runoff river or storage hydropower plants may have considerable impacts on the environment and/or the competing water uses at the river. Water rights and land ownership issues are often difficult to solve. In general, both - the use of energy in stand-alone or grid connected operation - require clear regulations.

Given the fact that no feed-in law exists in Lebanon so far, it seems that private ownership of a hydropower plant is not a realistic option, except in the case of self-supply. In case of a governmental project, the produced energy can either be consumed directly (on-site) or it can be fed into the national grid. For hydropower systems in thermal power plants, the produced energy from the hydropower plant can be considered as "alternative energy production" and sort of "replace" thermal power production. Hydropower electricity is then fed into the grid as the electricity from the thermal power plant would be. In this case, the specific production cost of electricity from the thermal power plant is taken as a reference (avoided cost) in order to evaluate if electricity from hydropower is an attractive alternative.

	Hydropower system in			
Relevant aspects	**Irrigation system (A)**	**Wastewater treatment plant (B)**	**Thermal power plant (C)**	**Drinking water system (D)**
Land issues	Possible	no	no	Possible
Water right	Possible	no	no	no
Water conflict	Possible	no	no	Possible
Community involvement	Possible	no	no	Possible
Catchment area	Yes	no	no	yes
Fish and aquatic live	Yes	no	no	no
Residual water in river	Yes	no	no	Possible

8 General Conclusions

Increasing the security of energy supply is one of the most important objectives of modern day economies, and Lebanon is no exception. The diversification of energy sources increases the resilience of the electricity system, making it less subject to the impact of certain fuel source interruptions and fuel price fluctuations. Therefore every kW counts, and in this respect this study, driven by the Lebanese Ministry of Energy and Water (MEW), has focused on a power source that has not, to date in Lebanon, been considered for power consideration.

The main messages of the report are the following;

- Non-river based hydropower plants have potential in Lebanon, although the lack of sufficient data such as, for example, the mapping of water supply networks, does not allow the complete potential to be exactly measured.
- Data availability and proper information recording (i.e., digitizing information) is required, particularly from the National Water Authorities.
- In the present study, the most interesting sites are related to thermal power plants
- Investment in hydropower systems which can be integrated into thermal power plants in Lebanon was found to be economically attractive (mainly due to high operational hours which translate into a high load factor and high avoided costs).
- A well-defined feed-in tariff for hydropower which exceeds the specific production costs (per kWh) would also encourage private investors.
- A new electricity tariff for hydropower electricity would encourage the investment in drinking water hydropower plants.
- Hydropower in irrigation systems in Lebanon can be utilized when the operation period is, at least, longer than 56-months. If water is flowing all year round via the irrigation channel (in wet and dry seasons), hydropower exploitation would become even more attractive.
- The annual saving of oil, in all cases, contributes to the saving of foreign currency and thus improves the trade balance.
- Avoiding greenhouse gas accumulation by a considerable amount should allow for the application of a CDM or even a newer negotiated agreement.

Tapping into hydropower from non-river sources increases the available locally secured supply of renewable energy power by approximately 5 MW. To put this in perspective, and taking the capacity factor of all the indicated sites across all types of hydropower sources listed in this report (see Chapter 5.5), the annual output of 5 MW is approximately 27.4 million kWh per annum. This amount of power can electrify 5,477 homes assuming 5,000 kWh annual electricity demand per household. Put another way, this amount of power is sufficient to electrify 273 tall buildings (with 20 apartments each) as those found in Beirut and/or other major cities. This power is there for the harvest.

Furthermore, a second and yet major benefit of securing this power source is also in the form of CO_2 equivalent emissions reduction, a fact that should not go unmentioned. The latest CO_{2e} ,grid factor, based on a Clean Development Mechanism (CDM) project submitted by Lebanon in 2011 to the UNFCCC, used 0.65 kg CO_{2e} / kWh. Therefore, approximately 17,800 tons of CO_{2e} would be saved annually.