Technical and economic prefeasibility study of mini-hydro power plants in Venezuela. Case study: El Valle River

[1*] Victor TREJO, [1] Gabriela DIAZ, [2] Luis ROJAS-SOLORZANO,

[1] Simón Bolívar University, Department of Energy Conversion and Transport
Sartenejas, Caracas, 1080, Venezuela
[2] Nazarbayev University, Faculty, Department, Institute
Astana, 010000, Kazakhstan

* E-mail: victormanueltn@gmail.com

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Abstract

The technical and economic feasibility of the installation of a mini-hydroelectric power plant on El Valle River in Venezuela is assessed. Special attention is paid to modeling Venezuela's energetic and economic scenarios. Sensitivity, risk and emission analyses are also carried out. The results of the study show very attractive economic indicators, such as a 280.3% internal rate of return and a 0.4 years pay-back period. The positive results of the study are indication that clean energies could find very fertile scenarios in countries such as Venezuela, where the advantages of their application may not be evident.

I. Introduction

Venezuela's income derives almost exclusively from oil exports and it is one of the few countries favored with both, large amounts of fossil fuels and important renewable resources. According to statistics from the International Energy Agency (2013), 68.5% of the country's internal electricity consumption is produced by hydroelectric power plants and the rest is covered by thermoelectric generation. However, over 87% of the hydroelectric production comes from a single source, the Simón Bolívar Hydroelectric Central, which ranks as the fourth largest in the world, and no investments in small hydros are scheduled. Investments in thermoelectric power generation are instead currently being carried out. At this moment, Venezuela is also the country with the largest CO_2 generation per capita in Latin America (IEA, 2013). This situation, along with typical highly competitive international fuel prices that otherwise would increase internal revenues received from oil exports, extremely needed to fund education and social programs, make Venezuela a very particular scenario for renewable energies. Recent changes in oil prices introduce uncertainty in the described scenario.

The RETScreen® V.4 software is a widespread clean energy project analysis tool that facilitates the execution of prefeasibility and feasibility analyses. Several different types of projects have been studied with this tool, a few examples of which are a comparison between landfill gas and waste incineration for power generation in Ghana by Anaglate et al. (2012), the evaluation of prospects of wind farm development in Algeria by Himri et al. (2009) and an environmental, technical and financial feasibility study of solar power plants in Iran by Hajiseyed et al. (2012), the Assessment of the prediction capacity of wind-electric generation models by Romero and Rojas-Solórzano (2014), to mention just a few.

In this work, the technical and economic feasibility of the installation of a mini-hydroelectric power plant on El Valle River in Venezuela is assessed supported on RETScreen® software. This paper is organized as follows: In the first two sections, technical and economic feasibility studies and their results are described in detail. Special attention is paid to modeling Venezuela's energetic and economic scenario to assess the viability of the project under these circumstances. Sensitivity and risk analysis complement the prefeasibility study and are presented in section three. In section four, the CO_2 emission analysis is described Finally, conclusions are drawn.

II. Technical analysis

II.1. Installation site and type of power plant

The El Valle River in the Los Salias Municipality of the Miranda State, Venezuela, was chosen for this study. The river, along with the streams Cují and El Indio, feed the La Mariposa reservoir. The water from the reservoir flows by gravity into the La Mariposa water purification facility, which, according to Hidrocapital (2013), the company in charge of its operation, has a maximum capacity of 4.3 m^3/s and provides drinking water to 80% of Los Altos Mirandinos community and 15% of Caracas, Venezuela's capital city. In order to minimize investment costs and the effect on the environment, the installation of a run-of-the-river hydroelectric power plant was chosen.

II.2. Evaluation of hydric resource

The estimate of usable flow was based on hydrological data provided by Venezuela's National Institute of Meteorology and Hydrology (INAMEH). The data comprised monthly average, minimum and maximum flows in the El Valle River during the period 1978-1991 measured at El Valle in la Mariposa hydrological station. With this information, the flow-duration curve in fig. 1 was prepared. In accordance with the type of power plant (run-of-the-river) and turbine selection, a flow of 1.25 m^3/s exceeding 97.7% was set as design flow for the power plant.

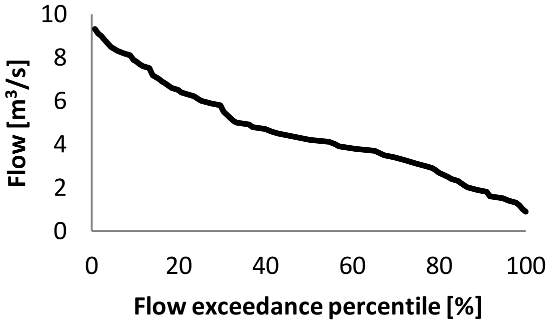

Fig. 1: Flow duration curve of El Valle river

For estimating the available hydraulic head, the computational tool Google Earth was employed. This tool is capable of providing the elevation profile along a trajectory drawn by the user on a satellite view of the terrain. A trajectory along the El Valle River was traced in order to estimate the hydraulic head. The resulting elevation profile is shown in fig. 2 with two arrows indicating possible positions for the flow intake and the turbine. The section limited by these two positions has an horizontal length of 0.55 km and a hydraulic head of 40m.

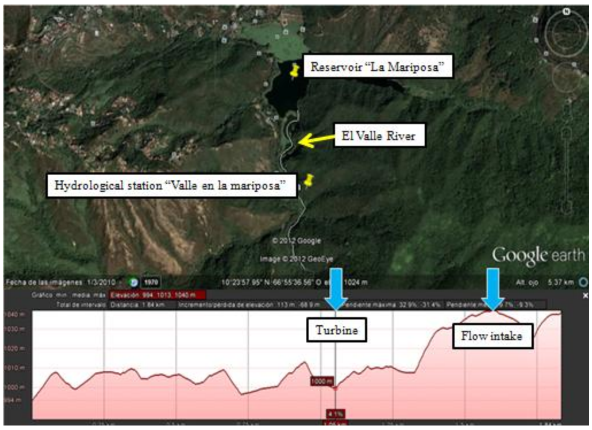

Fig. 2: Elevation curve along the El Valle River [Google Earth, 2012]

II.3. Turbine selection

Based on the available flow and head, a Francis turbine emerged as the most appropriate unit ("Minicentrales hidroeléctricas - Manual de energías renovables", 2006). A 405 kW turbine along with its accessories (generator, governor, excitation system, main inlet valve, spare parts and special tools) were chosen from the catalogue of a manufacturer and its characteristics are summarized in table 1.

Table 1: Key characteristics of selected turbine

Turbine features	
Max head	42m
Design head	40m
Runner diameter	0.5m
Design flow	1.25m^3/s
Unit output	405kW
Turbine efficiency	89%
Generator efficiency	92.5%
Frequency	60Hz

The annual production of energy was estimated taking into consideration the operating conditions of the turbine, its type and flow-duration curve, a typical power curve and the generator-turbine efficiencies. The obtained projected annual energy is 3121 MWh, which shows that the El Valle River is adequate for the installation of a mini-hydroelectric power plant.

III. Economic analysis

The economic prefeasibility analysis was carried out in the RETScreen® V.4 software. Electricity prices in Venezuela are very low since they are subsidized by the government, which means that investing in electricity generation is not profitable for any private entity unless some sort or arrangement is agreed upon with the authorities. Therefore, the study was carried out from the perspective that the only possible investor is the Venezuelan government, for whom the investment may be beneficial in the sense that it opens up the opportunity for substituting thermoelectric generation and exporting the fuels that would have been otherwise consumed. The modeling of the project is described in detail in this section.

III.1. Value of the produced kWh

Electricity prices in Venezuela has been subsidized under regulation since the year 2002 as indicated by the official gazette from April 3th (2002) and do not reflect inflation rates. For this reason, using the commercialization price of electricity as the value of the produced kWh underestimates greatly the economic impact of any generation project in the country. Since Venezuela is an oil producer and exporter, each kWh produced via renewable energies translates into a kWh that is not produced in thermoelectric power plants and can thus be exported at considerably higher international rates.
The investment in renewable sources of energy competes directly with the ongoing expansion of Venezuela's thermoelectric installed capacity. More specifically, hydroelectric power currently competes with power generation with gasoil (diesel); according to Venezuela's Centro Nacional de Despacho (2010) generation with fueloil and natural gas decreased 0.57% and 6.77%, respectively in the year 2010 with respect to 2009, while generation with gasoil increased 25.4%. Therefore, the value of the saved kWh was set to $242/MWh according to gasoil prices reported by the IEA (2012) for the date of the modeling and after considering the efficiency of a typical diesel power plant according to the U.S. Energy Information Administration (2013).

III.2. Financial parameters

A project life of 50 years was considered since hydroelectric power plants can operate for over 50 years without major overhauls. A yearly average escalation rate for gasoil was calculated with available data corresponding to the period 2007-2014 and an average U.S. inflation rate was calculated with data corresponding to the period 1980-2010 (Index Mundi, 2014). The obtained value of the former is 1.1% and for the latter 2.6%. For the discount rate, a value of 10% was chosen, which corresponds to a typical return value of Venezuelan U.S.$ bonds

III.3. Costs

The costs of the selected turbine and related equipment are detailed in table 2 and in total add US$104000, which representsthe highest portion of the initial costs.

Table 2: Costs of turbine and related equipment

Equipment	Cost [US $]
Turbine	38000
Generator	25000
Governor	17000
Excitation system	12000
Main inlet valve	6000
Spare parts and special tools	6000

The costs of the feasibility study, development and engineering were estimated as 10% of the equipments and civil work costs, and equal to 8.4% of the initial costs. As reported by the Instituto para la Diversificación y Ahorro de Energía (2006), civil works for a hydroelectric power plant typically represent 40% of the initial costs. This is a conservative value for a run-of-the-river installation and it is meant to account for any contingencies. Transportation fees for the equipments were calculated as $10000, near 10% of the equipments costs.
3 months were estimated as the time necessary for the construction and start up of the power plant. It was estimated that during this period, 2 engineers, 3 technicians and 3 manual workers would be required. Additionally, the turbine provider demands a supervisor and the future operator of the power plant would require training during this period. The costs associated to the described personnel are detailed in table 3. The salary of the supervisor is fixed by the provider, while the rest of the salaries were calculated based on Venezuela's labor market.

Table 3: Salaries of staff during construction and start up

Quantity	Position	$/month	Total
1	Supervisor	2400	2400
2	Engineers	1860	3720
3	Technicians	1290	3870
3	Manual workers	1000	3000
1	Operator	1290	1290
	Complete staff (3 months)	$40260	

III.4. Results of the prefeasibililty study

The economic indicators resulting from the prefeasibility analysis carried out are summarized in table 4.

Table 4: Economic indicators of the project's profitability

Indicator	Value
Internal rate of return	280.30%
Pay-back period	0.4 years
Net present value	US$7 992 008
Equivalent anual savings	US$804 050
Benefit-cost ratio	30.77

As the resulting economic indicators show, the herein described project would be highly profitable, the investment of which would be recovered rather quickly (1.1 years) and that would produce benefits during its complete lifetime. The study shows a very high internal rate of return (280.30%), which is quite superior to the discount rate (10%). Figure 3 shows the growth of the Net Present Value in the cumulative cash flow during the project's lifetime. The benefit-cost ratio indicates that for each dollar invested, $30.77 will be gained including all expenditures, which equates to $804050 as annual savings.

III.5. Risk analysis

The economic gains of the project are achieved through gasoil savings and sales. Fuel prices are difficult to predict since they depend heavily on international politics. For these reasons, it is especially important to assess the possible impact of a decrease in the price of gasoil on the profitability of the project. Sensitivity and risk analyses were carried out.
In the sensitivity analysis, the effects of possible variations of initial costs, maintenance costs and the price of gasoil (modeled as the electricity export rate) on the internal rate of return, the net present value and the pay-back period were considered. Results are summarized in table 5 and show that the most influential factor is the price of gasoil followed by the initial costs. The price of gasoil has a strong influence on all three economic indicators, while the initial costs impact the internal rate of return and the pay-back period mostly. The operation and maintenance costs do not show an important relative impact.

Table 5: Results of sensitivity analysis

Parameter	Relative impact (-)		
	Internal rate of return	Pay-back period	Net present value
Gasoil price	0.8	-0.8	1
Initial costs	-0.55	0.6	>-0.1
Operation and Maintenance costs	>-0.1	<0.1	>-0.1

Following the results of the sensitivity analysis, the influence of the price of gasoil and the initial costs on the profitability of the project were quantified with the risk analysis. A wide sensitivity range of 50% was considered for both factors, i.e., scenarios that combined variations of each factor ranging from 50%

to 150% of the original values were considered. The results of the risk analysis are shown in tables 5 and 6 for the internal rate of return and pay-back period, respectively.

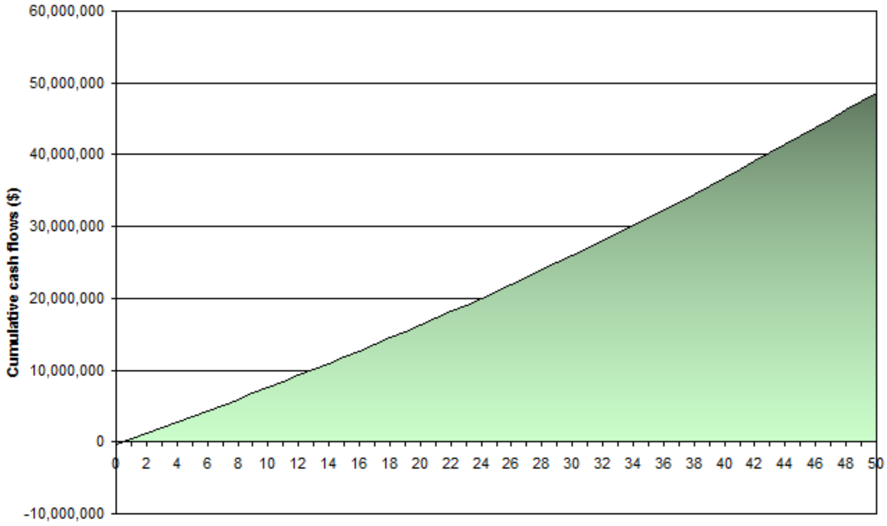

Fig. 3: Cummulative cash flow

Table 6: risk analysis for the internal rate of return

Price of Gasoil variation [%] \ Initial costs variation [%]	-50	-25	0	25	50
-50	274%	183%	138%	110%	92%
-25	417%	278%	209%	167%	140%
0	559%	373%	280%	224%	187%
25	702%	468%	352%	282%	235%
50	845%	564%	423%	339%	282%

An increase of 50% in the initial costs and a decrease of 50% in the price of gasoil result in the worst case scenario: an internal rate of return of 92% and a pay-back period of 1.1 years. These are less attractive, but still very profitable indicators, which shows that, even though the project is very sensitive to variations in initial costs and the price of gasoil, it can still be profitable when facing very unfavorable scenarios such as recent changes in oil price, as long as the gap between gasoil production costs and its sale price remains wide enough.

Table 7: risk analysis for pay-back period

Price of Gasoil variation [%] \ Initial costs variation [%]	-50	-25	0	25	50
-50	0.4	0.5	0.7	0.9	1.1
-25	0.2	0.4	0.5	0.6	0.7
0	0.2	0.3	0.4	0.4	0.5
25	0.1	0.2	0.3	0.4	0.4
50	0.1	0.2	0.2	0.3	0.4

III. Emission analysis

Due to the high demand that the Venezuelan electrical network has been experiencing since the energy crisis of 2009, new thermoelectric plants have been installed along the Venezuelan territory in the recent years.
With the installation of the mini-hydropower plant in the El Valle River, it is possible to contribute to the relief of the already existing network.
Since the electric grid is overloaded, the proposed mini hydropower plant would displace the thermoelectric power plants that are to be installed, likewise contributing to reduce the fuel consumption required for the operation of these new thermoelectric plants and thus, the greenhouse gases emissions. To determine the amount of emissions that would be reduced with the proposed project, an analysis of emissions was performed.
The resulting savings in greenhouse gases emission resulting from this study is 3079t of equivalent CO_2 per year. Some equivalent measures to better visualize this benefit may be considered: 3079t CO2 are equivalent to removing 564 automobiles from circulation, to avoid consuming 7160 barrels of gasoline or 1322961l of gasoline per year.

III. Conclusions

A technical and economic prefeasibility study of the installation of a mini-hydroelectric power plant on the El Valle River in Venezuela was carried out. The technical prefeasibility study showed that the El Valle River reunites the necessary characteristics for the installation of a run-of-the-river hydroelectric power plant.
The economic prefeasibility study was carried out from the perspective that, taking Venezuela's very particular energetic and economic characteristics in consideration, the national government is the only possible investor. The results of the study show very attractive economic indicators, such as a 280.3% internal rate of return, a 0.4years pay-back period and a 30.77 benefit-cost ratio.
Sensitivity and risk analyses demonstrated that, even when facing highly unfavorable variations in gasoil prices and initial costs, the project can still be profitable.

The emission analysis' results indicate possible annual reductions of greenhouse gases emissions equivalent to 3079t CO2.
The profitability of the project, as well as its environmental advantages, is enhanced by the fuel savings and possible export. Both, economic and environmental attractiveness of the installation of the mini-hydroelectric power plant are strongly reinforced by Venezuela's current energetic and economic characteristics. In this sense, the positive results of the study are indication that clean energies could find very fertile scenarios in countries such as Venezuela, where the advantages of their application may not be evident.

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