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Performance in Feasibility Studies of Micro Hydro Power Plants. New Software Development and Application Cases in Cameroon.

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Abstract

Currently in the world, the development of renewable energy appears as a relevant contribution fighting against the climate change. Micro hydro power plants (MHPP) are an excellent method of harnessing renewable energy. Cameroon has lots of small waterfalls suitable for the development of MHPP. But, their development is not yet effective because of the lack of data and technology skills. The objective of this work is to develop and propose a software tool for the feasibility studies of MHPP in Cameroon, which take into account locals advantages and constraints in the intention to contribute to the efficiency of their development in that country. The software named Mass_Hydro has been developed using the development environment called Eclipse. That tool has particularity to allow respectively, through nine (9) modules, to register data about acknowledgement of the site and calculate the height of the waterfall (m), to estimate the demand of power (kW), calculate the potential (kW), plot flow duration curve and propose a installed power (kW), propose a turbine, estimate the investment cost and simulate the profitability, payback period and finally help to design Weir, intake, channel, fore bay, penstock and power house. The effectiveness of that software was successfully confirmed in the application on two MHPP (Kemken and Bakassa) already studied in Cameroon.

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1. Introduction

Considering the fact that the development of renewable energy is an excellent method to fight against the climate change, Cameroon also intends to develop and integrate lots of renewable energies for the efficiency of its energy system. Wind resources in this country are quite poor (less than 4m/s) and are inconsistent over the year [1]. Wind energy is therefore not a feasible energy supply option. Solar energy resources, although abundant in this Country, cannot be developed alone due to the limited number of cloudless days per year [2]. The consumption of renewable energy in Cameroon is still dominated by wood combustible and waste which constitutes a consumption of 77% (with more than 95% used for meal cooking) [3].

The rate of access to electricity in Cameroon is around 49%, which is less than 20% in the rural area. But, that country has significant hydroelectric potential [4]. Only large power plants are often developed, leaving out many other sites favorable to the implantation of the Micro hydro power plants (MHPP), able to satisfy the needs of electrification in the remote rural areas and thus contribute to their sustainable development. There is the lack of data and skills for the development of that area in Cameroon. It is necessary to develop a tool for the efficiency of the feasibility studies of MHPP in that country [4,5].

The objective of this work is the development of software for the efficiency of feasibility studies of MHPP in the intention to contribute boosting that sector of activity in Cameroon, which can take into account local constraints and advantages. That software will be develop through eight modules which are: to register data about acknowledgement of the site and calculate the height of the waterfall (m), to estimate the demand of power (kW), calculate the potential (kW), plot flow duration curve and propose a installed power (kW), propose a turbine, estimate the investment cost and simulate the profitability, payback period and finally help to design Weir, intake, channel, charge chamber, penstock and power house. The effectiveness of that software will successfully confirmed in the application on two MHPP (Kemken and Bakassa) already studied in Cameroon..

2. Method

2.1. The equipment flow rate and waterfall height

In the intention to do a good design of MHPP, it is necessary to collect (or simulate with a suitable rainfall-runoff model) discharge on waterfall of one year and then, plot the curve of the classified discharges in the intention to identify the flow rate of equipment used to design the turbine [3]. The waterfall height is the altitude difference between the upstream and downstream water levels of the waterfall. Lots of recognitions visits were done. The gross fall height was measured using an electronic laser level with a suitable accuracy. It is a topographic datum which can also be measured thanks to a map for high falls.

2.2. Technical Elements of MHPP

- **Installed power generation**

The power generated from hydraulic turbines is a function of the available net head, the flow rate, and the efficiency of the turbine. It can be estimated by:

$$P = \eta_t \rho \cdot g \cdot Q \cdot H \quad (1)$$

Where P is hydro power generation capacity of plant in kW, H is net head of water in meter, Q is discharge in m³/s, g is gravity acceleration constant (= 9.81 m/s²), H_n = net head (m) and η is turbine efficiency (80-90%) [6]:

- **Weir**

Several types of notch can be used such as rectangular, Vee or trapezoidal. The material may be metal plate, concrete or hard wood with sharp edges. A simple linear measurement of the difference in level between the up-stream water surface and the bottom of the notch is sufficient to quantify the flow rate. The height takes into account the point of entry of water into the supply pipe [7].

- **The water intake**

Placed at the inlet of the supply line, the water intake avoids turbulence, stops heavy or light debris with the screen, threshold and chicane. The inlet water level must be below the water level to prevent air from entering the line. The flow rate through it can be given as [8]:

$$Q = 1.8 \times (w - 0.2h) \times h^{1.5} \quad (2)$$

Where, Q is discharge in m³/s w = weir width (m), h = Weir height (m).

- **The supply channel**

Not only, for its stability channel must be a rigid structure and do not permit deformations, but also Channel does not support thrust or up lift pressure. It is recommended to consider that the minimum permissible speeds in the channel are limited to reduce sedimentation, to avoid the erosion of the walls or the bed [5].

- **Fore bay**

For a good decantation of water before entering the penstock, it is recommended to equip it with a 20 cm high concrete sill which retains the creeping particles, a screen which overcomes the threshold and stops the other particles, and a deflector which stops the floating debris. The depth of the fore bay varies from 1.50 to 2.50 m [7].

- **The penstock**

The economic diameter in (m) is calculated using several methods, including the following equation:

$$D_p = 2.69 \times (n_p^2 \times Q^2 \times L_p / H_g)^{0.1875} \quad (3)$$

Where, n_p is Manning's coefficient (=0.009-0.011 for PVC in example), Q is turbine water flow rate (m³/s), L_p is penstock length (m), H_g = gross head (m). The minimum wall thickness recommended is:

$$t_p = \frac{D_p + 508}{400} + 1.2 \quad (4)$$

Where, D_p is penstock diameter (mm), t_p = minimum penstock thickness (mm) [2,5].

- **Electromechanical equipment**

The turbine and generator depend on the characteristics of the Fall River (net head and flow rates). The choice of the turbine is made as a function of the nominal flow rate Q_n and the net head H_n according to the Sulzer-Escher Wyss diagram [4], as shown in the following figure1.

• **The power house**

The turbo-generator equipment and control elements are installed in power house. The dimension can be calculated using the following equations.

$L = n (5d + 2,5) + e$ (5)

$l > 5d + 2,5$ (6)

$2,5 > h > 2$ (7)

Where, L is the length (m), l is width (m), height h (m), n is the number of turbo-generator sets, d is the turbine outlet diameter (m), e is the length of the loading dock equivalent to the maximum right-of-way of one unit (m) [6].

• **The distribution network**

Grid voltage: For low power and short distances. The experts recommend that, the distribution can be done directly in low voltage, 380/220 Volts with a frequency of 50 Hz [9].

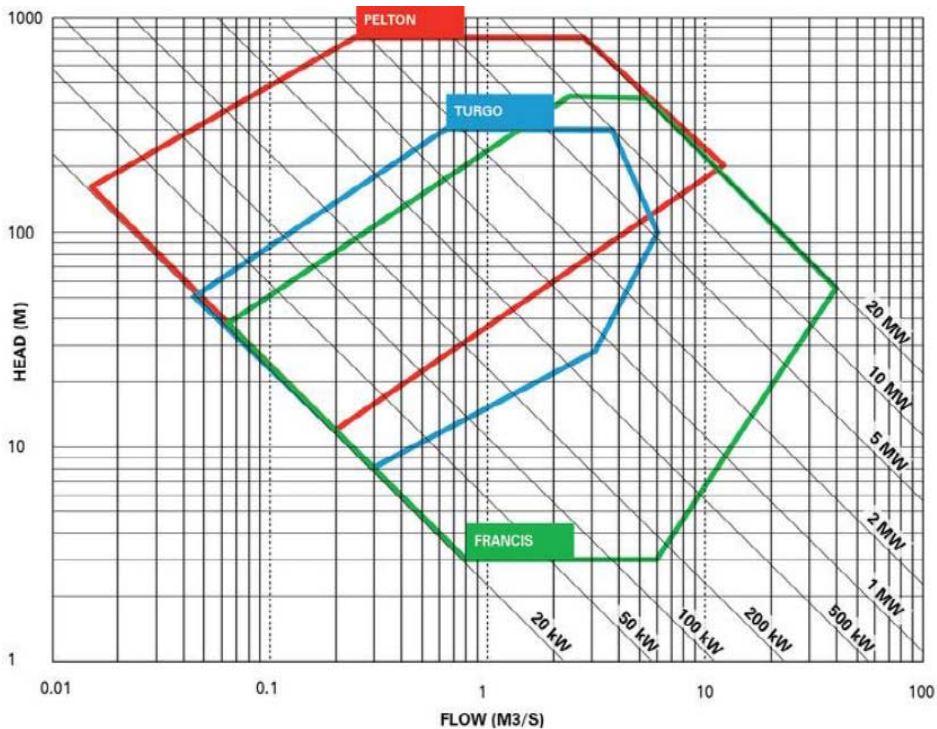


Figure1: Turbine Selection

2.3. Cost and financial analyze

To set up a MHPP, the costs of different element depend on environment constraints and vary from a site to another. Local materials are much recommended to reduce costs [10]. A MHPP can usually operate during around 60% of time per year, and the operating costs represent 30% of the cash-flow [5].

- **The net present value (NPV)**

Considering that the initial investment cost is I_0 ; discount rate is 'a'; for years 1, 2,...,N, Cash-flows and Operating costs can be respectively represent by: CF_1, CF_2, \dots, CF_N ; C_1, C_2, \dots, C_N ; The net present value (NPV) of the project is given by the following equation[5],:

$$NPV = \sum_{i=1}^N \frac{CF_i - C_i}{(1 + a)^i} - I_0 \quad (8)$$

The project is profitable if $NPV \geq 0$.

- **The pay-back period**

It is the time takes for the net present value to be zero [8].

2.4. Developed software

The help tool for decision of the feasibility studies of MHPP called Mass_Hydro we developed is software that has the characteristics to determine the information regarding the calculations that help solve the planning problems for the decision making on the basic project of MHPP. The software was developed using the development environment called Eclipse. Eclipse is computer software that has many tools to help the development of Applications with the objective of making this process efficient, as well as being a platform for developing computer systems. This system has a large number of features for application development, especially when it comes to following the standard Windows operating system [10-12]. Considering the fact that as all Hydropower, a Micro-hydro system is based on the principle that flowing and falling water has a certain amount of kinetic energy potential associated with it. Thus, Hydropower comes from converting the energy in flowing water, by means of waterwheel or a turbine, into useful mechanical energy. Then, our software were developed using a model of MHPP illustrated in the following figure 2.

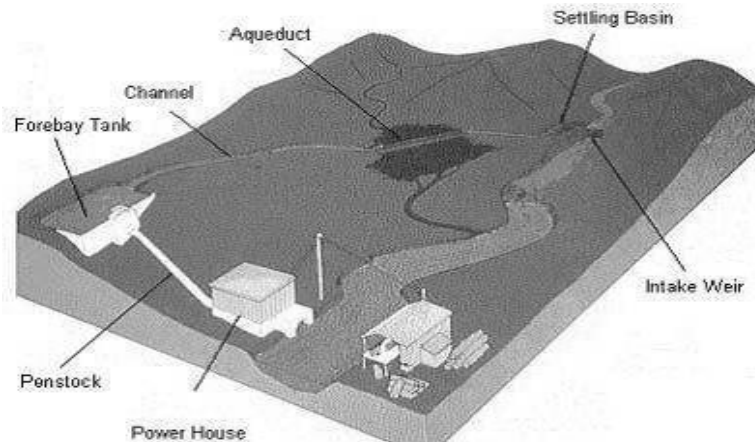
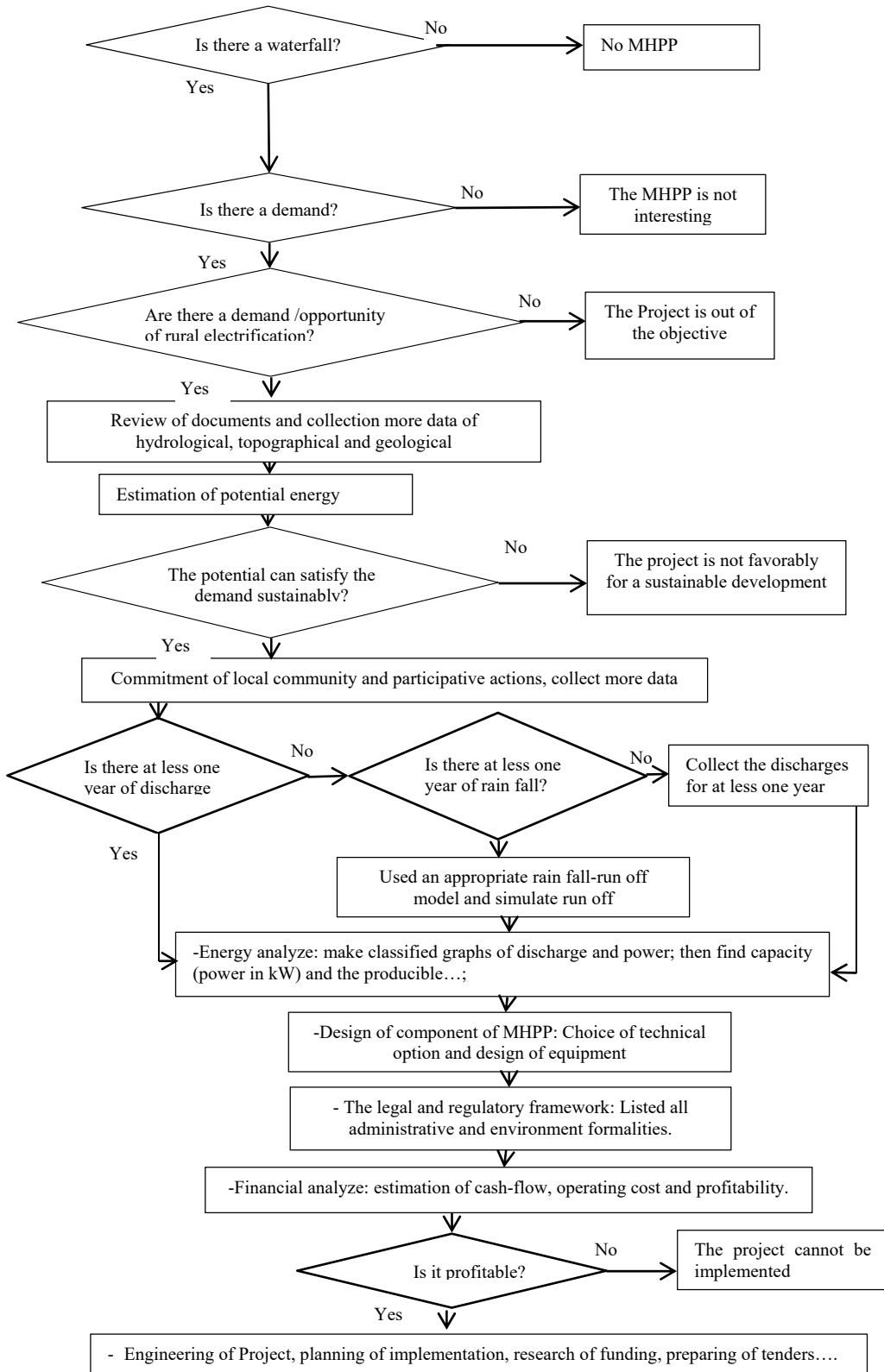


Figure 2. Main components of a micro-hydro power plant [13]

2.5. Algorithm steps

The software use data insert by the user, and calculates the values based on the inserted data. The operating scheme of the software is the implementation of the methodology of feasibility studies of MHPP in Cameroon and other countries proposed in previous articles [5,14,15]. That methodology has summarized by a decisional organogram as shown in the following figure 3.



Phase 1: Preliminaries studies / prefeasibility

Phase 2: Feasibility studies

Phase 3: Implementation

Figure 3: A Methodology of the feasibility studies of projects of MHPP in Cameroon [5]

2.5.1. Administration and authentication

Under the access right, the user can do modifications of code if he has suitable skills. This opportunity allows adapting the application in many changes as (variety of equipment, equipment costs, cash-flow parameters, the profitability parameters, etc.). The following figure 4 presents the administration and authentication step.

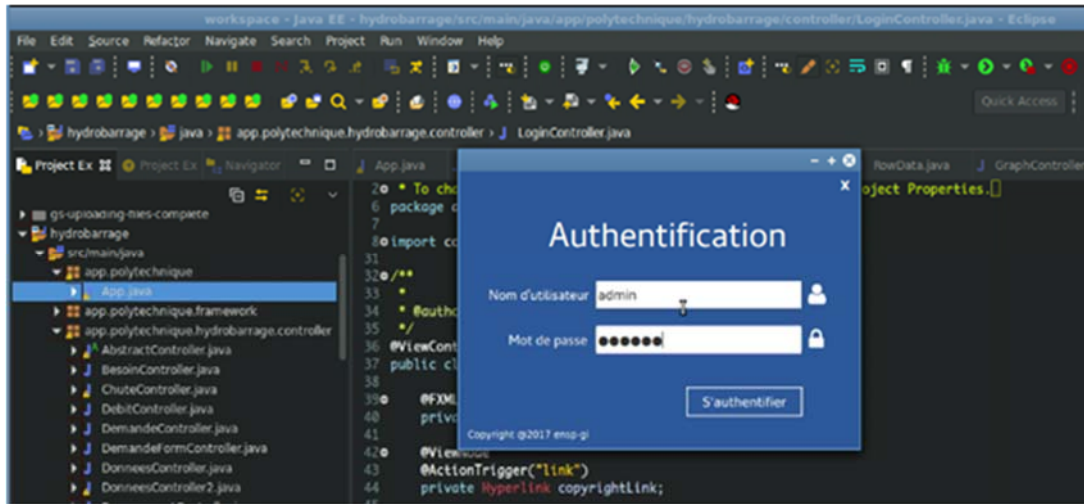


Figure 4: Authentication and administration step (software available in French version only).

2.5.2. The modules of the application

Using all considerations explained in points 2.1, 2.2 and 2.3 above and others important elements for MHPP projects [16-18]; the application has been developed through nine main modules declined as follow:

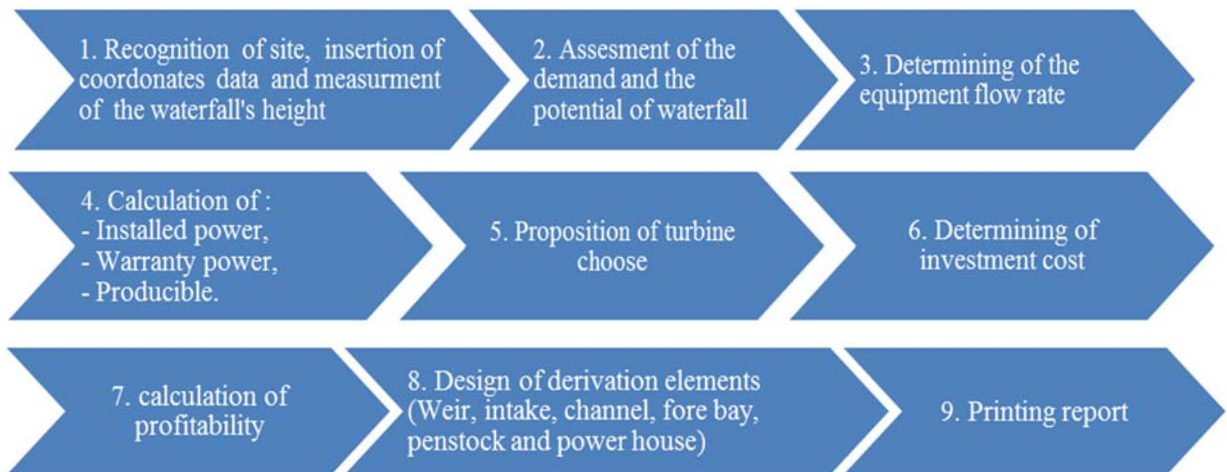


Figure 5: Steps and modules of application

3. Results and discussion

Two MHPP were already studied in previous researches:

- The MHPP of Kemken: on a river in Banéghang district ($5^{\circ} 26' 54''$ North, $10^{\circ} 18' 49''$ East), Bansa village, Penka-Michel subdivision, Menoua department, West Region of Cameroon [5]. The following figure shows a photo of that waterfall;



Figure 6: The waterfall of Kemken (photo from authors).

- The MHPP of Bakassa: Bakassa is on a river in Bansa District, Menoua Division and West Region of Cameroon. Located in between $5^{\circ} 26' 54''$ North, $10^{\circ} 18' 49''$ East [4]. The following Figure 7 shows a photo of that waterfall.



Figure 7: The waterfall of Bakassa (photo from authors).

The results of feasibility studies of the MHPP of Bakassa are obtained by the software Mass_Hydro and can be observed the following figures. By same method, the results of feasibility studies of the MHPP of Kemken were also obtained similarly by the software Mass_Hydro. Finally, the results of feasibility studies of that two MHPP obtained by the both methods (Mass_Hydro and classical method) are summarized in the following figure 8.

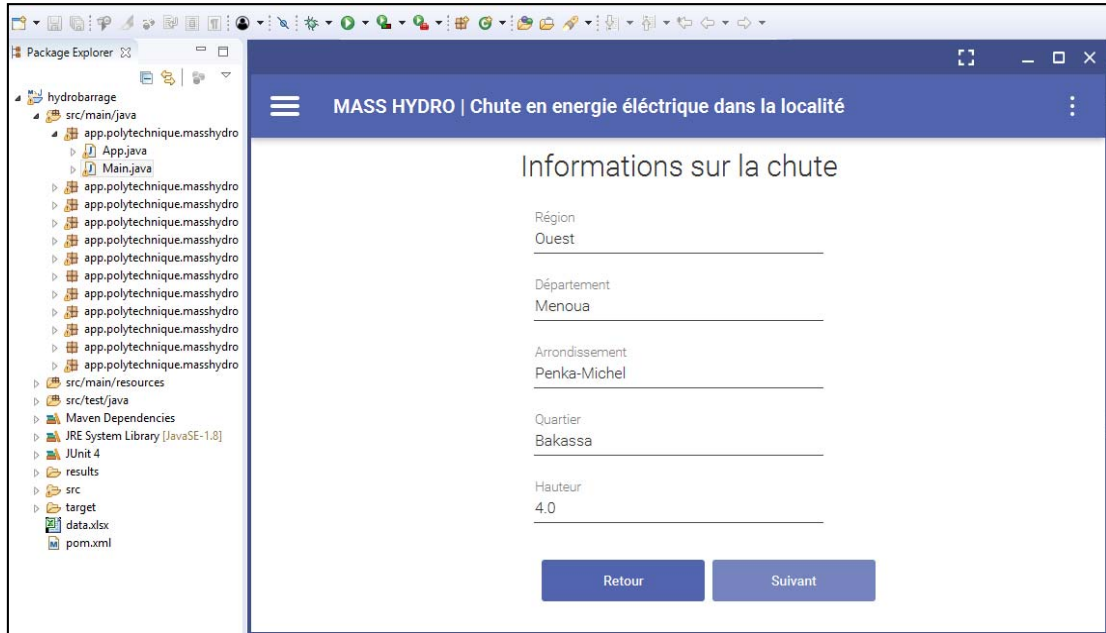


Figure 8: Module of recognition of the site of Bakassa (software available in French version only).

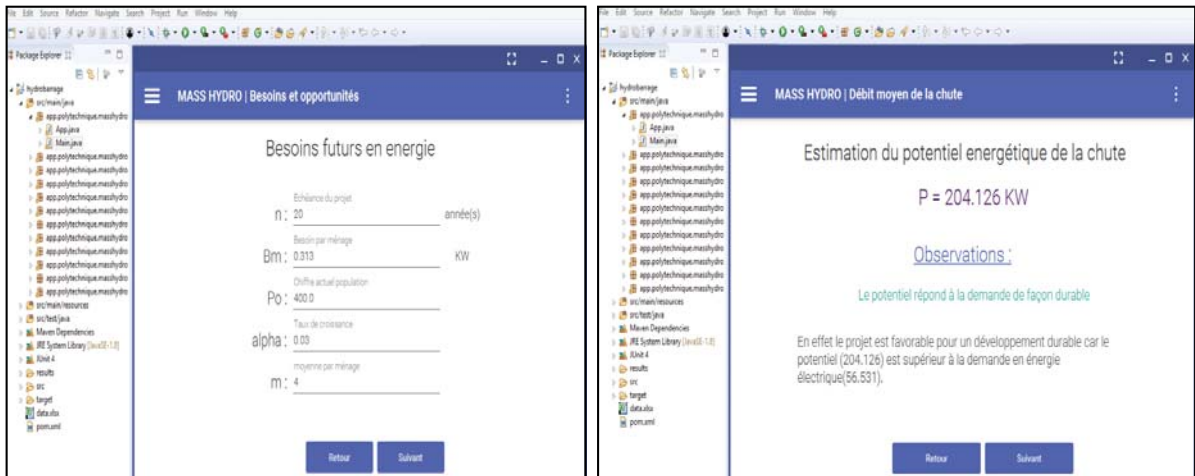


Figure 9: Module of demand (left) and potential of waterfall (right) (software available in French version only).

For the module of the determining of the equipment flow rate, some hydrological data collected by OSTROM in Cameroon were used [19].

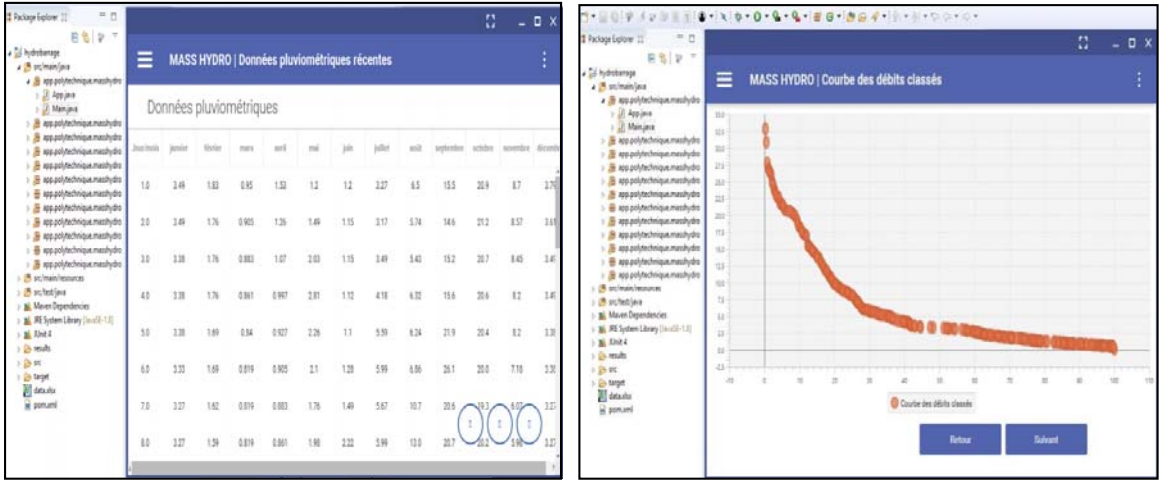


Figure 10: Module of importation of flow rate data (left) and determining of the equipment flow rate (right) (software available in French version only).

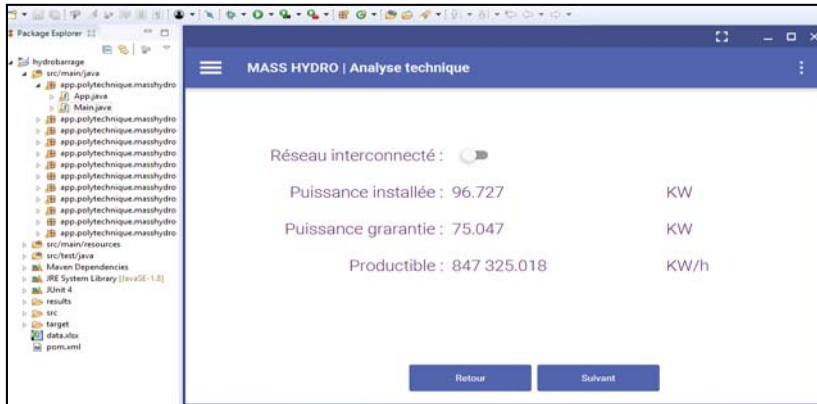


Figure 11: Module of installed power, warranty power and producible (software available in French version only).

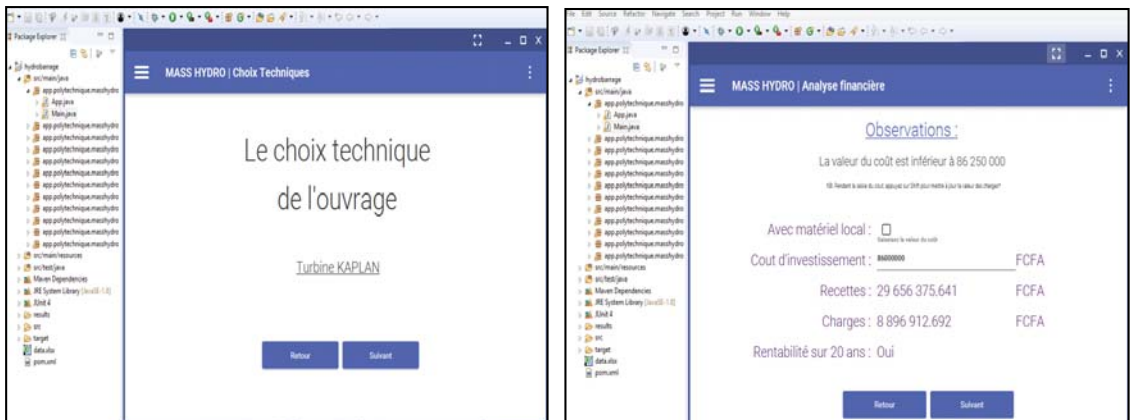


Figure 12: Modules of technique choice (left), Investment cost and profitability (right) (software available in French version only).



Figure 13: Module of design of Weir, intake, channel, fore bay, penstock and power house (software available in French version only).

Table 1: Results of feasibility studies of MHPP of Kemken and Bakassa

<i>Sizes</i>	<i>Values of Kemken</i>		<i>Values of Bakassa</i>	
	<i>Classical method</i>	<i>Software Mass Hydro</i>	<i>Classical method</i>	<i>Software Mass Hydro</i>
Site characteristics				
Gross head	10,5 m	10,5 m	4 m	4 m
Mean flow rate	9,3 m ³ /s	9,3 m ³ /s	9.72 m ³ /s	9.72 m ³ /s
Turbine				
Type	Kaplan S	Kaplan S	Kaplan S	Kaplan S
Rotation speed	375 tr/min	375 tr/min	375 tr/min	375 tr/min
Net head	10 m	10 m	4 m	4 m
Nominal flow rate	3.8 m ³ /s	3.8 m³/s	2.9 m ³ /s	2.8 m³/s
Nominal power	320 kW	317 kW	97 kW	96.73 kW
Alternator				
Type	Synchrone	Synchrone	Synchrone	Synchrone
Tension	380/220 V	380/220 V	380/220 V	380/220 V
Frequency	50 Hz	50 Hz	50 Hz	50 Hz
Interconnection / distribution				
Type of grid	Isolate	Isolate	Isolate	Isolate
Production of electricity				
Producible	2, 777, 000 kWh	2,776,920 kWh	849,720 kWh	847, 325 kWh
Financial elements				
Investment cost	212 486 656 FCFA	211 284 550 FCFA	88 440 068 FCFA	86 500 000 FCFA
Net Present value	Positive (it is profitable)	Positive (it is profitable)	Positive (it is profitable)	Positive (it is profitable)
Payback period	6 years + 16 days	6 years + 3 days	8 years + 2 months	8 years + 1 months 14 days

The feasibility studies of MHPP on Bakassa and Kemken sites as detailed and presented in Figs. 8 to 13 yielded results obtained from the Mass_Hydro software compared to those obtained by the classical method [20] as summarized in Table 1 above point out that:

- The proposal of the turbine is identical for both methods;
- The installed power and the producible are slightly minimized by Mass_Hydro compared to the conventional method, but the differences are negligible;
- The estimation of the investment costs and the calculation of the payback times are also slightly minimized by the software compared to the conventional method, but the differences are also negligible.

The software thus makes it possible to carry out the feasibility studies of the MHPP and to obtain the results which are also very interesting. It also makes it possible to design the derivation elements (Weir, intake, channel, fore bay, penstock and power house). This software has a database which also offers the advantage that its functional requirements take into account local constraints such as: the choice of the technical option, the legal and institutional framework and the competent administration, the investment cost (local or imported manufacturing option) ... etc.

4. Conclusion

Since energy produce from Micro hydro power plants (MHPP) is renewable and can also support the sustainable development of rural areas all over the world, all simulating, modeling and predictive tools that can contribute to the efficiency of the development of that sector of activities is relevant [21].

In this contribution, we have presented an efficient original software tool that we have developed to analyze, in a confident approach, the feasibility studies of micro hydro power plants. After the presentation of this new software, specific applications to the case of MHPP on two sites (Bakassa and Kemken) in Cameroon validate the method by comparison with classical existing tool.

In front of all this, the use of this software which takes into account the advantages and the local constraints is more effective for the feasibility studies of the MHPP compared to the classical method because it makes it possible to save a lot of time, avoids tedious calculations to operators and allow to makes efficient decisions as soon as possible when we know that lots of these projects are often abandoned because of lack of expertise and local skills. The international extension of this software in non-French-speaking regions of the globe is already being considered with translations into English and other national languages

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